

UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Edificación



**Provision of a Blockchain-Based Inspection
Framework for Managing Building
Information Modeling (Case Study: MARS
Buildings)**

**Provisión de un marco de inspección basado
en blockchain para la gestión de modelado
de información de construcción (Estudio de
caso: Edificios en Marte)**

DOCTORAL THESIS

Submitted for the Degree of Doctor by:

AMIRHOSSEIN JAVAHERIKHAH

Master's Degree in Construction Management

Madrid, 2024



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Doctoral Degree in Technological Innovation in Building

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For my father, mother, and sisters

Acknowledgment

Four years have passed since I started my Ph.D. course, and there have been many challenges and stress. Although it has been a long time due to the hardships of being away from my homeland and family, I cannot feel left behind at this stage, and therefore, I do not need to have points. My gratitude to all those who accompanied me during this memorable period of my life is infinite.

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We will not stop exploring, but at the end of the search, we will reach the starting point and learn a new method.

Thanks, Everyone

Amirhossein Javaherikhah

Abstract

Space researchers are exploring Mars as a potential destination for independent human life due to climate change and environmental degradation. Providing solutions for Martian buildings using local materials and advanced technologies is a pressing challenge. NASA is one of the organizations that seriously devotes itself to Mars exploration and research. The main goal of this research is to provide a Blockchain-based framework for the information management of Martian buildings.

Recent library research and previous studies have identified eleven main criteria. These criteria include meteor shields, building facilities, windows (weather changes), air pressure, temperature, oxygen, carbon dioxide, humidity, and light. We evaluate these criteria alongside Smart Contracts, excluding them from the BIM criteria .

To extract and determine the final criteria of construction information management, these eleven criteria are provided to the experts and then determined using the Delphi phase questionnaire. The questionnaire's results led to the selection of six final criteria, which serve as the primary criteria for the study. These criteria include walls, roofs, building facilities, air exchange, temperature, and ambient oxygen .

For these six criteria, eight transactions have been identified, the first two of which are related to concluding a contract and storing it in the Blockchain, and the other six are related to receiving data from sensors to manage the data of Martian buildings .

In our research, Martian buildings need a security and protection shield to process information. Blockchain is a general tool due to its ability to process information accurately and without manipulation, a feature that has yet to be considered in studies on Martian buildings .

The proposed framework for this research is focus on the different levels of health of Martian buildings and their relationship with sensor data and Smart Contracts on the Blockchain. This framework uses four different levels to assess and manage buildings' condition .

The first level, or "normal level," represents the health of the building. At this level, the building is generally considered healthy, with no unusual signs of deterioration .

The second level, or "emergency level 1," is activated when a problem is detected in the building's installations. At this stage, the rescue robots identify problems using their sensors and data and try to fix them.

The third level, or "Emergency Level 2," is activated when oxygen levels and ambient temperature have dropped dangerously low. In this case, people's lives are at risk, and rescue robots must react faster to save people .

The fourth level, or "Emergency Level 3," is activated when the health of structures such as walls and roofs is compromised. The structures undergo inspection at this stage and may require repairs or reinforcements .

This framework collects information using sensors and their data and stores it on the Blockchain through a Smart Contract. The central server then compares this information with the data it has received. If there is a match, it activates at various alert levels, enabling the rescue robots to respond .

The research results show that the proposed framework has a favorable performance compared to the proposed method. This Method is focus on the structural differences between Martian and Earth environments, providing a foundation for further research and support. The findings could improve knowledge about space environments and technologies for extraterrestrial life, potentially enhancing fields like science, industry, and technology in the long term.

For extreme environments, such as Mars, this has important implications for improving living conditions on Earth. By applying the principles gleaned from these designs, we can develop better structures to handle the increasing frequency and intensity of extreme weather events on Earth.

Keywords: Construction, Management Building, Blockchain, Bim, Mars

Resumen

Los investigadores espaciales están explorando Marte como un destino potencial para la vida humana independiente, debido al cambio climático y a la degradación ambiental. La NASA es una de las organizaciones que se dedica seriamente a la exploración e investigación en Marte. El objetivo principal de esta investigación es desarrollar un marco basado en blockchain para la gestión de la información de los edificios en Marte.

En nuestra investigación hemos realizado en nuestros estado del arte studios previos, para identificar once criterios principales. Estos criterios abarcan escudos contra meteoritos, instalaciones del edificio, ventanas (para adaptarse a cambios climáticos), presión del aire, temperatura, oxígeno, dióxido de carbono, humedad y luz. Evaluamos estos criterios junto con los contratos inteligentes (Smart Contracts), excluyéndolos de los criterios BIM.

Para definir y seleccionar los criterios finales de gestión en la información de la construcción, se presentaron estos once criterios a expertos y luego se determinaron mediante el cuestionario de la fase Delphi. Los resultados del cuestionario condujeron a la selección de seis criterios finales, que sirven como criterios principales para el estudio. Estos seis criterios incluyen paredes, techos, instalaciones del edificio, intercambio de aire, temperatura y oxígeno ambiental.

Para estos seis criterios, se han identificado ocho transacciones: las dos primeras están relacionadas con la creación de un contrato y su almacenamiento en blockchain, y las otras seis están relacionadas con la recepción de datos de sensores para gestionar los datos de los edificios en Marte.

En esta investigación, los edificios en Marte requieren un sistema de seguridad y protección para procesar la información. Blockchain es una herramienta de gran alcance debido a su capacidad para procesar información de forma precisa y sin manipulación.

El marco propuesto para esta investigación se centra en los diferentes niveles de idoneidad de los edificios en Marte y su relación con los datos de sensores y los contratos inteligentes en blockchain. Este marco utiliza cuatro niveles diferentes para evaluar y gestionar el estado de los edificios.

El primer nivel, o "Nivel Normal", representa la idoneidad general del edificio. En este nivel, el edificio se considera generalmente saludable, sin signos inusuales de deterioro.

El segundo nivel, o Nivel de Emergencia 1, se activa cuando se detecta algún problema en las instalaciones del edificio. En esta etapa, los robots de rescate identifican problemas utilizando sus sensores y datos, e intentan solucionarlos.

El tercer nivel, o "Nivel de Emergencia 2", se activa cuando los niveles de oxígeno y la temperatura ambiente han descendido peligrosamente. En este caso, la vida de las personas está en peligro y los robots de rescate deben actuar con rapidez para salvar a los habitantes.

El cuarto nivel, o "Nivel de Emergencia 3", se activa cuando hay problemas en las estructuras como paredes y techos. Las estructuras se someten a inspección en esta etapa y pueden requerir reparaciones o refuerzos.

Este marco recopila información mediante sensores y almacena sus datos en blockchain a través de un contrato inteligente. Luego, el servidor central compara esta información con los datos previamente registrados. Si hay una coincidencia, se activan varios niveles de alerta, lo que permite que los robots de rescate respondan.

Los resultados de la investigación muestran que el marco propuesto tiene un desempeño favorable en comparación con otros métodos existentes. Este marco se centra en las diferencias estructurales entre los entornos marciano y terrestre, proporcionando una base para futuras investigaciones y soporte. Los hallazgos podrían conducir a un mejor conocimiento sobre los entornos espaciales y las tecnologías para la vida extraterrestre, mejorando potencialmente campos como la ciencia, la industria y la tecnología a largo plazo.

Palabras clave: Construcción, Edificios de Gestión, Blockchain, Bim, Mars

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Abbreviations and acronyms

2D	Two-Dimensional Graphics: Height, Width
3D printer	Manufacturing Is The Construction Of A Three-Dimensional Object From.
3D	Three-Dimensional Graphics: Height, Width, And Depth
4D	Four-dimensional space Of Length, Width, And Height, Plus Time
5D	Five-Dimensional Way Of Showing The Physical & Functional Aspects Of Any Project
ADEPT	Autonomous Decentralized Peer-To-Peer Telemetry
AECO	Is The Acronym For Architecture, Engineering Construction, And Operations
AI	Artificial Intelligence
AEC	Architectural Engineering And Construction
AEC/FM/D	Architecture/Engineering/Construction-Facility Management – Design
AGC	American General Contractors
EC2	Elastic Computer 2
ACID	Advanced Construction Information Development
AES	Advanced Encryption Standard
AIM	Provides All The Information Necessary To Support The Management Of An Asset
AIA	American Institute Of Architects
BM	Billing Model
BC	Blockchain
BIM	Building Information Modeling

Bcxml	Building Construction Xml
BMS	Building Management Systems
BCC	BIM Contract Conditions
BCS	Building Control Systems
BSI	Professional Organizations Company
BAS	Building Automation Systems
BEMS	Building Energy Management Systems
CAD	Computer-Aided Design
COBie	Construction Operations Building Information Exchange
CMMS	Computerized Maintenance Management System
CMMI	Capability Maturity Model Integration
CMM	Capability Maturity Mode
CCM	Depict The Climate Using A Three Dimensional Grid Over The Globe
CIC	Construction Industry Council
CSA	Cloud Security Alliance
CDE	Common Data Environment
CIA	Confidentiality, Integrity, And Availability
CRMS	City Resources Management System
CFD	Contract For Difference
DAC	Distributed Autonomous Corporations
DAO	Decentralized Autonomous Organization
DDC	Direct Digital Controls
ECDSA	Elliptic Curve Digital Signature Algorithm
ERM	Exchange Requirement Model
FM	Facility Management
AHP	Fuzzy Analytic Hierarchy Process

GHOST	Greedy Heaviest- Observed Sub-Tree
GIS	A Geographic Information System
GBXML	Green Building Xml
GUID	Globally Unique Identifier
HTML	Hyper Text Markup Language
HVAC	Heating, Ventilation, And Air Conditioning/ Mechanical, Electrical
HMI	Human Machine Interfaces
HAN	Home Automation Networks
IOT	Internet Of Things
ICT	Information And Communication Technologies
ISO	International Organization For Standardization
IPD	Integrated Project Delivery
IP	Link User Pseudonyms
IDM	Information Delivery Guide
IFD	International Framework For Dictionaries
IFC	Industrial Foundation Classes
IPD	Integrated Project Delivery
IFCOWL	provides a Web Ontology Language
IFCXML	International Finance Corporation Xml
IPFS	Interplanetary File System
JSC Mars-1a	Low-Ti Lunar Mare Simulant
JSON	JavaScript Object Notation
LC	Life Cycle
LCA	Life Cycle Analysis
LOD	Level Of Detail
MDV	Model Display Definitions

MVD	Model View Definition
MPa	Megapascal
MAWD	Five-Channel Grating Spectrometer Measuring Solar Radiation Reflected From The Surface And Atmosphere Of Mars
NG	Next Generation
Node	A Point Of Intersection/Connection Within A Data Communication Network
NAT	Network Address Translation
NPSA	National Protective Security Authority
NBIMS	Industry-Consensus Standard For The Creation And Use Of Building Information Models
NBS	National Building Specification
NaCl	Sodium Chloride
NIST	National Institute Of Standards And Technology
NASA	The National Aeronautics And Space Administration
NOSQL	An Approach To Database Design That Enables The Storage And Querying Of Data Outside The Traditional Structures Found In Relational Databases
POW	Proof Of Work
POS	Proof Of Stake
P2P	Peer-To-Peer
PBFT	Practical Byzantine Fault Tolerance
PKIS	Conventional Public Key Infrastructures
PIM	Product Information Management
PLC	Programmable Logic Controllers
RFID	Radio-Frequency Identification
SCP	Special Containment Procedures Foundation

SDT	Self-Determination Theory
SPIE	Society Of Photo-Optical Instrumentation Engineers
SQL	Structured Query Language
SMES	Small And Medium-Sized Enterprises
SB	Smart Buildings
SCADA	Supervisory Control And Data Acquisition
TLS	Transport Layer Security
UNL	Unique Node List
VM	Virtual Machine
XHTML	Extensible Hypertext Markup Language
XML	Extensible Markup Language
ZK-SNARKS	Zero-Knowledge Succinct Non-Interactive Arguments Of Knowledge

Table of Formulas

1	"T_ID Request _ Smart_ Contract SP _ PK User _ PK Sing"
2	"T_ID P_T_ID User _ PK User_Sign SP_PK SP_Sign Rfe.contract.ID"
3	"T_ID P_T_ID S_ID Oxygen_content"
4	"T_ID P_T_ID S_ID Temperature"
5	"T_ID P_T_ID S_ID Type_Sensor Type_Control Amount"
6	"T_ID P_T_ID R_ID Roof_type Material Height Load amount Description"
7	"T_ID P_T_ID W_ID Wall_type Material thickness Load amount Description"
8	"T_ID P_T_ID D_ID Location Size Description"
9	$F_{AVE} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n}$
10	$F_{ave} = (L, M, U)$ $x_m^1 = \frac{L + M + U}{3}$ $x_m^2 = \frac{L + 2M + U}{4}$ $x_m^3 = \frac{L + 4M + U}{6}$ $crisp \ number = Z^* = \max(x_{\max}^1, x_{\max}^2, x_{\max}^3)$
11	$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1}$
12	$V(S_i > S_k) = \begin{cases} 1 & m_i \geq m_k \\ 0 & l_k \geq u_i \\ \frac{l_k u_l}{(m_i - u_i) - (m_k - l_k)} & otherwise \end{cases}$
13	$V(S \geq S_1, S_2, \dots, S_k) = (V((S \geq S_1), (S \geq S_2), \dots, (S, S_k)))$ $= \min(V((S \geq S_1), (S \geq S_2), \dots, (S, S_k)))$ $= \min V(S \geq S_i) \quad i = 1, 2, \dots, k$

1. INTRODUCTION

1.1. Introduction

As humanity increasingly explores the possibility of inhabiting Mars due to concerns about Earth's resource depletion, researchers are intensifying their efforts to develop viable construction methods tailored to Martian conditions .

Building information management (BIM) is paramount in safeguarding against accidents and ensuring building safety, with its effective implementation proven to save structures and lives. Acknowledging its significance, stakeholders have prioritized the security and accuracy of BIM data through various security solutions, which have been extensively researched and implemented in the field .

One solution that holds promise is blockchain technology, renowned for its decentralized and tamper-resistant nature. Integrating blockchain into BIM processes can substantially enhance data security and accuracy, a topic that researchers and industrialists have delved into extensively.

This integration holds particular promise for addressing the unique challenges posed by constructing and managing buildings on Mars. While existing methodologies may not directly apply, adopting blockchain technology is proposed as a novel approach to ensuring the safety and precision of building data in such exceptional scenarios.

Building management in extraterrestrial environments necessitates comprehensive strategies that adapt to the challenges of interplanetary housing. The proposed methodology emphasizes an inspector-oriented approach, leveraging technology to expedite problem detection and resolution, thus enhancing overall efficiency and reliability in Martian habitats.

The suggested framework for this research focuses on the various degrees of health of Martian buildings and their link with sensor data and Blockchain-based Smart Contracts. This system assesses and manages building conditions at four different levels.

The first level, often known as the "normal level," shows the building's overall health. In this category, the building is typically regarded as healthy, with no obvious symptoms of degradation.

The second level, "Emergency Level 1," is triggered when defects are discovered in the building's installations. At this point, the rescue robots utilize their sensors and data to discover and attempt to correct faults.

The third level, "Emergency Level 2," is activated when oxygen levels and ambient temperature become dangerously low. In this situation, people's lives are in danger. Thus, rescue robots must move quickly to save them.

The fourth level, often known as "Emergency Level 3," is activated when structures such as walls and roofs are undermined. At this step, the structures are inspected and may need to be repaired or reinforced.

This framework takes information from sensors and their data before storing it on the Blockchain via a Smart Contract. The central server then matches this information to the data it received. If there is a match, it activates at different alarm levels, allowing the rescue robots to respond.

The outcomes of this research not only advance our understanding of Martian construction but also have far-reaching implications for terrestrial infrastructure development.

1.1.1. why we do this work?

It's important to underscore that the future of humanity depends on finding an alternative to Earth for the next generation's lives. Shelter, providing the minimum conditions for a person's normal life, is a crucial factor in this search. Given the proximity and environmental conditions of Mars, it emerges as the only viable option for humanity .

But Mars has differences from Earth in terms of atmosphere and living conditions, and these differences lead to tougher decisions and better equipment with less risk management. Therefore, it was decided to control and manage the building information fully automatedly with minimal errors and high security. Therefore, in this research, we designed a building information management framework for Mars buildings by combining blockchain with BIM.

1.1.2. Why is this important?

On Mars, the weather conditions are extremely harsh and unsuitable for human survival. The atmosphere is thin and mostly carbon dioxide; temperatures can drop to as low as -125°C (-195°F), and the planet is constantly exposed to high radiation levels due to its lack of a protective magnetic field. In addition, dust storms can engulf the entire planet for weeks, making it even more challenging for humans to survive without proper shelter. These conditions mean that any habitat or building on Mars must be highly specialized to protect inhabitants from extreme cold, radiation, and the lack of breathable air.

Given these challenges, Mars buildings' smallest design or construction error could have catastrophic consequences, such as structural failure or air leaks, leading to injury or death. Therefore, providing a reliable and robust framework for constructing habitats is crucial. This framework must include airtight living spaces, strong radiation shielding, and a way to regulate temperature and air supply. Advanced materials, precise engineering, and rigorous testing are essential to ensure that Martian habitats can safely support human life in an inherently hostile environment.

1.1.3. what is the innovation of this work?

The first point that can be pointed out is that no one has provided a framework for managing the information of buildings on the planet Mars. Also, due to the huge differences between Martian and terrestrial buildings, the defined transactions are completely different from other transactions offered for terrestrial buildings. Also, the proposed framework has innovation, which includes four normal levels: emergency level 1, emergency 2, and emergency 3.

It can be stated that the most important point of the presented research was the following:

- Integration of BIM and blockchain.
- Refers to the expert review for the evaluation of Mars buildings.
- The research innovation presents a proposed Framework for building information management.

1.1.4. Why have we done this in Madrid (Spain)?

Madrid is a leading hub for urban development and innovation in Europe, particularly in the construction industry and the application of new technologies. The city is at the forefront of integrating advanced methods like Building Information Modeling (BIM) into major construction projects, making it an ideal environment for research in innovative areas such as blockchain-based frameworks for BIM management. Additionally, Madrid is home to some of Europe's most prestigious universities and research institutes, with extensive expertise in architecture, civil engineering, information technology, and blockchain. Collaborating with these institutions provides access to world-class knowledge, international networks, and valuable experiences, thereby enhancing scientific credibility and quality.



Figure 1.1: BIM in Spain (Author)

Figure 1.1 combines the flag of Spain with a visual representation of Building Information Modeling (BIM). The flag's characteristic red and yellow stripes and the national coat of arms are overlaid with a 3D model of a building. The BIM

concept is illustrated through layers of structural details, such as walls, roofs, and facilities.

Spain's active membership also influences the choice of Madrid for this research in the European Space Agency (ESA), which highlights the country's strong track record in developing advanced technologies, especially in data management and cybersecurity. Prominent figures such as astronaut Pedro Duque exemplify Spain's commitment to technological advancement, further reinforcing its leadership in cutting-edge fields. These factors make Madrid a strategic location for conducting research at the intersection of construction, technology, and space-related innovations.



Figure 1.2: Collaboration Beyond Earth (Author)

Figure 1.2 blends Spain iconic landmarks with symbols of the European Space Agency's (ESA) advanced space technology, such as satellites and spacecraft, illustrating the fusion of cultural heritage and modern space innovation.

1.2. Definition of Terms

Blockchain: “is a public, digital, decentralized record containing data, assets, and associated transactions executed and shared by network participants.” Although Blockchain is most commonly linked with digital coins such as Bitcoin, it is seen as an emergent technology capable of transforming the digital operating environment and business processes in banking, computing, government services, and almost every sector.

The central premise of Blockchain is to create a distributed digital agreement that ensures that data is decentralized among multiple nodes that share the same information and that no user has full authority over the network. This allows transparency in activity and increased data security. While it was initially created only for financial transactions to create a system that enables secure data transfer between two parties without the need for an intermediary, the enormous destructive potential of Blockchain has become clear. With the rapid growth of numerous cryptocurrencies in recent years.

With its focus on trust and collaboration, blockchain is set to revolutionize workflow paths in any organization. Its implementation promises many benefits, including collaborative learning, instant data exchange, automated contract execution, and more. It enhances network security and fosters improved participant cooperation (Nawari & Ravindran, 2019).

Figure 1.3 depicts blockchain technology as interconnected digital blocks linked by glowing chains, symbolizing secure, immutable connections. Each block contains data, forming a decentralized ledger, emphasizing blockchain's tamper-proof and cryptographically secured structure for data integrity.



Figure 1.3: Blockchain (Author)

Building Information Modeling (BIM)¹: “It is a set of policies, processes, and interacting technologies that result in a method for managing basic building design and project data throughout the building's lifespan”. It supports a single display, data frame, and structure. In building automation, the architecture enables information and communication technology (ICT)² To manage the life cycle information of buildings.

During a building's lifespan, the primary elements of BIM may be characterized in four ways: integration with various databases, document management assistance, visualization of analytical processes and conclusions, and sustainability analysis and simulation. The current use of ICT architecture for BIM is the standard client-server architecture, including conventional systems (Rongyue Zheng et al., 2019).

BIM has evolved as a phase that affects the architecture, engineering, construction, owner, and operator (AECO)³ Industry (B, 2020). BIM information transfer varies

¹ BIM: <https://www.buildingsmart.es/bim/>

² ICT: <https://www.techtarget.com/searchcio/definition/ICT-information-and-communications-technology-or-technologies>

³ AECO: <https://www.marsbim.com/blog/bim-in-aeco-architecture-engineering-construction-operations/#:~:text=AECO%20is%20the%20acronym%20for,Engineering%2C%20Construction%2C%20and%20Operations.>

based on the model and time frame, providing risks to participating parties such as issuer liability, intrusion vulnerability, and information abuse.

These risks generate a variety of contractual, legal, security, and system difficulties that impede the development and simplicity of BIM adoption at the industry level (A. S. Erri Pradeep et al., 2019).



Figure 1.4: Building Information Modeling (BIM) (Author)

Figure 1.4, the conceptual images of Building Information Modeling (BIM) display a digital 3D model of a building, showcasing its architectural, structural, and mechanical layers. This highlights BIM's capability to integrate and visualize multiple aspects of a building's design in one cohesive model.

1.3. Structure The Theoretical Framework

When traveling from one place to another, people usually evaluate various factors before deciding to embark on the journey. This evaluation includes considering the local culture, climate, and any other relevant aspects of the destination. By understanding these factors, travelers can anticipate and prepare for potential challenges. In the context of space exploration, especially when traveling from

Earth to another planet like Mars, these challenges are significantly more complex and crucial to address.

The challenges associated with Mars are critical for the success of any mission to the planet. Whether it's the harsh environment, lack of breathable air, or extreme temperatures, these difficulties must be thoroughly understood and reviewed. Identifying these challenges allows researchers to build strategies to address them, which is a fundamental part of planning any successful mission. The proposed framework for such missions should be designed to prevent and mitigate these potential obstacles.

Addressing these challenges is not only about awareness but also about developing proactive solutions. For instance, ensuring a reliable supply of oxygen, managing radiation exposure, and maintaining stable living conditions on Mars are vital. By carefully reviewing each of these aspects, engineers and mission planners can develop systems and technologies to support long-term survival and functionality on the planet.

A deep understanding of the challenges Mars presents allows us to build a comprehensive framework for sustainable missions. By anticipating potential obstacles and offering concrete solutions, researchers can help ensure that human missions to Mars will be both successful and safe. This thoughtful preparation is key to overcoming the planet's harsh conditions and achieving a lasting human presence there.

1.4. Approach to The Problem

The three principles of temperature, oxygen, and shelter are essential for human life, but these three things are not available on Mars, and if humans are going to go there, they must be checked. These are the three vital elements of life on Mars that must be controlled in the place where humans live on this planet.

Shelter refers to the buildings that are supposed to continue human life on Mars. These buildings must be able to control the other two. Information management preservation and security have always been essential in sensitive areas and buildings, and organizations and companies that build such buildings face the

challenge of how and in what medium the building information is stored to protect it.

The construction sector is still in the early stages of being fully digitalized. However, with the introduction of technologies such as BIM and intelligent digital technology, all participants, elements, and management of the building design and construction process may work together on a single platform. In the construction industry, production, business, and management levels may be efficiently integrated; project data and management information are connected; and BIM+ intelligent digital technology will usher in sustainable building design and construction.

Mars: the fourth planet from the Sun, is a sandy, frigid desert planet with a fragile atmosphere. It is also a dynamic planet with seasons, polar ice caps, valleys, dormant volcanoes, and indications of past activity. Mars is one of the most studied planets in our solar system, and it is the only one where rovers have been despatched to investigate its alien surface.



Figure 1.5: Martian landscape (Author)

Figure 1.5, the Martian landscape is depicted, featuring the characteristic red rocky surface. A futuristic Mars rover is visible in the distance, emphasizing exploration and advanced technology in the context of Mars.

NASA is actively studying the Martian surface using two rovers (Curiosity and Perseverance), a lander (Insight), and a helicopter (Ingenuity). NASA's Perseverance rover, the most extensive and sophisticated rover ever deployed to another planet, touched on Mars on February 18, 2021, after a 203-day trip of 293 million miles (472 million kilometers). The Ingenuity helicopter was mounted to the Endurance Belly and transported to Mars.

Figure 1.6 shows the official icon of NASA.

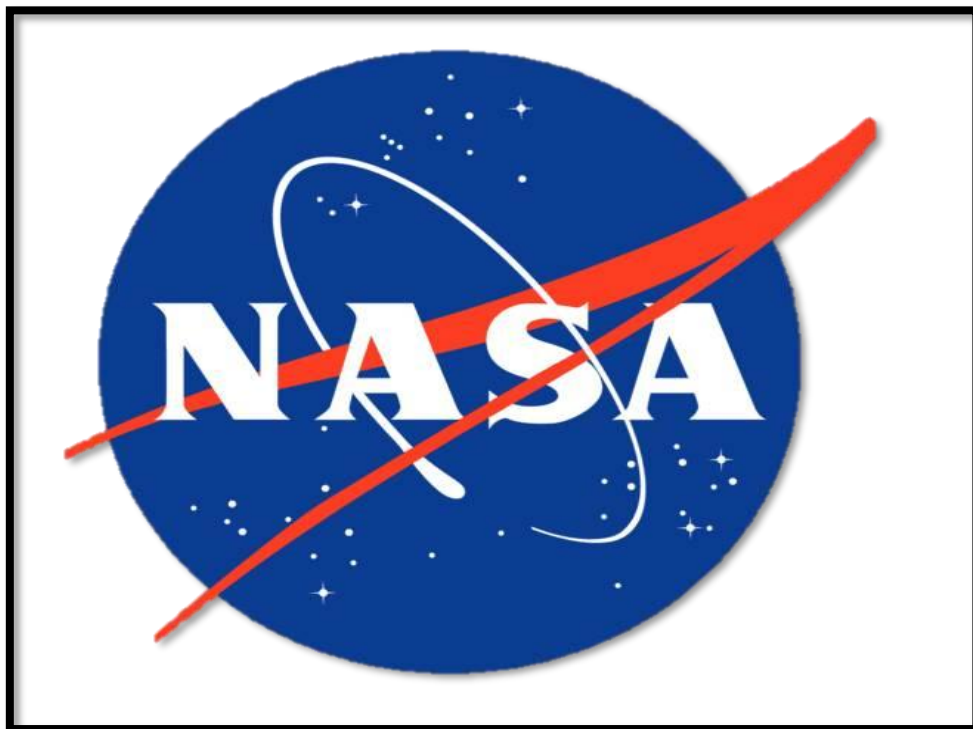


Figure 1.6: Nasa Icon (Nasa)

Perseverance is one of three spacecraft scheduled to reach Mars in 2021. The Hope orbiter was delivered from the UAE on February 9, 2021. The Tianwen-1 mission from China landed on February 10, 2021, and consists of an orbiter, a lander, and a rover. Europe and India have also had spacecraft exploring Mars' orbit. With the Jurong rover's landing in May 2021, China became the second country to reach Mars.

A multinational fleet of eight orbiters, including three NASA orbiters: the Mars Odyssey (2001), the Mars Reconnaissance Orbiter, and MAVEN, will study the Red Planet from above. These robotic probes have found evidence that Mars was significantly wetter, warmer, and had a thicker atmosphere billions of years ago.

Table 1.1: Planetary data for Mars (Author)

Mars	
Mean distance from the Sun	227,943,824 km (1.5 AU)
eccentricity of orbit	0.093
the inclination of the orbit to the ecliptic	1.85°
Martian year (sidereal period of revolution)	686.98 Earth days
visual magnitude at mean opposition	−2.01
mean synodic period*	779.94 Earth days
mean orbital velocity	24.1 km/sec
equatorial radius	3,396.2 km
north polar radius	3,376.2 km
South polar radius	3,382.6 km
surface area	$1.44 \times 10^8 \text{ km}^2$
Mass	$6.417 \times 10^{23} \text{ kg}$
mean density	3.93 g/cm ³
mean surface gravity	371 cm/sec ²
escape velocity	5.03 km/sec
rotation period (Martian sidereal day)	24 hr 37 min 22.663 sec
Martian mean solar day (sol)	24 hr 39 min 36 sec
inclination of the equator to orbit	25.2°
mean surface temperature	210 K (−82 °F, −63 °C)
typical surface pressure	0.006 bar
number of known moons	2

The issues in Table 1.1 are significant because they provide information about Mars's demographic characteristics. It is necessary to identify each location, determine its demographic characteristics, and understand how much and how little it is adapted to our situation and what obstacles and challenges it may present for us to consider when developing a framework.

Mars has recently piqued people's interest for reasons other than its terrifying aspect. It is the second-closest planet to Earth, after Venus, and is generally visible in the night sky since it is outside Earth's orbit. It is also the only planet whose solid surface and atmospheric processes can be seen using ground-based telescopes.

Centuries of diligent study by ground-based observers, supplemented by satellite views since the 1960s, have revealed that Mars is quite similar to Earth. Mars, like Earth, contains clouds, winds, a nearly 24-hour day and night, seasonal weather patterns, polar ice caps, volcanoes, valleys, and other recognizable characteristics. There are tantalizing hints that Mars was much more similar to Earth billions of years ago than today, with a thicker, warmer atmosphere and far more water—rivers, lakes, flood channels, and maybe oceans.

Mars appears to have become a barren, frozen desert. Nevertheless, close-up photographs of black streaks on the slopes of several craters during Martian spring and summer imply that at least a tiny quantity of water may flow periodically on the planet's surface. Radar reflections of a putative lake beneath the Antarctic Cap imply that water might remain liquid in protected regions under the surface.

Water availability on Mars is a vital concern since life, as currently understood, cannot live without it. If tiny life forms began on Mars, there is a distant possibility that they currently exist in these hidden blue nooks. In 1996, a team of scientists stated that they had found signs of ancient microbial life in a shard of a Mars meteorite. However, most experts disagreed with their interpretation.

1.5. Theoretical Basis

Humans are looking for an alternative place on Earth to continue their lives, and the closest option and choice for this is the planet Mars. Nevertheless, migration to

Mars, in addition to difficulties and the need for more studies, is the primary requirement for the continuance of human existence; researchers must investigate aspects such as how to construct buildings and structures.

Shelter is the first element of human life. People may live in bad weather conditions but have changed their living places and buildings depending on the weather and climatic conditions. For example, in the polar regions, the inhabitants of the pole and their natives try to control the cold and continue their lives with an interesting structure, as well as save their lives from the wild animals living in the poles.

In the desert areas, they try to use the hot desert winds and turn them into calm winds by installing wind deflectors on the buildings and dome-shaped buildings. Among the famous buildings of Badgiri, we can mention the historical buildings of Yazd, Iran, which were used to continue their lives in the desert climate. Also, the houses and buildings built in the forest have tried to prevent moisture from entering by increasing the height of their buildings above ground level. Of course, this also protects human lives against the attack of wild animals in the forest.

With all these interpretations, these people were able to form civilizations in different climates to continue their lives. Nevertheless, there are some differences in life on Mars. These differences come from the fact that on Earth, no human has ever worried about the use of oxygen or felt the danger of being exposed to the sun's ultraviolet rays, and no human has tried with all patience to trial and error until finally an ideal standard has been reached.

However, there is no opportunity for trial and error on Mars because this matter directly relates to human lives. If the buildings on Mars cannot control oxygen or the temperature of the buildings is out of the normal range, it may be hazardous and lead to the fact that all the people living on Mars will be at risk of their health with the slightest mistake. Therefore, in This Research, the most secure system that humanity has discovered and used in the industry will be used to preserve information about the building on Mars to advance the stated protection goals.

After recognizing the challenges of continuing to live on Mars, a solution must be provided to manage and address those challenges. The first solution is to build

buildings that can solve significant problems. The second solution comes from the fact that these problems are always threats that put humans at risk. The building can be controlled at any moment by maintaining and managing it using BIM.

BIM is a Building Information Modeling technique that employs specialized software to collect and manage building data in 3D models. This strategy is used in the construction sector to increase building quality while lowering construction and operational costs.

However, it is essential to protect this information because, on Mars, the first mistake can be the last and endanger the lives of many humans. Blockchain technology will be used for this purpose. Blockchain is a digital recording system that securely stores financial transactions and other data in a chain of (encrypted)⁴ Blocks.

Blockchain is an innovative technology used to store and transmit data. It was first introduced in 2008 by a person or group nicknamed Satoshi Nakamoto, the lead author of Bitcoin Whitepaper, who refers to a set of interconnected blocks with several transactions in each block as a directory. By combining the two, it can be acknowledged that the necessary protection and safety are provided.

1.6. Objective

1 • Enhancing BIM security to maintain information security

Information security in construction information technology (BIM) is a critical issue facing various challenges. Many ways to keep BIM information secure have been proposed in the past, but all have had flaws that put information security at risk.

The implications of compromised information security in BIM should not be taken lightly. Any manipulation or unauthorized access to this data can lead to catastrophic injuries and damages. Given the rapid production of information related to buildings and large projects, verifying its accuracy and integrity is challenging, often resulting in numerous errors.

⁴ ENCRYPTED: Is the process of encoding information

Traditional security methods may also protect against malicious attacks and intrusions, but due to today's sophistication, they may have vulnerabilities that allow them to be compromised.

Therefore, increasing information security in BIM is essential. This not only helps to ensure the accuracy and health of the information but also allows for better management of building information and prevents irreparable damage.

Blockchain technology has revolutionized transactions involving eight parts. Its implementation ensures more precise tracking of transactions and bolsters the security of building information management (BIM) systems. By establishing an immutable and unbiased system for recording and verifying transactions, Blockchain significantly reduces the risk of fraud and unauthorized alterations. Moreover, the creation of a centralized storage system not only safeguards the information necessary for BIM but also assures users of protection against unauthorized access. In this way, Blockchain plays a pivotal role in enhancing BIM security and upholding the integrity of information, providing a potential solution to the challenges we face.



Figure 1.7: The enhancement of BIM security (Author)

Figure 1.7, the conceptual images illustrate the enhancement of BIM security, showing layers of protection surrounding the 3D building model. These layers represent advanced security measures to safeguard the building's digital data and information within the BIM system.

2 • Using BIM for Mars buildings

An appropriate and non-interfering system is needed to continuously and efficiently manage construction data in Martian environments. The system should automatically check information about temperature, pressure, oxygen, light, and other essential parameters and take corrective action immediately if needed. Therefore, Building Information Modeling (BIM) technology, which can connect to other management systems, is the best method for managing building data in off-ground environments.

Any failure or delay in building data review in extraterrestrial environments can have serious and even dangerous consequences. Therefore, automatic and continuous checks are necessary. This becomes more important in Martian environments with very different living conditions than Earth.

BIM technology, with its advanced capabilities and efficiency, plays a crucial role in managing building data in Martian environments. Its ability to crackslessly connect with other management systems and automatically verify information makes it a key tool in the creation of safe and habitable living conditions in these unique environments.

A process involving library studies is first carried out to achieve this goal. At this stage, the necessary criteria for BIM implementation are evaluated and screened using experts' opinions. These criteria should include the requirements for Martian buildings and fully relate to the unique conditions of these environments.

The fuzzy hierarchical analysis (AHP) method plays a pivotal role in our process. It determines the importance of each criterion based on the priorities and values crucial in Martian buildings. This allows us to rank the criteria in order of

importance, guiding the optimal implementation of BIM for the best solutions in building data management in Martian environments.

Using the presented framework, building information in the Martian environment is controlled and managed. This framework includes Blockchain technology, which allows data to be recorded accurately, provides information security, and prevents unauthorized changes. This approach makes building information available continuously and without interference, and the necessary improvements are applied optimally.

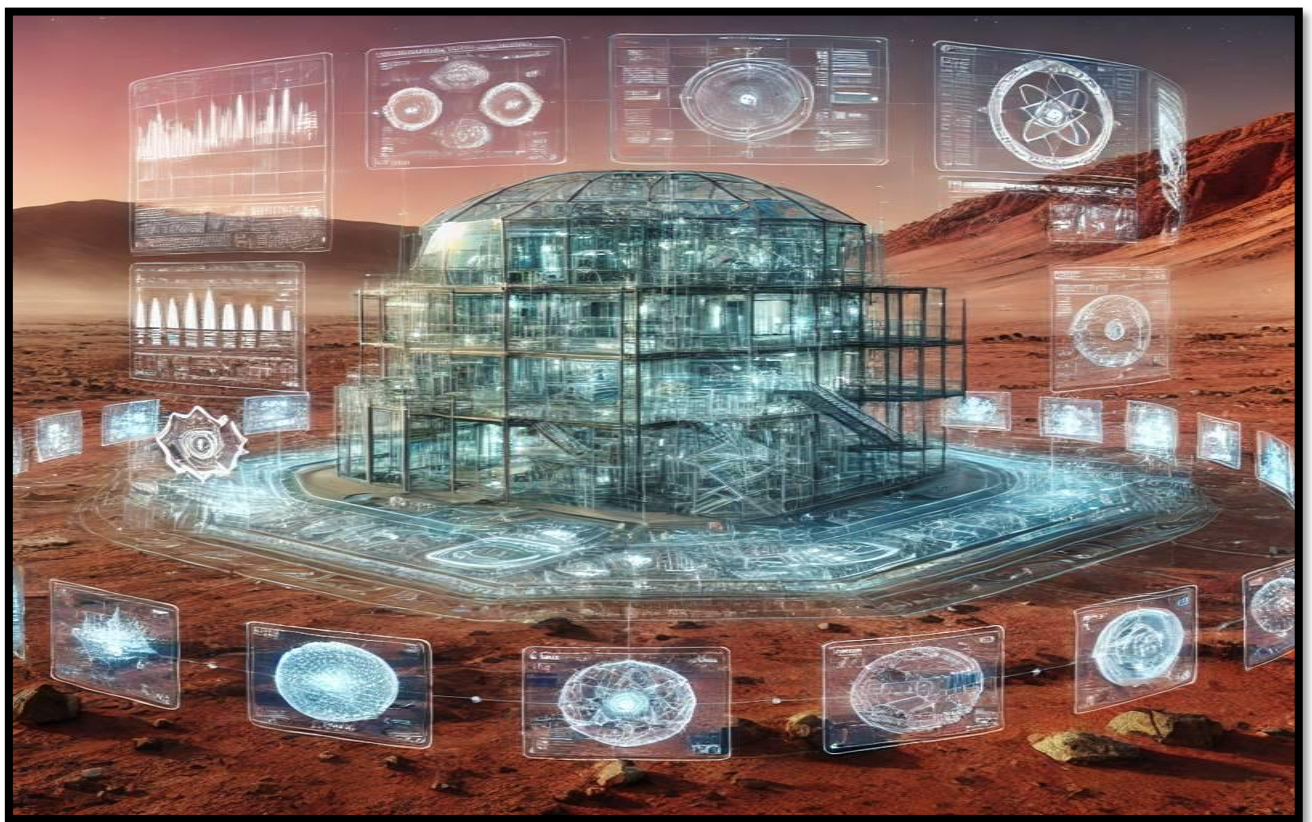


Figure 1.8: Use of Building Information Modeling (BIM) for Mars buildings (Author)

Figure 1.8, the use of Building Information Modeling (BIM) for Mars buildings is depicted, featuring a futuristic habitat on the Martian surface.

3 • Integration of BIM and Blockchain

The combination of BIM technology and Blockchain is known to increase the security and accuracy of information in building management, especially in extraterrestrial environments such as Mars. As an innovative and powerful

technology, Blockchain allows the creating of highly secure information without changing or deleting it. This technology stores information in sequential blocks and encryption, ensuring information reliability and security.

On the other hand, BIM, as a comprehensive method for building information management, encompasses information related to building design, construction, and maintenance. When these two technologies are combined, they form an incredibly robust and reliable platform for building information recovery in sensitive environments like Mars, instilling a sense of confidence and reassurance in their potential.

The combination of these two technologies results in the information collected and recorded by BIM being stored securely and accurately through the Blockchain. This connection between BIM and Blockchain significantly enhances the trust, security, and accuracy of information, leading to a promising improvement in building management and a boost in efficiency and effectiveness in unique environments such as Mars.

The four-level framework is proposed as an identification and implementation method by extracting essential criteria and evaluating them in BIM for Martian buildings. This framework has four main levels for managing building data and information in off-the-ground environments.

- The first level, or "normal level," represents the health of the building. At this level, the building is generally considered healthy, with no unusual signs of deterioration.
- The second level, or "Emergency level 1," is activated when faults are detected in the building's installations. At this stage, the rescue robots, using their sensors and data, detect problems and try to fix them.
- The third level, or "Emergency level 2", is activated when oxygen levels and ambient temperature have dropped dangerously low. In this case, people's lives are at risk, and rescue robots must react faster to save people.
- The fourth level, or "Emergency level 3," is activated when the health of structures such as walls and roofs is compromised. At this stage, the structures are checked and may need repairs or reinforcements.

A comprehensive and complete framework is provided for managing construction data and information in Martian environments using BIM by presenting these four levels. This framework can be a practical guide for organizations and engineering teams in projects related to Martian buildings and help improve efficiency and effectiveness in this field.



Figure 1.9: Integration of Building Information Modeling (BIM) and blockchain
(Author)

Figure 1.9 depicts the integration of Building Information Modeling (BIM) and blockchain technology. It showcases how blockchain enhances BIM by securely managing and sharing construction data through a decentralized, tamper-proof system, ensuring data integrity and transparency.

1.7. Sustainability on Mars

All the research has been carried out to a relatively large extent to improve the quality of human life. Experience has proven that using science improves and increases the quality of human life. Science can also have a negative aspect and threaten human life. But the important point is that the same progress of science was created to help human life, and man determines how to use science. The current research has also taken a step towards improving the quality of human life. Considering all the progress of science in different parts of the earth, there is a problem: With the progress of science, the earth has been transformed, and thinking about the future of humanity is essential (Hossain, 2017).

A future that may no longer have a place on Earth should be sought in other planets. The earth was a gift that man did not appreciate and is trying to destroy. Considering Mars for the future of humanity, this research tries to provide and improve the quality of human life on that planet so that Mars does not suffer the same fate as Earth. The presentation of blockchain and its integration with BIM can be used to control and save human lives on the Red Planet. Using this research, it is possible to control buildings and human settlements to protect human lives from possible dangers on Mars (Hossain, 2017).

Figure 1.10 illustrates sustainable building design on Mars, featuring key elements such as solar panels, greenhouses, and self-sustaining systems. These components emphasize renewable energy, food production, and independence in a Martian habitat.



Figure 1.10: Sustainable building design on Mars (Author)

1.7.1. Managing Resources for a Sustainable Future

As climate change and environmental degradation threaten Earth's ecosystems, space agencies such as NASA are turning to Mars as a potential destination for human life. With its harsh conditions—extreme temperatures, thin atmosphere, and high radiation—Mars presents immense challenges for sustaining human life. Innovative technologies and solutions are needed to develop habitats that protect humans from these conditions and make habitation feasible. This includes building materials that can withstand dust storms, solar radiation, and extreme colds and systems to produce water, oxygen, and food from local Martian resources (Sagar et al., 2023).

Establishing human life on Mars is not just a matter of survival, but also of sustainability. Since resupply missions from Earth would be limited, Martian

habitats must be largely self-sufficient. This involves creating closed-loop systems for recycling water and air, harnessing renewable energy sources such as solar power, and utilizing the Martian soil to produce food and even construction materials through 3D printing. These innovations are not just theoretical, but practical solutions that would allow humans to survive on Mars and reduce our environmental footprint, making long-term habitation viable and reducing our dependency on Earth (Petrov et al., 2005).



Figure 1.11: Managing resources (Author)

Figure 1.11, illustrates managing resources for a sustainable future on Mars, showcasing renewable energy systems, water recycling technologies, and agriculture. These elements highlight the importance of efficient resource use and self-sufficiency in supporting long-term life on Mars.

1.7.2. The Role of Blockchain in Martian Sustainability

A key innovation in the push for sustainable Martian habitation is introducing a blockchain-based framework to manage the information on Martian buildings. Blockchain technology offers a decentralized, secure, and tamper-proof system for recording and tracking data, ensuring accurate information processing and storage. This is crucial for maintaining the safety, integrity, and functionality of habitats and other structures on Mars, where human life would depend on precise monitoring and reliable systems. Blockchain's transparent and immutable nature guarantees that any changes or updates to building data are recorded without the risk of manipulation, making it a trustworthy tool for managing critical infrastructure (Anichur Rahman et al., 2020).

Blockchain, in addition to enhancing security, allows for real-time monitoring of key sustainability metrics. This data-driven approach enables scientists and engineers to make informed decisions swiftly, ensuring that Martian settlements are safe, efficient, and resource-conscious. With this system in place, blockchain could significantly contribute to protecting both the Martian environment and the well-being of its inhabitants, while fostering a resilient and adaptive infrastructure on the Red Planet (Arim Park et al., 2021).

Figure 1.12, illustrates the role of blockchain in Martian sustainability, showing digital blocks managing key resources like energy, water, and food. This highlights how blockchain technology can ensure efficient and transparent management of resources for a sustainable future on Mars.



Figure 1.12: Blockchain in Martian sustainability (Author)

1.7.3. Sustainability Challenges on Mars

Mars presents unique challenges to the sustainability of human habitats, requiring advanced solutions. Eleven criteria have been identified in previous studies that are essential for building sustainability on Mars:

- **Meteor Shields:** Protecting Martian buildings from meteorite impacts is essential due to Mars' thin atmosphere, which allows even small meteoroids to reach the surface. Structures can be built using advanced materials like reinforced polymers or regolith-based concrete, which are capable of withstanding impacts. Covering habitats with thick layers of Martian regolith provides additional shielding against meteorites and harmful radiation. Alternatively, constructing underground or partially buried buildings offers natural protection from impacts. Combined with early detection systems to monitor potential meteorite threats, these strategies ensure the safety and sustainability of human settlements on Mars (Reches et al., 2019).



Figure 1.13: meteor guards (Author)

Figure 1.13, depicts meteor shields or meteor guards protecting a futuristic habitat on another planet. It showcases advanced technology designed to deflect space debris and meteors, ensuring the safety and integrity of the extraterrestrial settlement.

- **Building Facilities:** Ensuring Martian buildings are equipped with the necessary facilities is crucial for the survival and well-being of their inhabitants. To create a safe and livable environment, these structures must include life-support systems for air and water purification, efficient energy generation (such as solar power), temperature regulation, and radiation shielding. Additionally, facilities for food production, waste management, and resource recycling are essential for long-term sustainability, reducing reliance on Earth for resupply missions. Advanced communication systems, medical stations, and emergency shelters are critical components, ensuring that inhabitants can maintain their health,

safety, and connectivity while adapting to the harsh Martian conditions (Kozicki et al., 2019).



Figure 1.14: Building facilities on Mars (Author)

Figure 1.14, building facilities on Mars, with a focus on essential infrastructure such as pipes, air conditioning, and lighting systems within a Martian habitat. This illustrates the importance of providing functional, livable environments in extraterrestrial settlements.

- **Windows and Weather Adaptability:** Managing windows in extreme Martian weather is a significant challenge due to the planet's harsh conditions, including intense dust storms, extreme cold, and high levels of radiation. Windows must be designed with durable, multi-layered materials, such as reinforced glass or transparent composites, to withstand the abrasive dust and powerful winds. They also need advanced thermal

insulation to prevent heat loss in the cold Martian environment while maintaining a stable internal temperature. Additionally, windows should be coated with radiation-resistant materials or equipped with automated shutters that can close during periods of high radiation exposure or severe dust storms, ensuring both safety and energy efficiency for the habitat (Chen et al., 2023).



Figure 1.15: windows on a futuristic Mars building (Author)

Figure 1.15, Showcases windows on a futuristic Mars building, providing a view of the Martian landscape. The windows feature advanced design elements, likely emphasizing durability, insulation, and the ability to withstand Mars' harsh environment while offering inhabitants a glimpse of the red planet's surface.

- **Air Pressure:** Maintaining suitable atmospheric pressure inside Martian habitats is vital for human survival, as Mars has an extremely thin atmosphere with less than 1% of Earth's surface pressure. To achieve this, habitats must be airtight and constructed with robust, pressure-resistant materials to prevent air leakage. Advanced airlock systems are necessary to maintain internal pressure when entering or exiting the habitat. Moreover, continuous monitoring and regulation of oxygen, nitrogen, and carbon dioxide levels are crucial to simulate Earth's atmosphere and ensure proper breathing conditions. In case of a breach, automated systems would need to rapidly detect and repair leaks to prevent depressurization and maintain the safety of the inhabitants (Kurokawa et al., 2017)

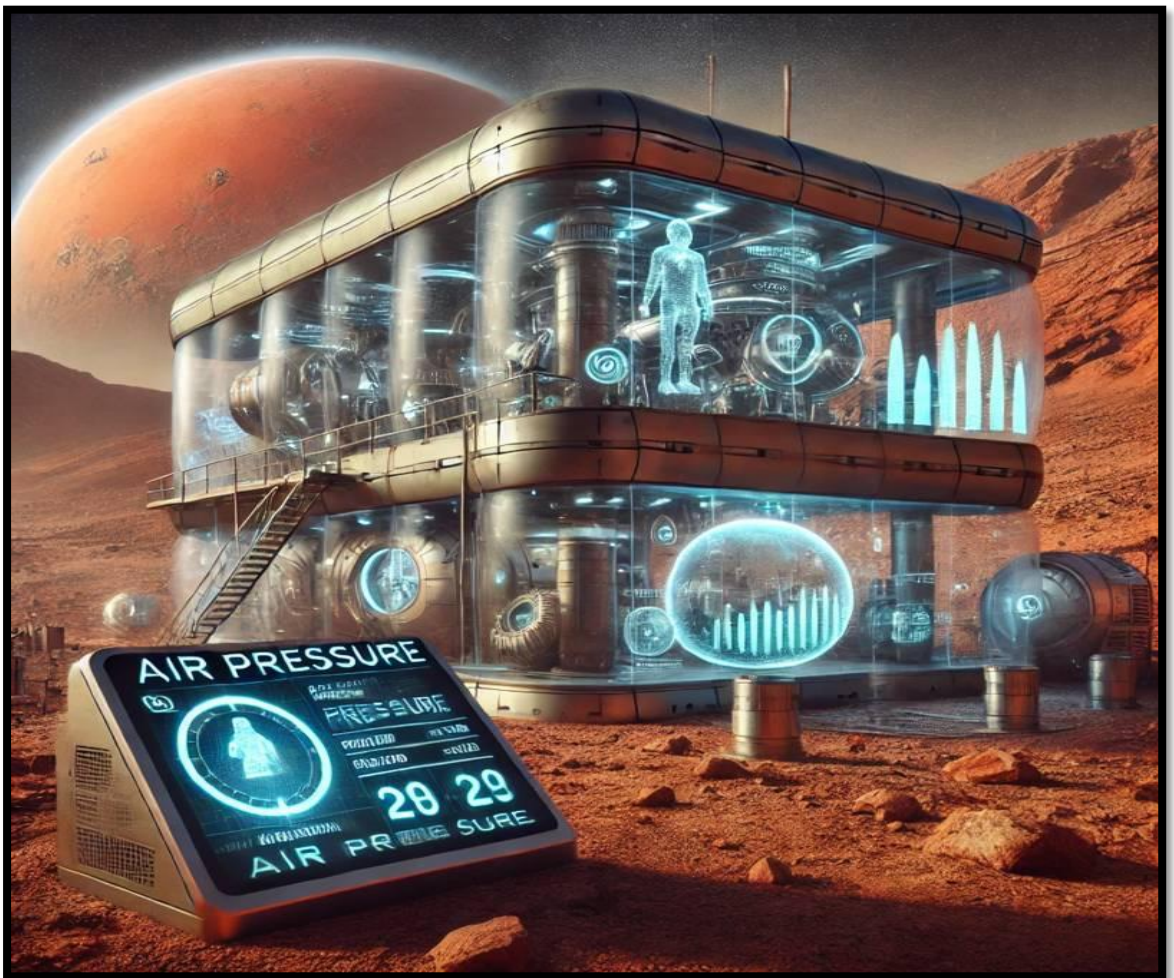


Figure 1.16: air pressure on Mars (Author)

Figure 1.16, Represents air pressure on Mars, highlighting a futuristic habitat equipped with advanced air pressure control systems. This

contrasts with the harsh external Martian environment, emphasizing the need for precise atmospheric regulation to maintain a livable interior for inhabitants.

- **Temperature Control:** Managing extreme cold temperatures on Mars is essential for maintaining livable conditions within human habitats. Mars experiences average surface temperatures around -80°F (-60°C) and can drop much lower, particularly near the poles or during nighttime. To address this, habitats must be well-insulated using advanced thermal materials that trap heat and prevent energy loss. Passive heating techniques, such as leveraging Martian regolith for insulation or building partially underground, can help. Active systems like solar-powered heating and thermal control units are also necessary to regulate internal temperatures. Energy-efficient heating solutions are critical, as relying on limited resources requires optimizing power consumption while ensuring that internal temperatures remain stable for the safety and comfort of inhabitants (Biswal M et al., 2021).



Figure 1.17: temperature control on Mars (Author)

Figure 1.17, Temperature control on Mars, focusing on the advanced systems used to maintain a livable environment inside a Martian habitat. These systems are crucial for regulating warmth and comfort despite the extreme cold temperatures of the Martian surface.

- **Oxygen Supply:** Ensuring sufficient oxygen for human life on Mars is a critical challenge, as the Martian atmosphere contains only about 0.13% oxygen compared to Earth's 21%. To address this, habitats must be equipped with life-support systems capable of generating and recycling oxygen. One approach is the use of technologies like NASA's MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment), which extracts oxygen from the abundant carbon dioxide in Mars' atmosphere through electrochemical processes. Additionally, oxygen can be produced through water electrolysis if water resources are available. Oxygen recycling systems must also be employed to continuously filter and recirculate air, ensuring efficient use of resources and maintaining safe, breathable levels of oxygen for inhabitants. Regular monitoring and backup systems are essential to prevent any risk of oxygen depletion (Petrescu et al., 2019).

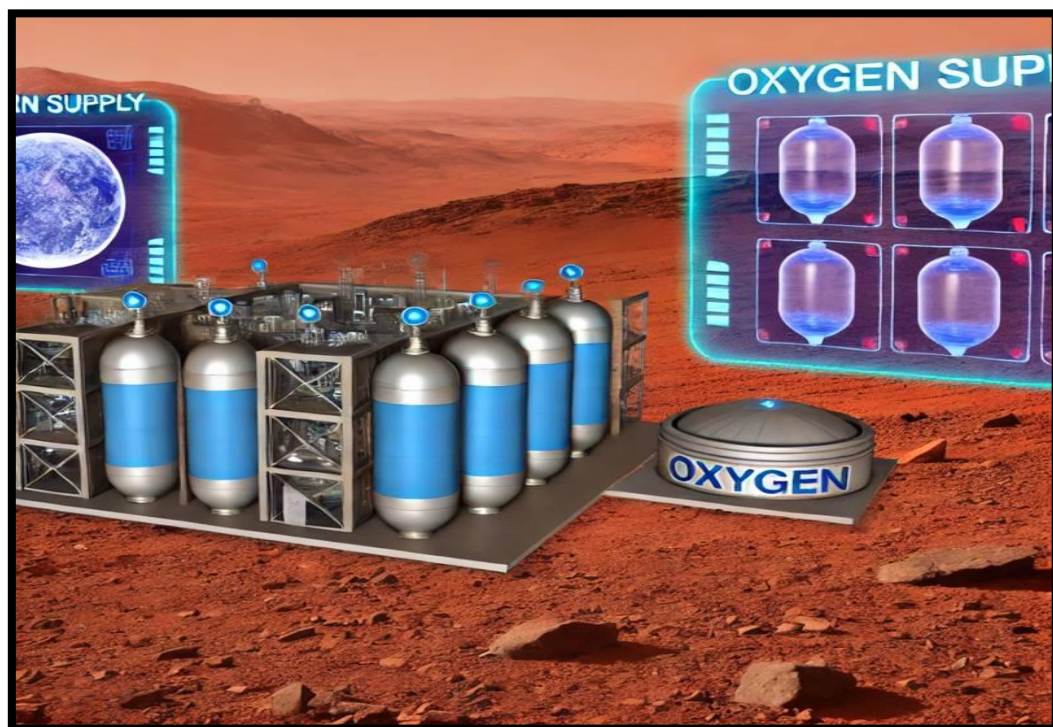


Figure 1.18: oxygen supply on Mars

Figure 1.18, Represents oxygen supply on Mars, showcasing advanced systems designed to generate and maintain a stable and breathable oxygen environment within a Martian habitat, essential for sustaining human life in the planet's thin atmosphere.

- **Carbon Dioxide Management:** Reducing high levels of CO₂ inside Martian habitats is crucial for maintaining a breathable atmosphere, as Mars' atmosphere consists of about 95% carbon dioxide (CO₂). Effective life-support systems must continuously remove excess CO₂ to prevent its accumulation, which can harm human health. One solution uses CO₂ scrubbers, which filter the air through chemical processes like adsorption, where materials such as lithium hydroxide or zeolites trap CO₂ molecules. Another approach involves using biological systems, such as algae or plants, which naturally absorb CO₂ during photosynthesis while producing oxygen. These technologies must work efficiently to regulate the internal environment, ensuring that CO₂ levels remain safe and manageable for long-term habitation (Jakosky et al., 2018).



Figure 1.19: Carbon dioxide management (Author)

Figure 1.19, Illustrates carbon dioxide management on Mars, showcasing advanced systems designed to capture and recycle CO₂. These systems are

essential for maintaining a livable environment by converting CO₂ into useful resources, ensuring sustainable life support in the Martian habitat.

- **Humidity Control:** Keeping humidity at sustainable levels inside Martian habitats is essential for both human comfort and the proper functioning of equipment. Mars' atmosphere is extremely dry, so humidity control must be carefully managed to prevent the air from becoming too dry, which could cause respiratory issues and skin irritation. On the other hand, excessive humidity could lead to condensation, which might damage electronic systems or promote mold growth. To maintain an optimal balance, humidity control systems must include dehumidifiers and humidifiers that continuously monitor and regulate moisture levels. Additionally, closed-loop water recycling systems can help control humidity by capturing excess moisture from the air, ensuring that habitats stay within a comfortable and sustainable humidity range for long-term human habitation (Valentin et al., 2015).



Figure 1.20: Humidity control on Mars

Figure 1.20, Humidity control on Mars, focusing on advanced systems that regulate and maintain optimal moisture levels within a controlled environment. These systems are essential for ensuring comfort and supporting life in the harsh, dry Martian atmosphere.

- **Light:** Harnessing solar energy on Mars is essential for powering human habitats, but managing light levels presents unique challenges due to the planet's distance from the Sun and frequent dust storms. Solar panels can capture sunlight, but since Mars receives about 60% less solar energy than Earth, the panels need to be highly efficient and expansive to meet energy demands. Additionally, systems must be in place to store energy for use during long periods of darkness or when dust storms reduce sunlight. To manage light levels inside the habitat, natural lighting can be supplemented with artificial lighting systems that mimic Earth's day-night cycle, supporting human circadian rhythms and plant growth. Smart shading systems or adjustable windows can also help control the amount of natural light entering the habitat, balancing energy efficiency with comfort and productivity (Saude et al., 2023).



Figure 1.21: lighting in a futuristic Mars building

Figure 1.21, the image showcases lighting in a futuristic Mars building, featuring advanced lighting systems designed to adapt to the low light conditions on Mars. These systems ensure adequate illumination for both functional and livable spaces, compensating for the planet's dimmer natural light.

The framework emphasizes six key criteria identified from expert opinion for ensuring building sustainability on Mars: walls, roofs, building facilities, air exchange, temperature regulation, and ambient oxygen levels. These criteria are fundamental in maintaining Martian habitats' structural integrity and habitability under harsh conditions.

The walls and roofs must be resilient against extreme weather, radiation, and meteorite impacts while providing insulation and shielding from dust storms. Proper building facilities are essential for life support, energy efficiency, and resource management. Effective air exchange systems ensure the removal of excess CO₂ and regulation of humidity, while temperature regulation keeps the interior livable despite Mars' freezing temperatures. Maintaining stable ambient oxygen levels is vital for survival, with systems designed to generate and recycle breathable air. Together, these criteria ensure both the safety of inhabitants and the sustainability of resources in a self-sufficient Martian habitat.

1.7.4. Smart Contracts and Sensor Data for Resource Management

The Blockchain-based framework uses Smart Contracts to manage Martian buildings' construction and maintenance data. Smart Contracts automate processes, ensuring that data is recorded and actions are taken when necessary. For instance, sensor data on environmental factors like temperature and oxygen levels are stored in the Blockchain, triggering pre-programmed responses when critical thresholds are reached.

The system also uses four levels of building health status, providing a scalable solution for ensuring sustainability. These levels include:

- **Normal Level:** At the Normal Level, no intervention is needed as the buildings are functioning optimally, and all systems are operating within

safe parameters. Environmental factors like temperature, humidity, air quality, and oxygen levels remain within predefined, healthy thresholds. In this state, the Blockchain-based framework monitors and logs sensor data in real time, ensuring transparency and a clear record of building conditions. Smart Contracts remain inactive but on standby, ready to trigger pre-programmed responses if conditions deviate from normal. This level signifies that the habitat is fully self-sustaining, with no immediate need for maintenance or adjustments.

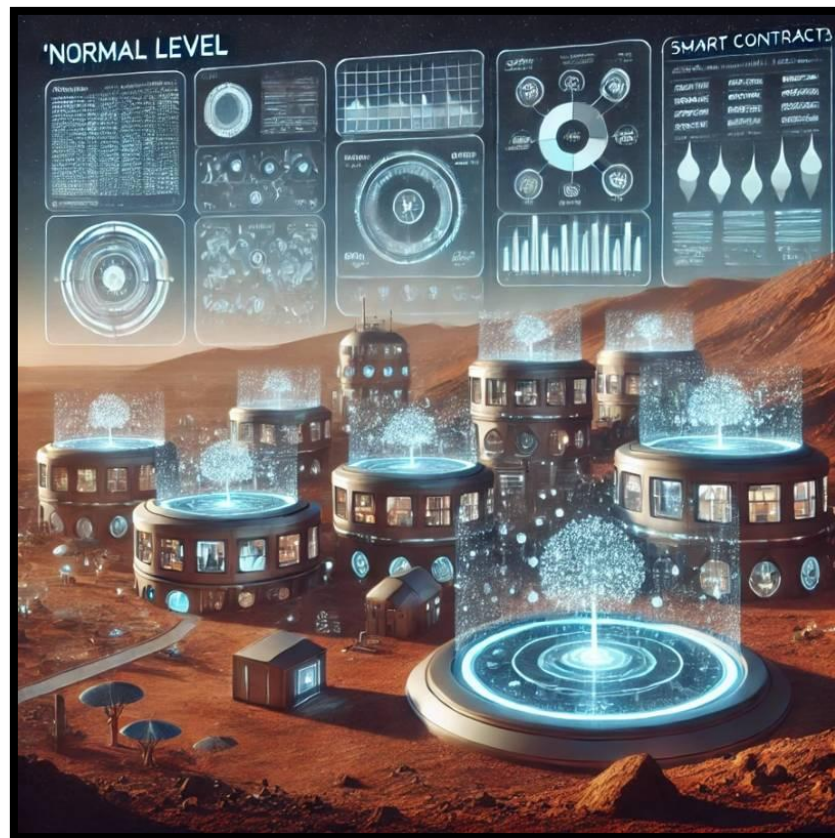


Figure 1.22: Normal Level (Author)

Figure 1.22 illustrates the "Normal Level" for a Mars habitat, indicating a state where all systems are operating at peak efficiency without the need for any external intervention or adjustments.

- **Emergency Level 1:** Small problems within the building facilities are detected but do not pose an immediate threat to the habitat's overall function or safety. These issues—such as minor malfunctions in air circulation, slight deviations in temperature, or small equipment failures—

are automatically addressed by robotic systems. The Blockchain-based framework logs the anomalies and triggers Smart Contracts that dispatch autonomous repair robots to fix the issues without human intervention. These robotic systems can handle routine maintenance tasks, such as tightening loose components or recalibrating sensors, ensuring the habitat remains operational and minimizing downtime. This proactive system helps maintain efficiency while optimizing resources and preventing minor problems from escalating into more significant threats.



Figure 1.23: Emergency Level 1 (Author)

Figure 1.23 represents "Emergency Level 1" for a Mars habitat, where minor issues are resolved by autonomous repair robots, maintaining the habitat's functionality without human intervention.

- **Emergency Level 2:** Significant risks to oxygen levels and temperature are identified, necessitating immediate intervention to safeguard human life. In this state, sensor data indicates alarming drops in oxygen concentration or extreme fluctuations in temperature, which could compromise the health and safety of the inhabitants. The Blockchain-based framework, through its Smart Contracts, triggers emergency protocols to address these critical issues rapidly.



Figure 1.24: Emergency Level 2 (Author)

Figure 1.24 depicts "Emergency Level 2" for a Mars habitat, a scenario where critical threats to oxygen levels and temperature arise, requiring immediate intervention protocols to prevent system failure and ensure survival.

- **Emergency Level 3:** Major structural problems arise, such as significant damage to walls or roofs, which pose an immediate threat to the integrity of the habitat and the safety of its occupants. These issues could result from meteorite impacts, severe dust storms, or other unforeseen events compromising the building's structural stability. In this critical state, the Blockchain-based framework detects the damage through advanced sensor systems and triggers Smart Contracts that initiate emergency protocols.



Figure 1.25: Emergency Level 3

Figure 1.25 illustrates "Emergency Level 3" for a Mars habitat, indicating a severe situation where major structural damage jeopardizes the habitat's integrity, posing significant risks to the safety and stability of the environment.

This multi-layered approach enables efficient resource use by integrating advanced technologies and automated systems for rapid issue identification and resolution. By leveraging the Blockchain framework and Smart Contracts, all data related to the habitat's conditions is continuously monitored, allowing for real-time insights into potential problems. This proactive monitoring ensures that even minor issues are detected early, preventing them from escalating into more severe threats that could waste resources or endanger human life.

1.7.5. Sustainability Through Local Resources

To ensure long-term sustainability on Mars, utilizing local Martian materials is crucial. Transporting supplies from Earth is neither cost-effective nor practical in the long run, given the immense resource limitations associated with interplanetary travel. Mars' surface is rich in materials such as regolith (Martian soil), which can be harnessed for 3D printing building structures, thus significantly reducing reliance on Earth-based supplies. This strategy promotes sustainable practices by minimizing resource depletion and enhancing the self-sufficiency of Martian habitats, allowing for the development of infrastructure that can adapt and thrive in the Martian environment (Naser et al., 2019).

Renewable energy sources, particularly solar energy, will be essential for powering Martian habitats. Mars receives abundant sunlight, making it an ideal location for solar panels to generate a reliable and sustainable energy supply. This renewable energy approach will reduce dependency on fossil fuels and other non-renewable sources, aligning with broader sustainability goals. By leveraging local materials for construction and harnessing solar energy for power, Martian habitats can achieve a high degree of autonomy, ensuring that human life can be sustained without overexploiting Earth's resources (Bergsrud et al., 2013).

Figure 1.26 represents "Sustainability Through Local Resources" on Mars, highlighting a colony that achieves self-sufficiency by utilizing Martian materials and resources to support its ongoing survival and development.



Figure 1.26: Sustainability Through Local Resources (Author)

1.7.6. Toward a Sustainable Martian Colony

The proposed Blockchain-based framework for managing Martian buildings establishes a robust foundation for ensuring the sustainability of human settlements on Mars. By integrating advanced technologies such as Smart Contracts, sensors, and decentralized data management, this system facilitates efficient resource use, enhances safety, and ensures the long-term functionality of habitats. The real-time monitoring and automated responses enabled by this framework will allow for quick adjustments to environmental conditions, minimizing waste and maintaining a livable atmosphere for inhabitants (Liu et al., 2021).

The success of such frameworks and technologies on Mars will provide invaluable insights into sustainable living practices that can be applied on Earth. As humanity extends its reach beyond our planet, the challenges encountered and lessons learned while establishing a sustainable presence on Mars could foster innovations that benefit both terrestrial and extraterrestrial ecosystems. The potential for this cross-pollination of knowledge, where insights from Mars inform Earth's sustainability, could lead to advancements in resource management,

renewable energy solutions, and habitat design, ultimately contributing to a more sustainable future for all environments (Losch et al., 2019).

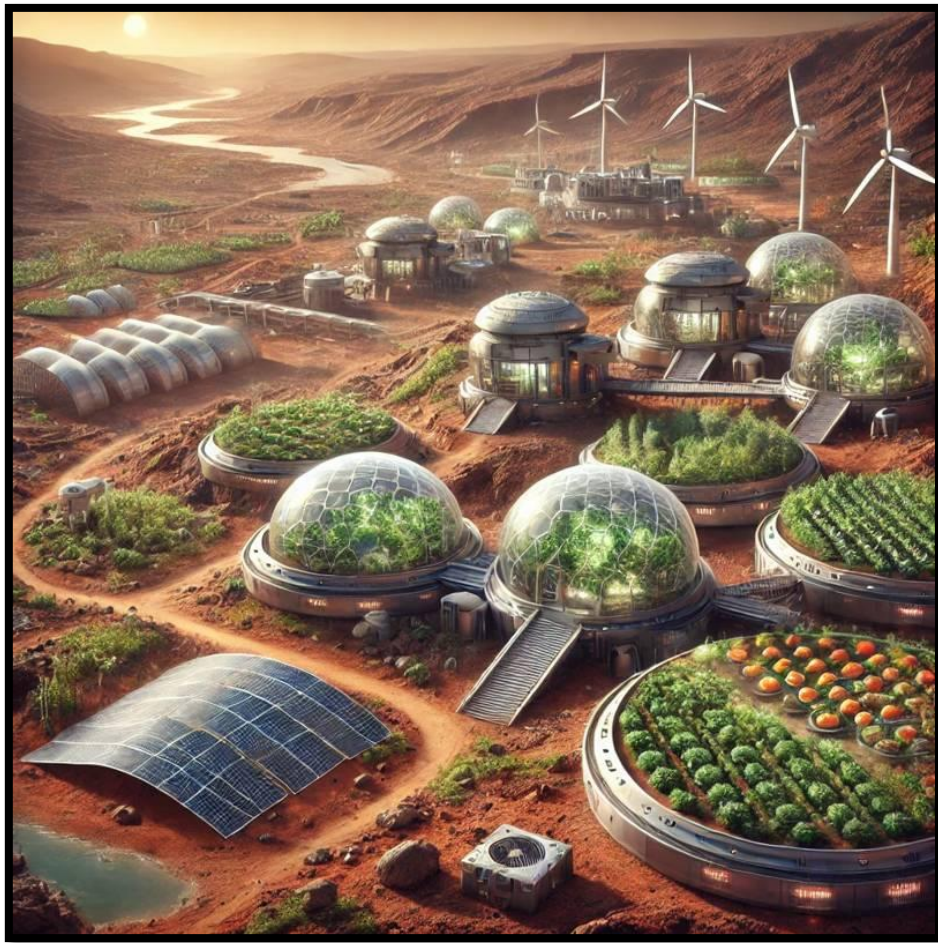


Figure 1.27: Mars colony (Author)

Figure 1.27 showcases a futuristic Mars colony specifically designed for long-term sustainability, featuring advanced systems and infrastructure that support continuous habitation and resource management for extended periods.

2. STANDARDS

2.1. Introduction

Standards are a set of documented agreements that contain technical specifications and other detailed requirements and are always used as principles, guidelines or specification definitions to ensure the suitability of materials, products, processes and services for their intended purpose.

What is the need for a standard and its use?

- Considered as a reference for a feature of a product, process or service.
- Provides information that improves safety, reliability of products, processes and services.
- Assures users about the reliability or other characteristics of a marketed product or service.
- Considering that it causes compatibility between different products, it gives users more opportunities to use various products.

In this chapter, the standards used in this research have been comprehensively reviewed. These standards include blockchain technology, building information modeling, temperature, and oxygen levels. Blockchain has been touted as a new technology in information recording and management, while Building Information Modeling (BIM) helps improve the design and construction process. Also, the importance of temperature and oxygen in different environments, especially in industrial and construction fields, is considered a key factor in optimizing working conditions and increasing efficiency.

2.2. Blockchain standards

Blockchain standards instruct token makers on how to develop, issue, and maintain tokens on a given network, ensuring consistency across platforms and wallets. Each standard often provides instructions on token functionality, address format, and how to interface with the blockchain.

These blockchain standards are a subset of the larger smart contract standards, as they provide a framework for developing decentralised apps and managing tokenised assets. Each blockchain network, such as Ethereum, Binance Smart Chain, or Solana, has created its own set of rules to support various sorts of smart

2.2.1. OMNI standard

Omni is a safe and fast standard developed on the most famous blockchain, Bitcoin. Users can receive, send and exchange their tokens through the OMNI standard. It should be noted that the famous Tether digital currency also uses a secure standard for its transmission. Due to the interest and acceptance of Tether by many users, this stablecoin was also installed on other blockchains.

The security was originally known as Mastercoin, which was finally officially renamed in 2015.

You can find the addresses of security-based wallets listed below. These wallets are designed to enhance the security of your digital assets, ensuring that your cryptocurrency transactions are safeguarded against potential threats. Each wallet address serves as a unique identifier for storing and managing various cryptocurrencies securely. Below are the details of the security-based wallets, including their types, features, and the specific cryptocurrencies they support. It's essential to choose the right wallet based on your security needs and the specific cryptocurrencies you intend to store or trade.

1. P2PKH format

In this case, the addresses start with the number one.

1Cvfhs3GH4n8KtfTeJugDbgtjfsDRfgTGty5

2. P2SH format

In this case, the addresses start with the number three.

3GThyFyhFEaSsfFDwwvHyUjmMHAdsar4

3. Beach32 format

In this case, the addresses start with bc1.

bc1UKdfgeg4THCGNDH7zgstezw6HAFsGSH4

2.2.2. ERC Blockchain Standards

ERC blockchain standards are frameworks for the operation of tokens launched on the Ethereum network. Various standards were launched on this network, the

most famous of which is the ERC-20 standard. This standard is a bit faster and less expensive than the security standard.

It is better to know that ERC stands for Ethereum request for comment. This phrase means asking Ethereum for a comment. These letters are present in all ethereum network standards and there is a number in front of them that means the number of the standard design.

All existing exchanges support this standard. This allows users to receive and transfer digital currencies that comply with this standard.

we will introduce you to other blockchain standards that have been launched on the Ethereum network.

- (ERC 721⁵)
- (ERC 725⁶)
- (ERC 865⁷)
- (ERC 884⁸)
- (ERC 621⁹)
- (ERC 165¹⁰)
- (ERC 777¹¹)
- (ERC 223¹²)
- (ERC 827¹³)
- (ECR 735¹⁴)
- (ERC 1400¹⁵)

ERC 721: <https://academy.bit2me.com/que-es-token-erc-721/> ⁵

⁶ ERC 725: <https://erc725alliance.org>

⁷ ERC 865: <https://medium.com/web3prophet/how-does-erc-865-revolutionize-token-transactions-6dea8c29c4d1>

⁸ ERC 884: <https://coinmarketcap.com/academy/glossary/erc-884>

⁹ ERC 621: <https://www.blockchain-council.org/ethereum/erc-token-standards/>

¹⁰ ERC 165: <https://eips.ethereum.org/EIPS/eip-165>

¹¹ ERC 777: <https://docs.openzeppelin.com/contracts/3.x/erc777>

¹² ERC 223: <https://coinmarketcap.com/academy/glossary/erc-223>

¹³ ERC 827: <https://coinmarketcap.com/academy/glossary/erc-827>

¹⁴ ECR 735: <https://kctheservant.medium.com/a-companion-guide-to-first-impressions-with-erc-725-and-erc-735-identity-and-claims-part-1-51b53603cfc0>

¹⁵ ERC 1400: <https://polymath.network/erc-1400>

There are many tokens that have been created using the ERC-20 standard, which is widely recognized for enabling the development of tokens on the Ethereum blockchain. Below, we list some of the most famous ERC-20 tokens:

- Tether (USDT): a cryptocurrency designed to provide a stable price point at all times.
- Binance (BNB): BNB chain transactions are fueled by a blockchain gas token called BNB, which stands for "Build and Build"
- Link: The LINK token is an ERC677 token that inherits functionality from the ERC20 token standard and allows token transfers to contain a data payload.
- DAI: DAI is an ERC-20 token that can be purchased from both centralized exchanges and decentralized exchanges (DEXs).

2.2.3. TRC Blockchain Standards

These standards were launched on the Tron blockchain network and include two standards named TRC-10 and TRC-20.

It is better to know that initially Tron token was working on the Ethereum blockchain. Finally, in 2018, it became independent by launching a dedicated blockchain with the aim of easier and faster facilities as well as lower fees than Ethereum. TRC-20 was launched after TRC-10 and tried to compensate for the shortcomings and simplicity of the previous standard. For this reason, this standard is now one of the most widely used standards for creating digital currency, offering and transferring tokens.

When you intend to trade a token based on the TRC-20 standard; Make sure that the beginning of the destination wallet address starts with the letter T.

2.2.4. BNB (Binance Chain) blockchain standards

The Binance blockchain network also spawned standards that are now known as BEP-2, BEP-20 and BEP-8. These standards include instructions and rules for the coordination of tokens based on this network.

Addresses of token transfer wallets on the BEP-2 standard begin with the abbreviation bnb. Currently, Ethereum and Bitcoin tokens are also able to be transferred on the Binance network. But note that when you intend to transact these tokens, because they are based on Binance blockchain standards, their wallet address will also start with the letters bnb.

Other widely used standards

- Algorand
- EOS
- Zcash
- BCH
- Band
- Iris

2.2.5. Blockchain standards; A way to easily recognize the characteristics of each network

Blockchain standards are a set of rules and regulations based on which all the behaviors of a token, including design, offering, and buying and selling, are done. These standards are a subset of smart contracts. In fact, they are intended for blockchains that can create tokens on their platform (coinmarketcap, 2024).

This research used a public Blockchain. In a public Blockchain, information can be stored one way; all data is coded using a one-way hash function and stored in it .

The one-way hash function is a mathematical function with no inverse function; the input cannot be reached from the output reason. This type of Blockchain is used for the security and accuracy of information .

This type of Blockchain makes it almost impossible to de-hash the information and ensure its accuracy.

Over the past few years, Blockchain has gone through significant periods of hype and skepticism. A few promising use cases and applications have emerged, and the ecosystem is moving forward with designing and building for scale. However,

several questions critical to Blockchain 's success – or failure – remain. As cataloged elsewhere, regulatory clarity remains a significant hurdle for many organizations.

In addition, technical and governance aspects such as interoperability, security, and models for ecosystem collaboration will have significant impacts on the technology.^{1,2} With the exploration of applications such as digital currencies and supply chain management which would fundamentally alter our ways of interacting and doing business there is an increasing need for common ground.

We are seeing the emergence of initiatives that aim to bring more excellent definitions to the new business models, platforms, and infrastructure that Blockchain demands and enables. There are certainly places where standardization is needed now – and others where it is too soon. Philosophical debates about the technology remain.

Furthermore, movements towards standardization must not come at the expense of carefully evaluating trade-offs related to technical architecture and governance. Decentralized technologies also introduce new possibilities for standard-setting across the ecosystem. As outlined in the paper, new ways of working challenge existing models that offer unique features or flexibility. The full scope of pros and cons remains to be seen, so it is important to continue to track the areas where new efficiencies and risks may come into play. Finally, standards have the potential to help level the playing field in the development of Blockchain – but only if they are designed and implemented thoughtfully. Without proactive attention to how standards are created and who is creating them, it is possible that they will be shaped according to specific interests and orientations – and potentially in the image of hegemonic powers or legacy systems.

2.3. BIM Standars

ISO 12006-3 consists of the specification of a taxonomy model, which provides the ability to define concepts by means of properties, to group concepts, and to define relationships between concepts. Objects, collections and relationships are the basic entities of the model. The set of properties associated with an object provide the formal definition of the object as well as its typical behaviour. Properties have values, optionally expressed in units.

Figure 2.1 shows the top level diagram with xtdRoot, its attributes and its derived types xtdObject, xtdRelationship and xtdCollection.

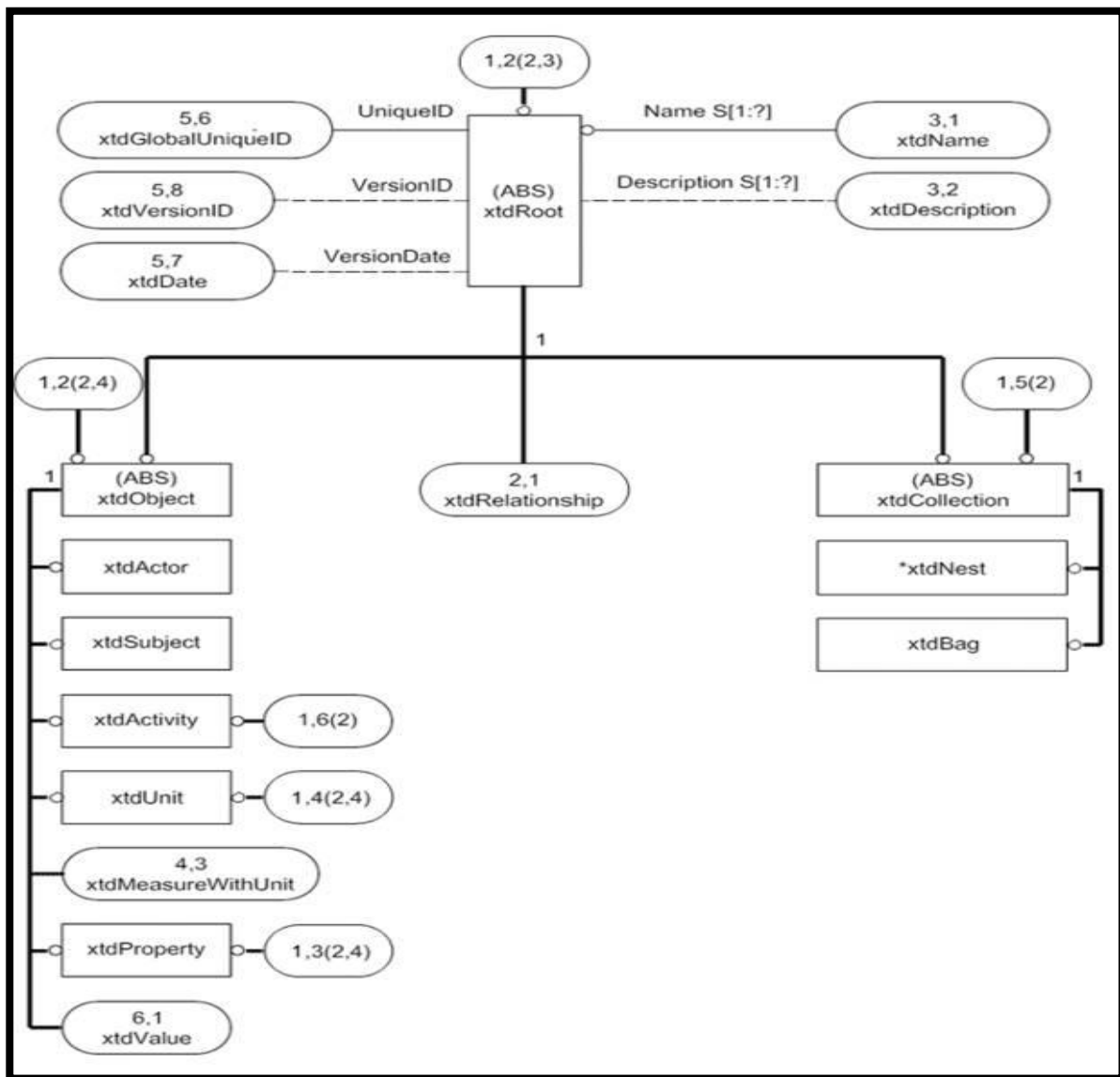


Figure 2.1: EXPRESS-G diagram 1 Top level with root concept (Global Standards)

Figure 2.2 shows xtdLanguageRepresentation with its derived types xtdName and xtdDescription that are attributed to xtdRoot and its subtypes.

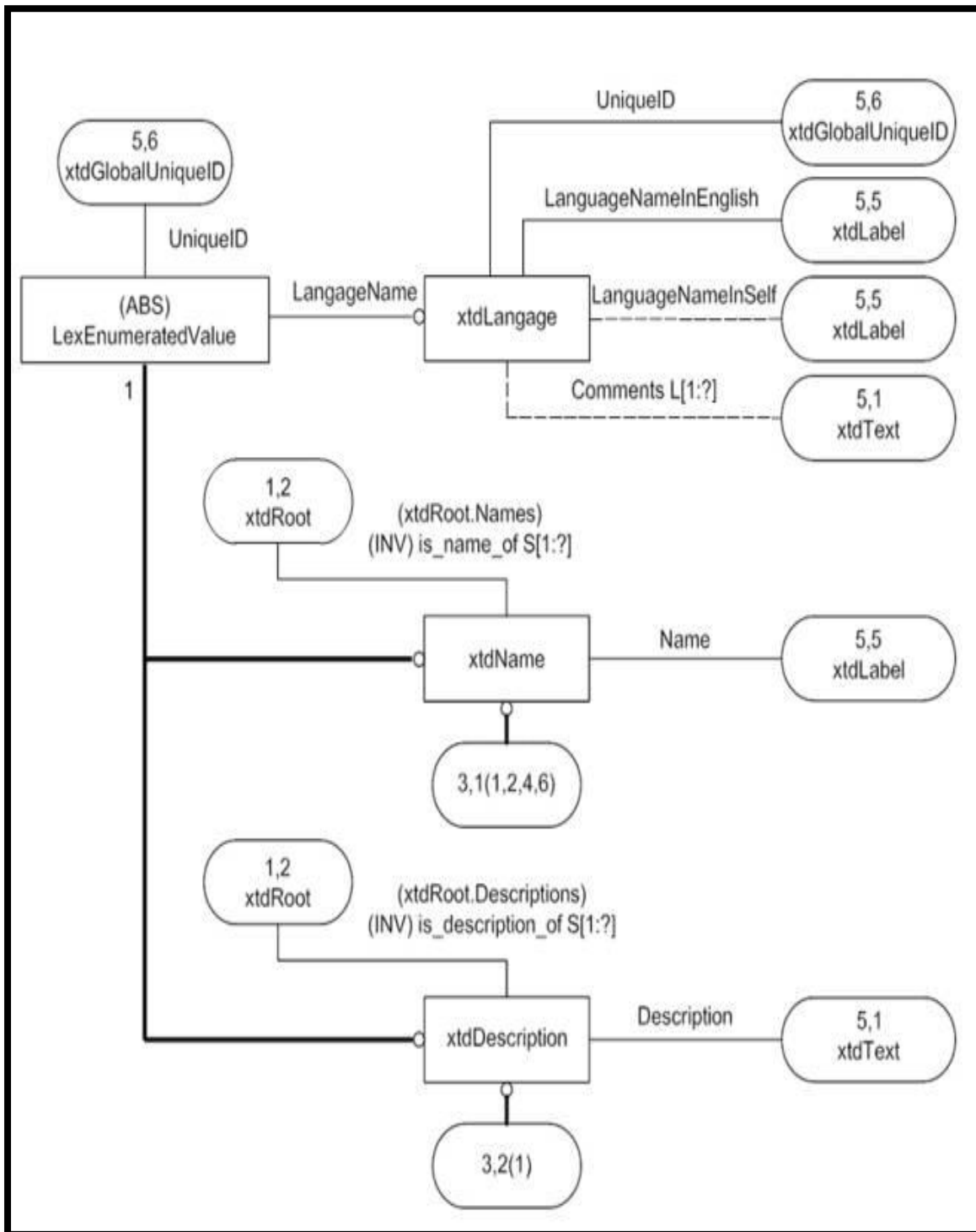


Figure 2.2: EXPRESS-G diagram 2 Language representation, names and descriptions
(Global Standards)

Figure 2.3 shows the relationship types derived from xtdRelationship that are used to establish possible relationships between xtdObjects, xtdCollections and xtdExternalDocuments or subtypes of these.

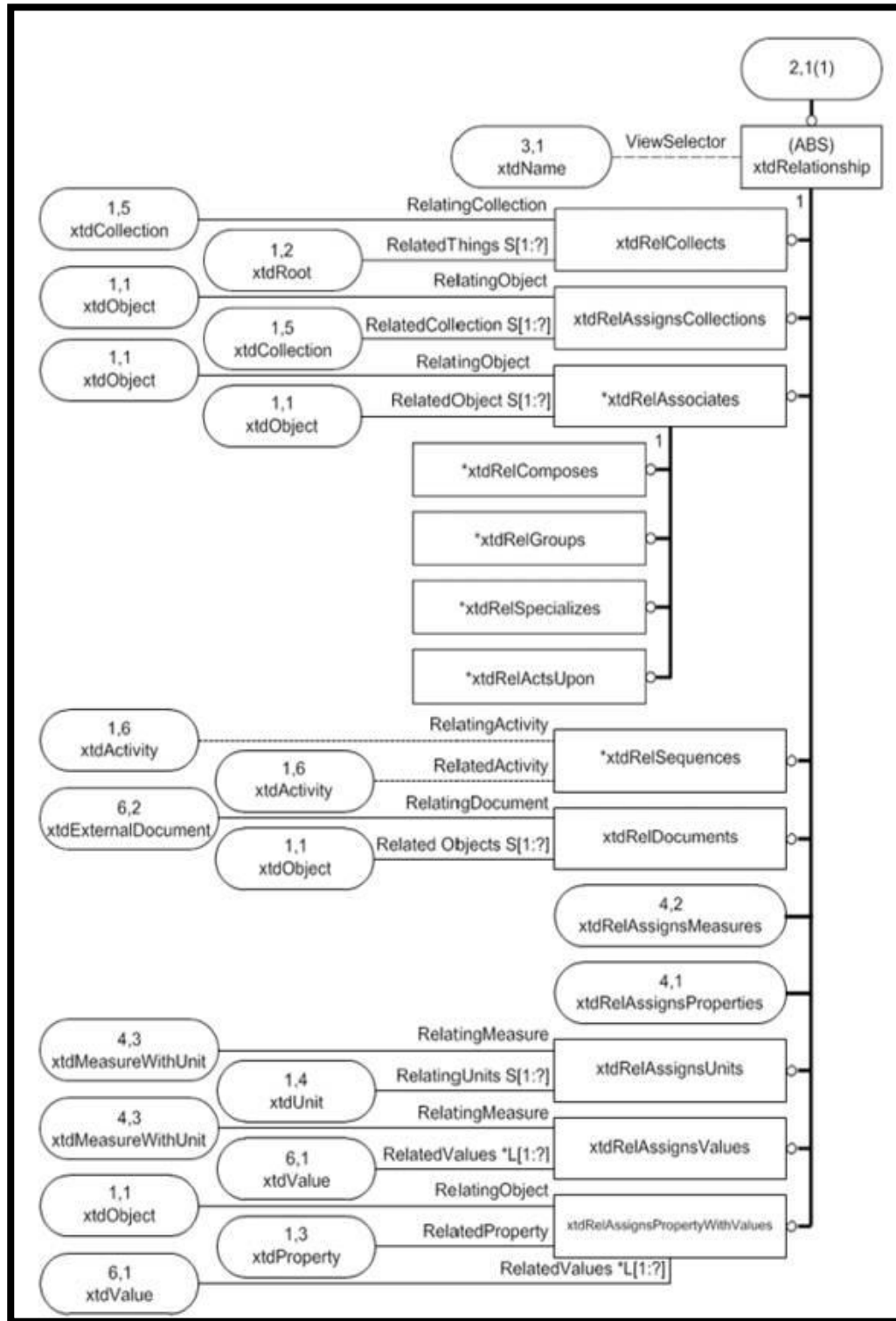


Figure 2.3: EXPRESS-G diagram 3 Relationships (Global Standards)

Figure 2.4 shows the assignment of `xtdProperties` to `xtdObjects` through `xtdRelAssignsProperties` and `xtdMeasureWithUnit` with the assignment of values, through `xtdRelAssignsMeasures`.

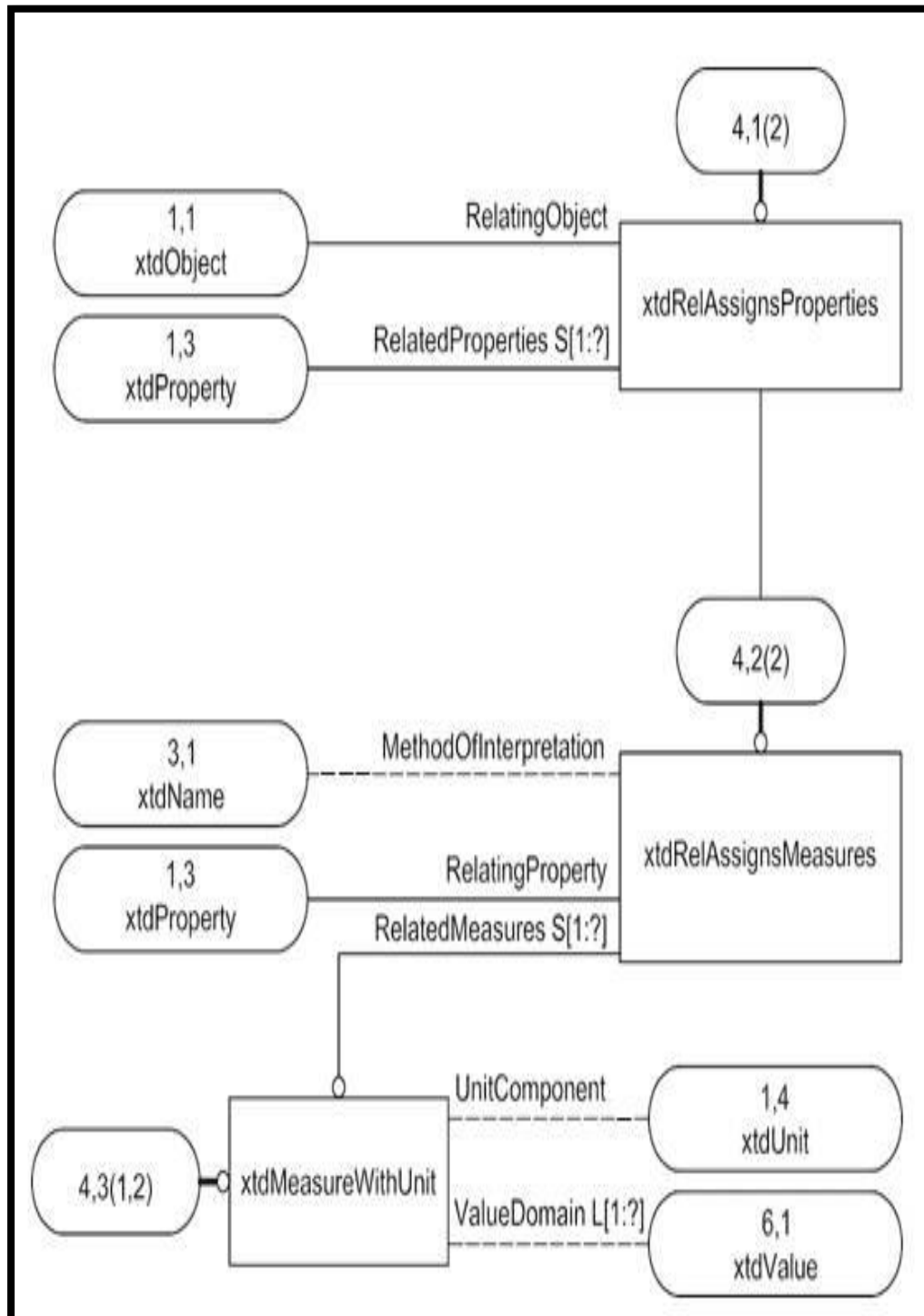


Figure 2.4: EXPRESS-G diagram 4 Assignment of properties and measures (Global Standards)

Figure 2.5 lists the basic types used in the model and their related EXPRESS types.

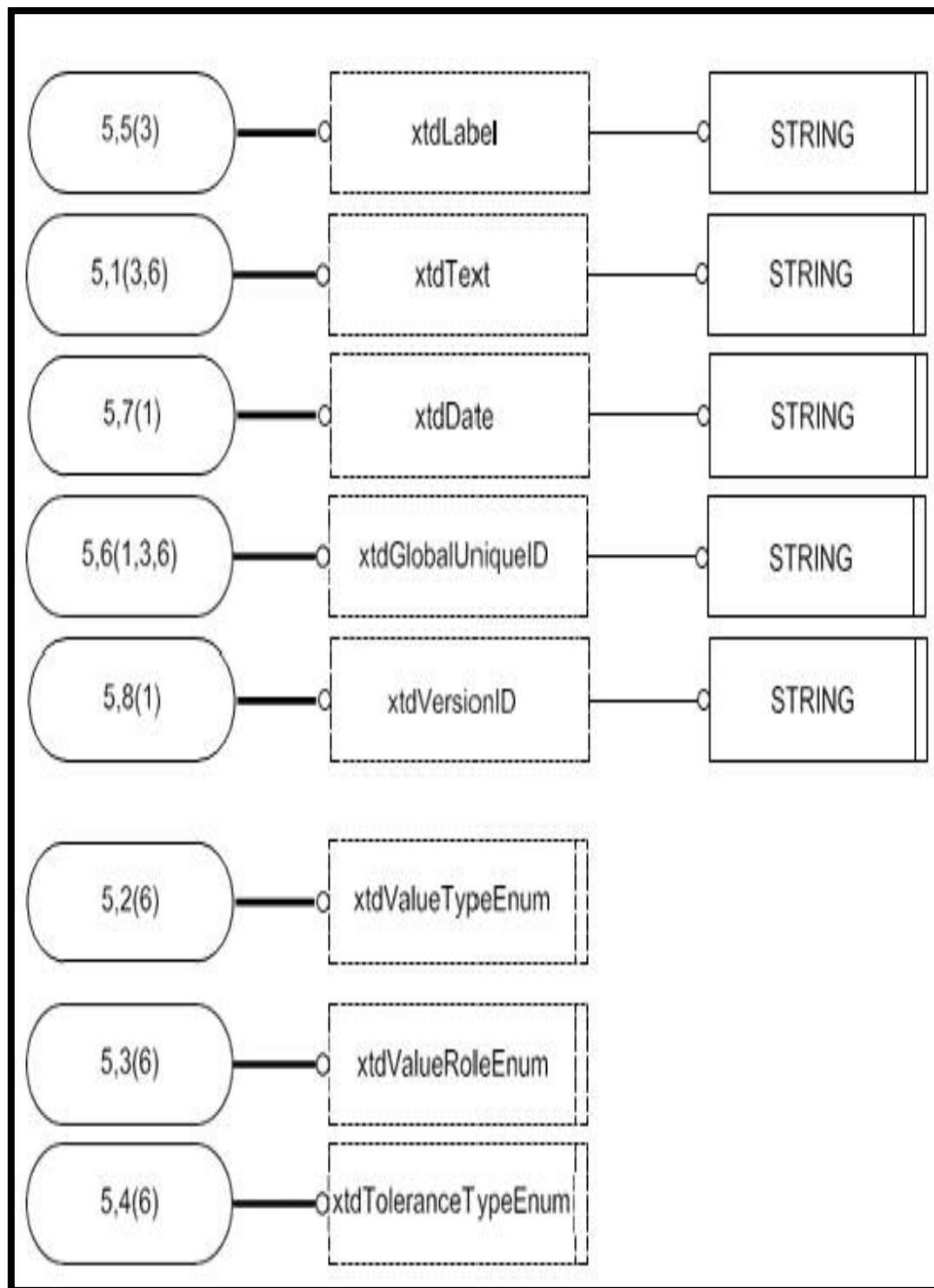


Figure 2.5: EXPRESS-G diagram 5 Basic types (Global Standards)

Figure 2.6 shows details of xtdValue and xtdExternalDocument.

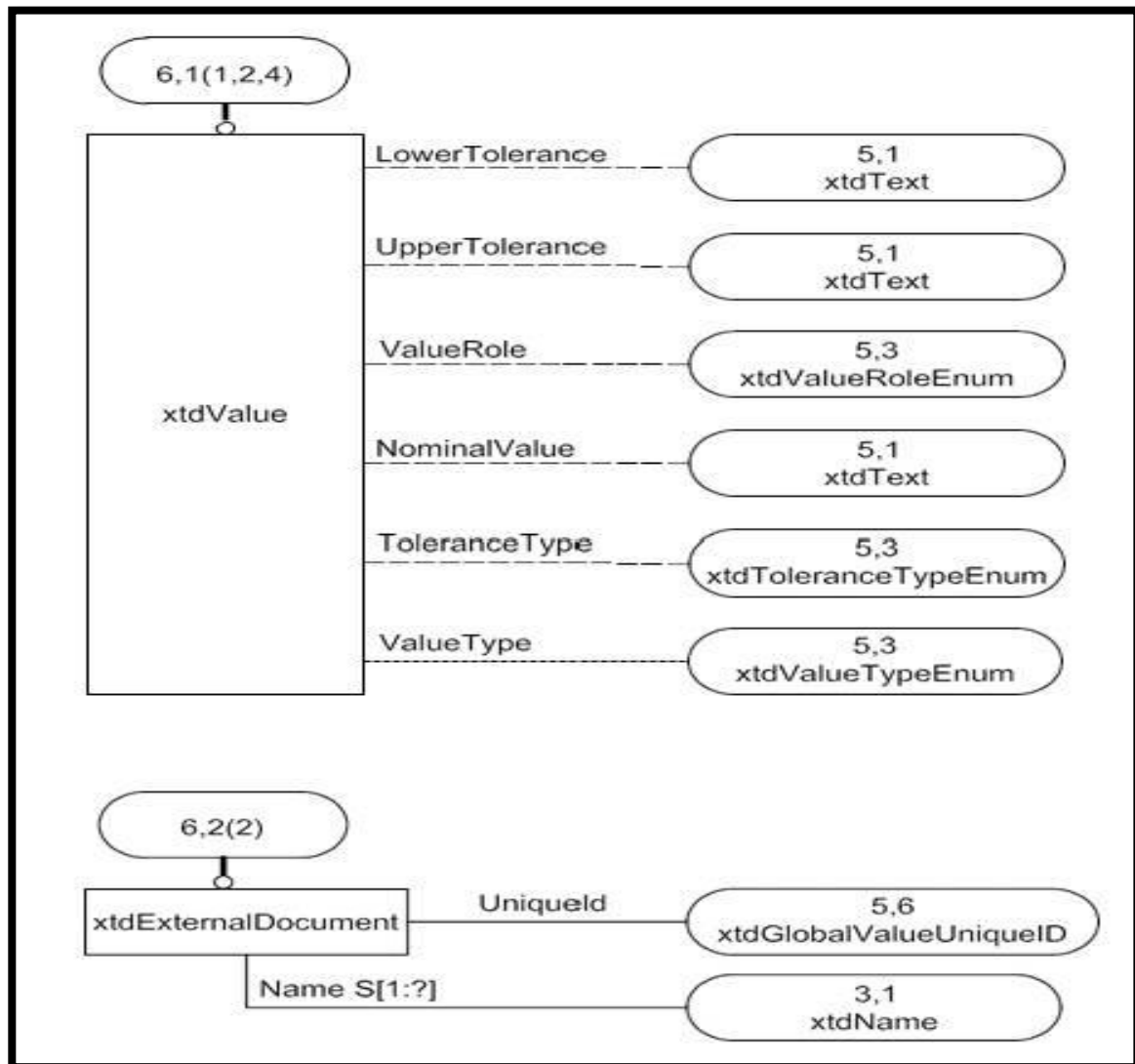


Figure 2.6: EXPRESS-G diagram 6 Values and external documents (Global Standards)

(PAS 1192-5:2015)¹⁶ It is a specification for security-minded Building Information Modeling (BIM), digital built environments, and smart asset management. It details the approach to applying appropriate and proportionate measures to manage the security risks that affect a built asset—in whole or in part—as well as asset data and information.

¹⁶ PAS 1192-5:2015: The PAS outlines security threats to information during the full life-cycle of built assets, from conception to disposal, https://www.designingbuildings.co.uk/wiki/PAS_1192-5:2015

The adoption of BIM and the increasing use of digital technologies in managing assets, whether buildings or infrastructure, will have a transformative effect on those involved in their design, building, and management. It will do this by promoting:

- more transparent, open ways of working;
- cross-sector collaborative working and the sharing of information; and
- better asset lifecycle management by capturing data about its real-time use and condition.

PAS 1192-5 specifies the processes that will assist organizations in identifying and implementing appropriate and proportionate measures to reduce the risk of loss or disclosure of information that could impact the safety and security of:

- personnel and other occupants or users of the built asset and its services;
- the built asset itself;
- asset information; and/or
- the benefits the built asset exists to deliver

Such processes can also be applied to protect against the loss, theft, or disclosure of valuable commercial information and intellectual property.

Good security can give commercial enterprises a competitive advantage by protecting their key assets and building trust with their stakeholders and customers in their services and products. For those involved in designing, delivering, or modifying assets, it can also enhance global positioning in the international construction market, particularly for high-profile and sensitive projects.

PAS 1192-5:2015 was commissioned by the National Protective Security Authority (NPSA)¹⁷, which provided the technical authors with the development. The British

¹⁷ NPSA: National Protective Security Authority

Standards Institution (BSI)¹⁸ It has facilitated its production with input from a panel of industry experts.

- **Purpose of this booklet**

This booklet provides a high-level overview of the critical components of PAS 1192-5.

Who are the intended users of PAS 1192-5, and what types of assets does it apply to? What is the primary objective of this standard?

PAS 1192-5 applies to any sensitive built asset or portfolio of assets. It is for use by asset owners or, within a project, the employer. It will also be relevant to other organizations and individuals involved in designing, constructing, maintaining, and managing built assets, especially those who wish to protect their commercial information.

¹⁸ BSI: The British Standards Institution,
<https://www.iso.org/member/2064.html#:~:text=The%20British%20Standards%20Institution%20was,recognized%20UK%20National%20Standards%20Body>.

2.3.1. Summary of the PAS 1192-5 process

Figure 2.7 summarizes the PAS 1192-5 standard review process, which shows different types of information and their management processes.

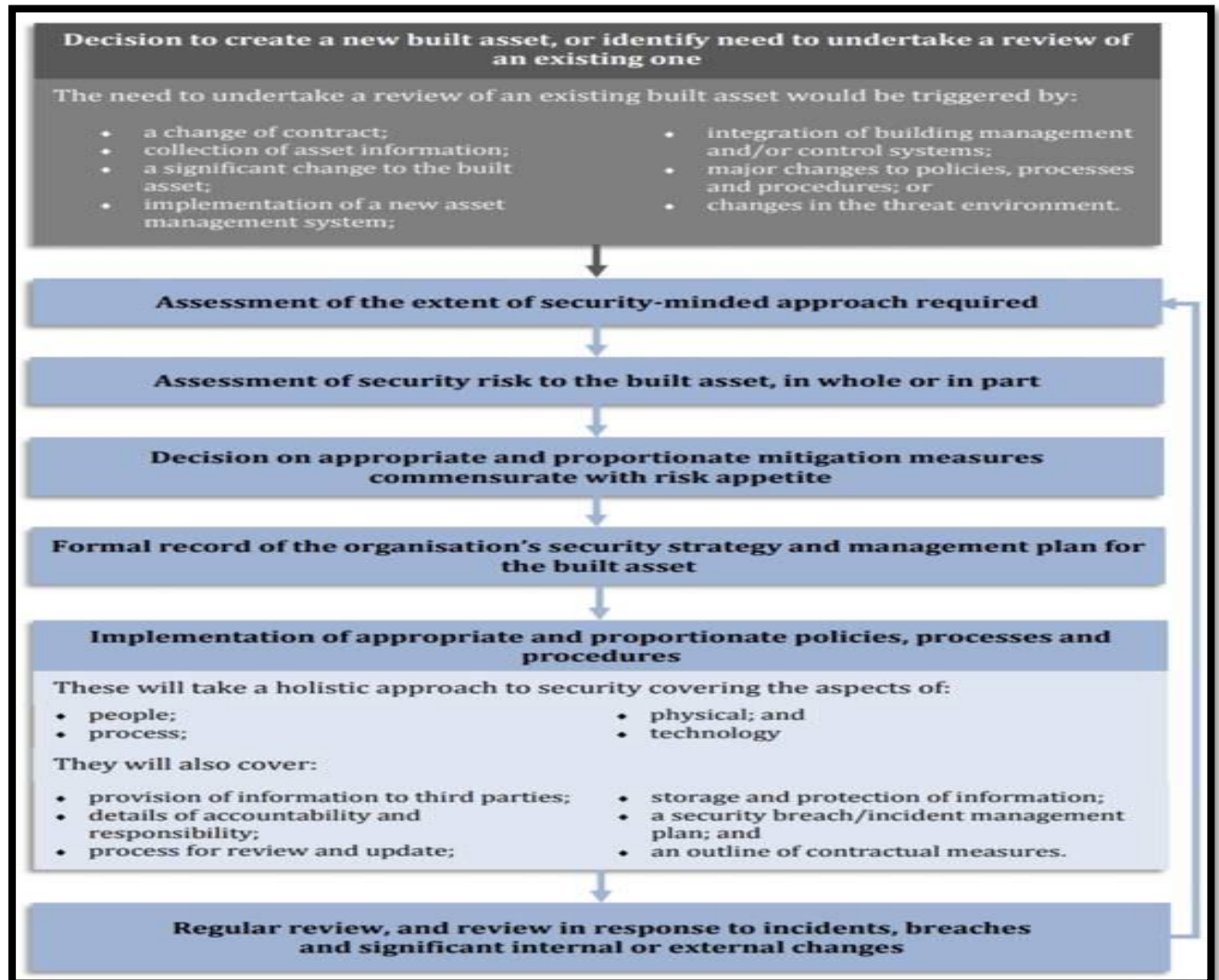


Figure 2.7: Summary of the BIM security Standard (Hoeber, 2016)

- **What is a sensitive built asset?**

A sensitive built asset is defined as one that may be of interest to a threat agent for hostile purposes as a whole or in part. Even if a built asset does not fall into the categories that would make it sensitive, there may be business benefits from applying a security-minded approach to its management.

Malicious, fraudulent, and criminal behaviors or activities. The need for a security-minded approach and the breadth of the protection measures required are determined by the Security Triage Process, shown in Figure 9 of PAS 1192-5.

- **Built Asset Security Strategy**

The Built Asset Security Strategy will comprise a record of:

- The extent of the security-minded approach required
- The built asset security risk management strategy
- A list of those to be informed of residual risks
- The mechanisms for reviewing and updating the strategy

2.3.2. Security Policies, Processes, And Procedures

The security risks identified in the Built Asset Security Strategy should be addressed through the policies, processes, and procedures in the Built Asset Security Management Plan. This plan should be holistic, encompassing people, processes, and physical and technological security. The measures should be appropriate and proportionate to both the sensitivity of the built asset and the related security risks.

In Figure 2.8, security processes and procedures are essential to an organization's security framework. They provide guidelines and measures to protect the organization's assets, including data, personnel, and physical infrastructure, against various threats such as cyber-attacks, theft, and unauthorized access.

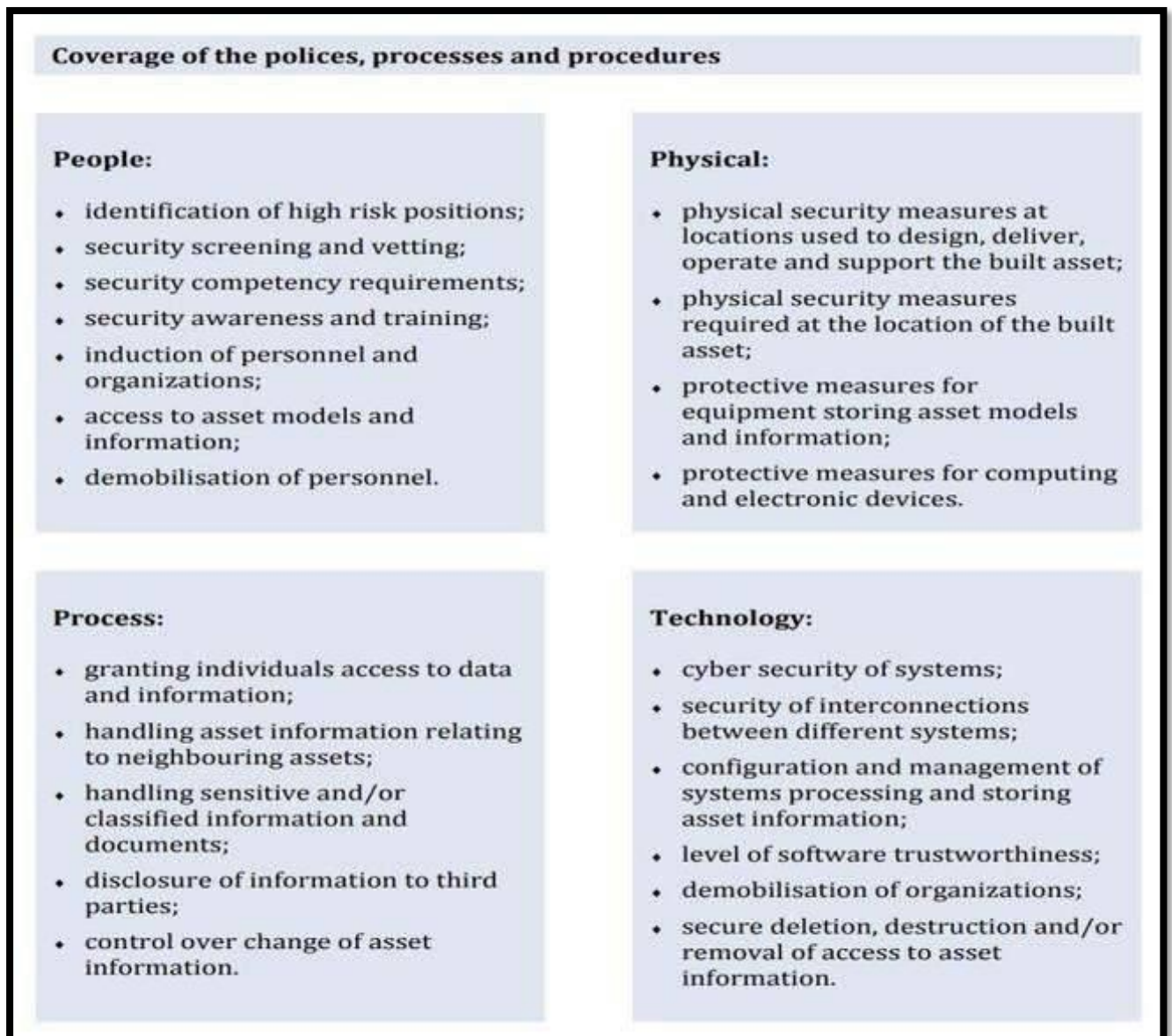


Figure 2.8: Summary Of The Security Policies, Processes And Procedures (Siponen, 2014)

2.3.3. Embedding Security

The security-minded approach must be integrated with other strategic policies, plans, and requirements for delivering, maintaining, and operating built assets.

Figure 2.9 depicts a framework for integrating an organization's security strategy with other policies, strategies, and strategic requirements for delivering, maintaining, and operating constructed assets.

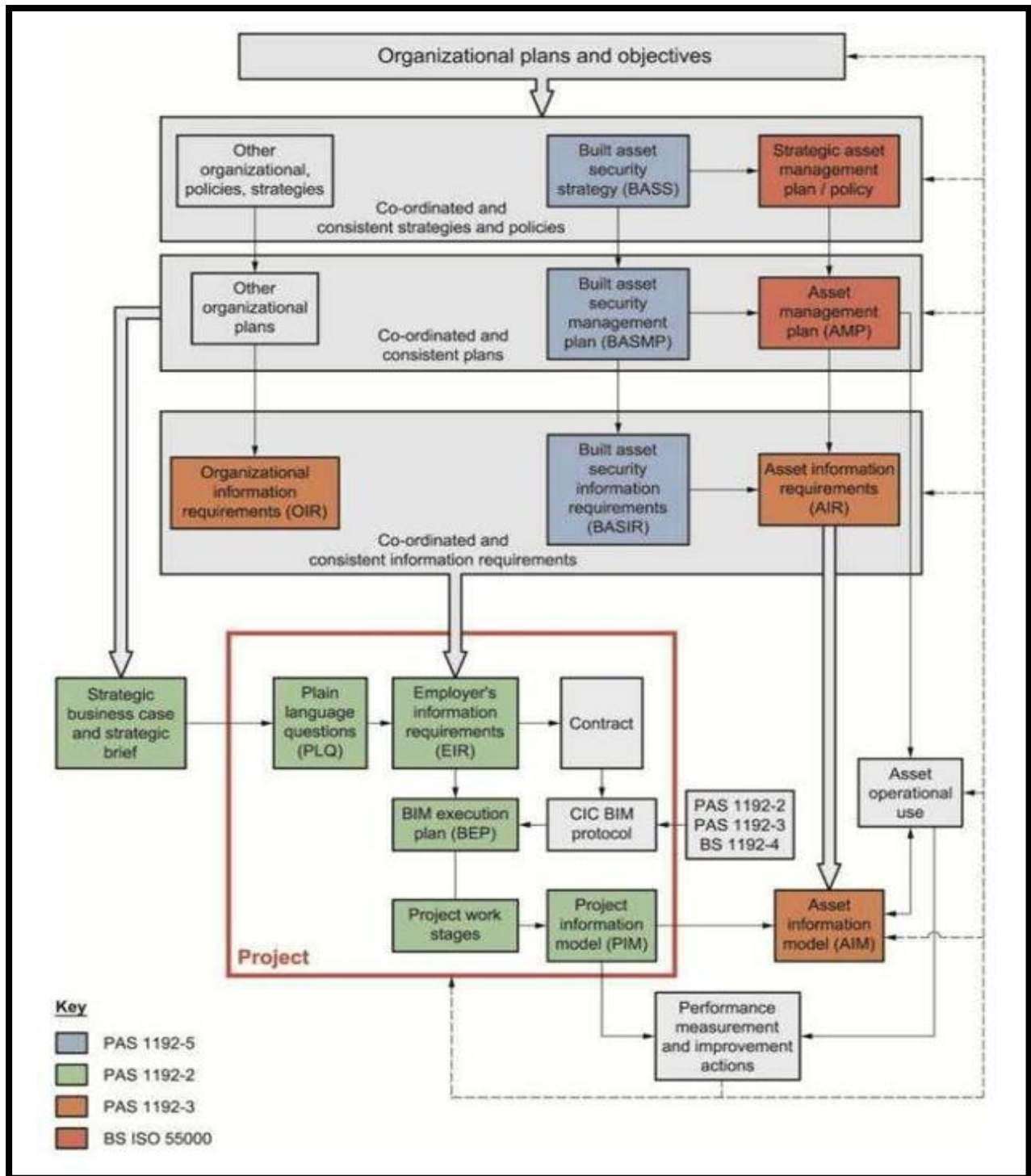


Figure 2.9: Framework To Help Organizations (Qinghua, 2017)

PAS 1192-5 provides a comprehensive framework to assist organizations in adopting a security-minded approach to the use of information and data within the built environment. This standard emphasizes the importance of integrating security considerations throughout the lifecycle of a project, from design and construction to operation and

maintenance. It outlines best practices for managing information security risks, protecting sensitive data, and ensuring compliance with relevant legislation and regulations.

The framework encourages organizations to assess their specific security needs and implement strategies tailored to their operational context. It also promotes collaboration among stakeholders, ensuring that all parties involved in a project are aware of and committed to security protocols. By adopting PAS 1192-5, organizations can enhance their resilience against potential threats, improve data integrity, and foster a culture of security awareness within their teams. Ultimately, this standard helps to safeguard not only the physical assets but also the valuable information that underpins decision-making in the built environment.

2.4. BIM Standard in Spain

At the end of 2018, ISO standards 19650 Parts 1 and 2, “Organization and digitization of information about buildings and civil engineering works, including building information modeling (BIM) — Information management using building information modeling”, were published. These standards were adopted and published in Europe by CEN in January 2019 and later by different countries. In Spain, these standards were published in July 2019, awakening a great interest on the sector.

2.4.1. Who creates BIM standards?

The purpose of standardisation is to define a set of technical specifications STANDARDS which are used in a voluntary way. Standards are the industry’s common language.

Standards are developed by standardisation bodies, in which a balanced representation of bodies interested in the subject participates, ensuring transparency, openness and consensus in their work. The process of elaborating a standard is open, allowing everybody to participate with their opinions or comments.

There are a several standardisation organisations, ISO and IEC at international level, CEN and CENELEC at a European level, and others at national level, such as UNE in Spain, DIN in Germany, bSI in the United Kingdom, etc .

In the specific case of BIM, standardisation is strategic in order to optimise resources and be able to have a common base between all the stakeholders involved in a project.

The productivity of the AEC industry, which accounts for around 6% of world GDP, has not advanced at the same ratios as other industrial sectors. The digitisation of construction,

which relies heavily on BIM, is probably one of the main tools in the medium term to reduce its costs by between 12% and 20%.

In February 2018, the World Economic Forum published a report, An Action Plan to Accelerate Building Information Modeling (BIM) Adoption[2], which clearly indicates that in order to improve its productivity, the AEC industry must accelerate the BIM adoption. This same report highlights that one of the necessary pillars is to realize the benefits of digitized built environments and that governments need to coordinate with the industry to develop BIM standards, improving efficiency and interoperability.

The main standardisation bodies developing standards on BIM are:

- International level: ISO/TC 59/SC 13, Building and civil works. Organization of information on construction works.
- European level: CEN/TC 442, Building Information Modeling.

On the other hand, on a national level, there is a national BIM standardization body per country, such as UNE/CTN 41/SC 13, Organisation of information models relating to building and civil works in Spain. Moreover, these standardization bodies work in close collaborations with some organizations in Figure 2.10, such as buildingSMART or OGC (Open Geospatial Consortium).

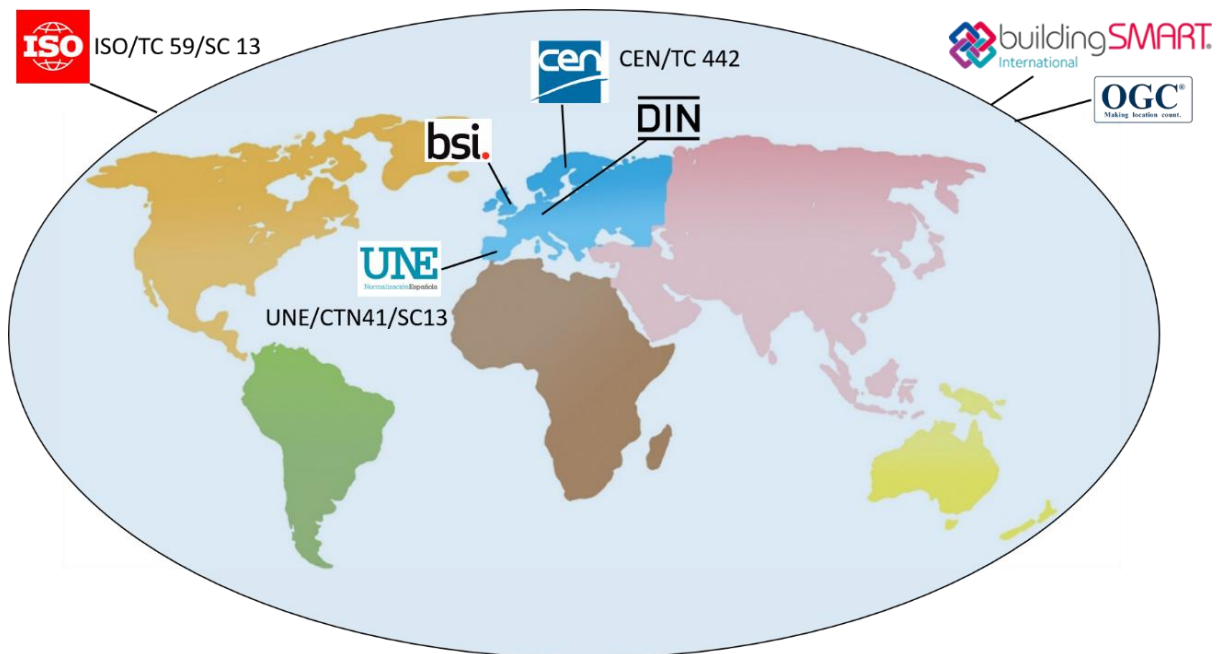


Figure 2.10: standardization bodies in the world (Muñoz, 2019)

2.4.2. Brief history of the BIM standards in Spain

Although the Spanish standardization body, UNE/CT41/SC13, was created in 2011, it is in 2015, when the European CEN/TC442 was created, which arranges the adoption of the first BIM standards in Spain:

- ISO 12006-3 Building. Organization of information on construction works. Part 3: Object-oriented information framework.
- ISO 16739 IFC (Industry Foundation Classes) for the exchange of data in the construction and property management sectors.
- ISO 29481, Parts 1 and 2. Modeling of building information. Information delivery manual. Part 1: Methodology and format and Part 2: Framework for interaction.

However, it must be said that of all these standards, the only one that has had a real impact in Spain is ISO 16739 IFC, because it is being included in public tenders as a requirement. The Observatory of public tenders of esBIM analyses the public tenders with BIM requirements in Spain, publishing very interesting reports periodically. During the last 3 years, half of “BIM tenders” require the IFC model, and one third request the use of other standards (such as PAS 1192 or LOD from BIMFORUM) Figure 2.11.



Figure 2.11: Standards requirements in public tenders in Spain (Muñoz, 2019)

But as I've said before, the rest of the ISO BIM standards have not had any real impact. This is mainly due to the fact that these standards were mostly about communication

between software (IFC), that affect the developers to meet the IFC requirements and not about the process of collaboration and information requirements for practitioners. And it is precisely this type of standards that are missed by the sector, as demonstrated by the result of the Macro study of BIM adoption in 2018 in Spain Figure 2.12.

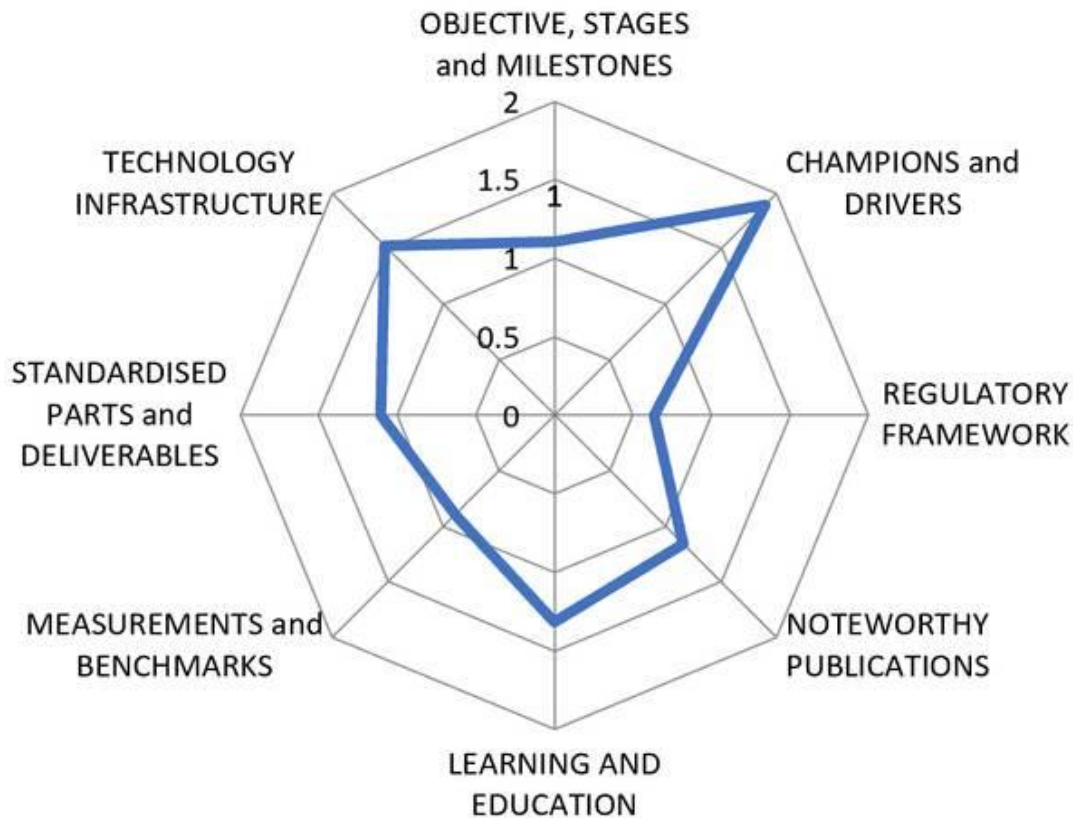


Figure 2.12: Analysis of level of maturity in 2018 in Spain through the model of components (Muñoz, 2019)

2.5. Temperature, Humidity, Winds, and Human Comfort

Within the human body, energy is produced by the metabolism of foods. Approximately 1800 kilocalories of energy per day is metabolized by the average person while resting, more if doing strenuous activities. Over half of this energy is converted to heat. Without some way to remove this internally-produced heat energy, the body temperature would increase indefinitely. Under certain atmospheric conditions (high temperature and high humidity), it becomes difficult for the body to remove this excess heat.

In the other extreme, problems also arise when the body loses heat too rapidly under conditions of cold temperatures and strong winds. Thermoregulation refers to the processes by which the human body regulates internal heat generation and external heat exchange so that its core temperature varies by no more than 2°C from its average of 37°C. "Core" refers to vital organs such as the brain, heart, kidneys, etc. If the body's core temperature moves outside of this range, essential life functions do not work properly.

Surprising to many, exposure to extreme heat and cold are responsible for more human deaths per year than all other weather disasters (e.g., thunderstorms, tornadoes, hurricanes, blizzards) combined.

The ideal conditions for a resting human body fall into a range called the thermalneutral zone, where the air temperature is between 20°C and 25°C, or (68-77)°F, with little wind and moderate relative humidity. Under these conditions, a resting body can easily maintain its core temperature. Outside of this narrow range, the body's thermoregulation responses take over.

Biological Control Systems: Living things, like mechanical engines, need regulators for effective operation. The regulators of living things are called biological control systems. Many homeostatic biological control systems are at work in the body. Homeostasis is the stable operation of physiological activities.

Control systems maintain a balance in the biophysical and biochemical functioning of the body. An important system is thermoregulation, which keeps the internal body temperature at a stable level in all kinds of weather.

Over half of all energy from food and other sources leaves the body as heat. Thus, the body needs a well-functioning homeostatic control system for thermal regulation.

Enzyme-controlled biochemical reactions in the body are usually most efficient at around 98°F (37°C). This temperature is the average set point for the inner body temperature of mammals. The flow Figure 2.13 below shows how the body reacts to heat-related stresses.

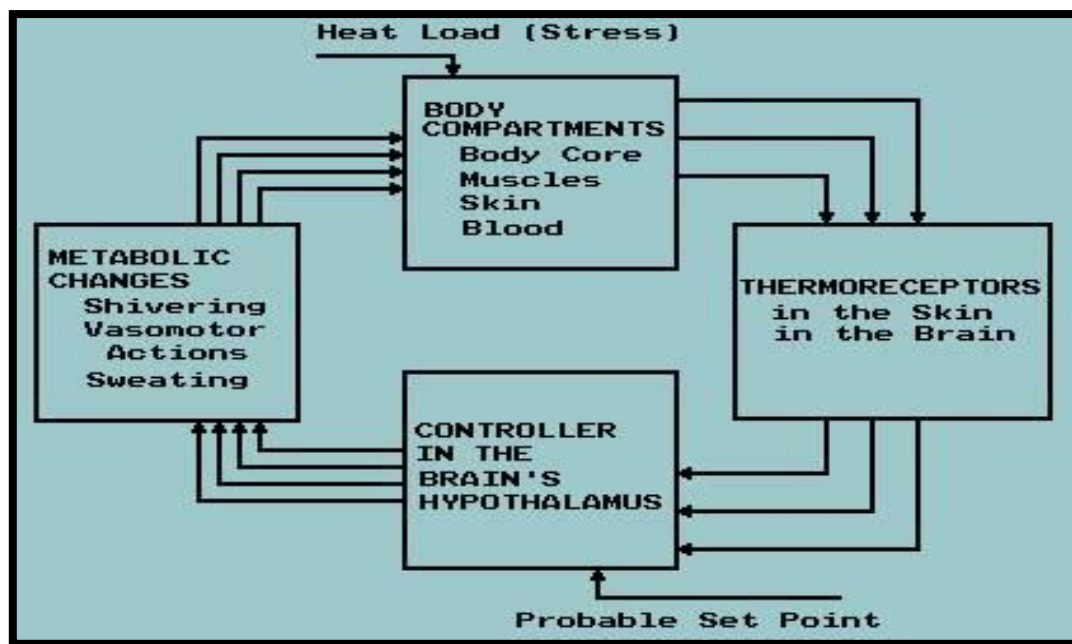


Figure 2.13: Heat Stress, or Load (Global Standard)

This heat stress, or load, is a disturbance of the thermoregulatory system. The disturbance can be (a) internal temperature too high or (b) internal temperature too low. The body compensates for it in the following ways:

2.5.1. Response to cold core temperature

1. Increase internal heat production by shivering (involuntary muscle contractions)
2. Reduce heat loss by vasoconstriction (constrict blood vessels). Vasoconstriction reduces blood (and heat) flow to extremities. Thus, extremities (forearms, lower legs) cool down. This reduces heat loss since temperature difference between extremities and outside world is less. It also reduces the surface area of warm blood that is in contact with the outside air. In severe cases this can lead to frostbite of extremities (freezing of skin).

2.5.2. Response to warm core temperature

- Sweating - body cooled by evaporation. Important to drink enough water in hot weather. This is by far the best way to lose heat. In fact,

sweating is the only means by which humans can survive for long periods when the air temperature exceeds body temperature.

- Increase heat loss by vasodilation (widening of blood vessels). Vasodilation increases blood (and heat) flow to extremities allowing more rapid heat transfer away from body. This exposes warm blood to the outside air over a larger surface area. NOTE: this only works if the air temperature is lower than the body temperature. If air temperature is warmer than body temperature, vasodilation would actually result in heat flow from air to blood.

These reactions are programmed by the brain's hypothalamus via information fed back from its own thermoreceptors and from thermoreceptors in the skin. Thermoregulation has a high set point, about 98°F, an indication that it is easier for the body to heat itself than to cool itself.

Thermoregulation and other forms of homeostasis do not maintain a condition at an unvarying level, but within an acceptable range. For example, most people experience a slight daily temperature variation during which body temperature dips nearly two degrees Fahrenheit (one degree Celsius) from an early evening peak to an early morning low.

2.5.3. Hypothermia and Hyperthermia

Addressing hypothermia and hyperthermia, it is very important in the standards because of its important implications for health and safety in the workplace. Both conditions can lead to serious health problems, including heat illness and exposure to extreme cold. Sometimes thermoregulatory processes fail to maintain the body's core temperature within its normal range. As the core temperature departs more and more from its optimal range, thermoregulatory processes may fail, resulting in rapidly deteriorating and potentially lethal conditions.

Hypothermia refers to conditions that develop when human core temperature drops below 35°C (95°F). Initially, shivering becomes more violent and uncontrollable. In addition, the victim has difficulty speaking and becomes apathetic and lethargic. If core temperature falls below 32°C (90°F), enzyme

activity further slows. Eventually shivering ceases, muscles become rigid, and coordination deteriorates. Mental abilities also are impaired seriously and the victim is generally unable to help himself or herself. At a core temperature of 30°C (86°F), a person may drift into unconsciousness. Typically, a person becomes totally unresponsive, even to pain, at a core temperature under 26°C (79°F). Death may ensue at core temperatures below 24°C (75°F), because the heart rhythm becomes uncontrollably irregular (*ventricular fibrillation*) or uncontrollably halted (*cardiac arrest*). The lowest core temperature measured in adults who subsequently recovered from hypothermia is about 16°C (61°).

Hypothermia rapidly can become a serious threat to survival. Only a 3°C (5.4°F) drop in core temperature greatly impairs the body's ability to regulate its core temperature. Thermoregulation essentially is ineffective when core temperature declines to 29°C (84°F). Hence, the first signs of hypothermia should never be ignored; action should be taken immediately.

Treatment of hypothermia victims takes two forms: prevention of further heat loss and addition of heat. Depending upon circumstances, further heat loss can be prevented by replacing wet clothing with dry clothing (reducing heat loss via evaporation), finding shelter from the wind (reducing heat loss via convection and evaporation), and insulating the person from the ground (reducing heat loss via conduction). The body can be heated by an external source, such as a space heater or other human bodies. If the victim is conscious, administering a warm (not hot), non-alcoholic beverage, helps warm the core from the inside. Efforts to warm the victim should never be discontinued in favor of moving the person or going for help. Medical attention, however, should be sought as soon as possible.

Hyperthermia refers to those conditions that take place when core temperature climbs to 39°C (102°F) or higher. Hyperthermia may be divided into two stages. Symptoms of the first stage, known as heat exhaustion, include profuse sweating, nausea, vomiting, and general weakness leading to an inability to continue normal activities. A person suffering from heat exhaustion should be taken immediately to a cool environment. Removal of excess clothing and sponging with water speeds the lowering of the core temperature. If necessary, evaporative and convective

cooling can be accelerated by placing the victim in front of fans. The person should be given fluids orally, if tolerated, because dehydration typically is the primary cause of heat exhaustion. Most victims of heat exhaustion recover without any complications.

Failure to treat a person with heat exhaustion usually leads to a further rise in core temperature. If the core temperature reaches 41°C (106°F), enzymes begin to fail and thermoregulatory mechanisms breakdown. The victim has a rapid and strong pulse, exhibits psychotic behavior, and may slip into unconsciousness. Symptoms at a core temperature of 41°C (106°F) or higher constitute heat stroke (or sunstroke), a life-threatening emergency.

A heat stroke victim must be treated promptly because, once thermoregulation fails, core temperature rises rapidly and death may occur within a few hours. Bringing about a rapid drop in core temperature is the top priority. Although initial field treatment can be similar to that for heat exhaustion, medical attention and hospitalization should be sought as soon as possible.

Heat cramps may occur as a concurrent symptom of heat exhaustion or by themselves. Heat cramps are extremely painful contractions of the large muscles of the calf, thigh, abdomen, or shoulder and result from the excessive loss of sodium and potassium salts (electrolytes) in sweat. Heat cramps differ from exertion-induced cramps which involve the entire muscle. Rather, an individual bundle of muscles will contract for a few minutes and then relax while an adjacent bundle contracts and so on. Hence, victims of heat cramps experience the sensation of a wandering cramp throughout the entire muscle.

Victims of heat cramps should rest in a cool environment. If not nauseated, the person should be fed a commercially available electrolyte solution such as Gatorade or Spirit. If such a solution is not available, heat cramps can be relieved by administering a salt solution consisting of a one-fourth teaspoon of table salt in a liter (approximately a quart) of water. If a person complaining of severe muscle cramps is also nauseated, he or she is probably also suffering from heat exhaustion and medical attention is needed as soon as possible.

Figure 2.14 shows a summary of the response of the human body to heat and cold.

Summary of Human Responses to Thermal Stress	
To Cold	To Heat
Thermoregulatory responses Constriction of skin blood vessels Concentration of blood Flexion to reduce exposed body surface Increased muscle tone Shivering Inclination to increased activity	Thermoregulatory responses Dilation of skin blood vessels Dilution of blood Extension to increase exposed body surface Decreased muscle tone Sweating Inclination to reduced activity
Consequential disturbances Increased urine volume Danger of inadequate blood supply to skin of fingers, toes, and exposed parts leading to frostbite Increased hunger	Consequential disturbances Decreased urine volume. Thirst and dehydration. Difficulty in maintaining blood supply to brain leading to dizziness, nausea, and heat exhaustion. Difficulty in maintaining chloride balance, leading to heat cramps. Decreased appetite
Failure of regulation Falling body temperature Drowsiness Cessation of heartbeat and respiration	Failure of regulation Rising body temperature Heat regulating center impaired Failure of nervous regulation terminating in cessation of breathing.

Figure 2.14: Human Responses to Thermal Stress (Global Standard)

2.5.4. Influence of weather conditions on heat loss

2.5.4.1. In Hot Conditions

Scientists have developed a variety of indexes that attempt to gauge the combined effect of temperature and humidity on humans and advise people of the potential danger of heat stress. Since the summer of 1984, the National Weather Service has regularly reported the heat index (sometimes called the apparent temperature index). The heat index attempts to take into account the decreasing rate of heat loss due to the combination of high temperature and high humidity. The heat

index is not a true temperature because it cannot be measured with a thermometer. The heat index is really just a number related to the computed and/or measured net rate of heat loss from the human body for a given combination of air temperature and relative humidity. The higher the heat index, the slower the rate of heat loss from the "average" human body. A heat index Figure 2.15 is given below.

The Heat Index																				
Air Temp	Relative Humidity (percentage)																			
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95
135°	1	1																		
	2	2																		
	0	6																		
130°	1	1	1																	
	1	2	3																	
	7	2	1																	

85°	7	7	8	8	8	8	8	8	8	8	8	8	9	9	9	9	9	9	1	1	1
	8	9	0	1	2	3	4	5	6	7	8	9	0	1	3	5	7	9	0	0	0
80°	7	7	7	7	7	7	7	7	7	8	8	8	8	8	8	8	8	8	8	8	9
	3	4	5	6	7	7	8	9	9	0	1	1	2	3	4	5	6	7	8	9	0
75°	6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8
	9	9	0	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	0
70°	6	6	6	6	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	7
	4	4	5	5	6	6	7	7	8	8	9	9	0	0	0	0	1	1	1	1	2

Figure 2.15: The Heat Index (Global Standard)

Color information is shown in Figure 2.16.

	= Heatstroke risk extremely high		= Heat exhaustion possible
	= Heat exhaustion likely, heatstroke possible		= Fatigue possible

Figure 2.16: Color guide (Global Standard)

Using the table, if the air temperature is 90°F and the relative humidity is 60%, the heat index is 100°F.

If the air temperature is 105°F and the relative humidity is 10%, the heat index is also 100°F. Note that it is possible for the heat index to be lower than the air temperature if the relative humidity is low. This often happens here in the desert during the months of May and June (before the summer monsoon arrives)

Interpretation: for an "average" person, the rate of heat loss will be the same under those two conditions. The heat index is only a guide. No single chart works for all people. The degree of heat stress also depends on a person's physical fitness, body type, the ability to sweat, and other factors. Circulation of air (by fans or winds) can help because it increases the rate of net evaporation. When the heat index is forecast to reach dangerous levels, the weather service issues a heat advisory.

Finally, keep in mind that the heat index is a fictitious temperature. An object in the shade will not become warmer than the air temperature.

2.5.4.2. In Cold Conditions

The National Weather Service reports the windchill equivalent temperature (sometimes called the windchill factor) to alert people to the dangerous combination of cold temperatures and high winds. The windchill equivalent temperature is not a true temperature in that it cannot be measured with a thermometer. The windchill is just a number related to the rate of heat loss from the human body for a given combination of air temperature and windspeed. The lower the windchill equivalent temperature, the faster the rate of heat loss from the "average" human body. The latest windchill chart (revised in 2001) is given below Figure 2.17.

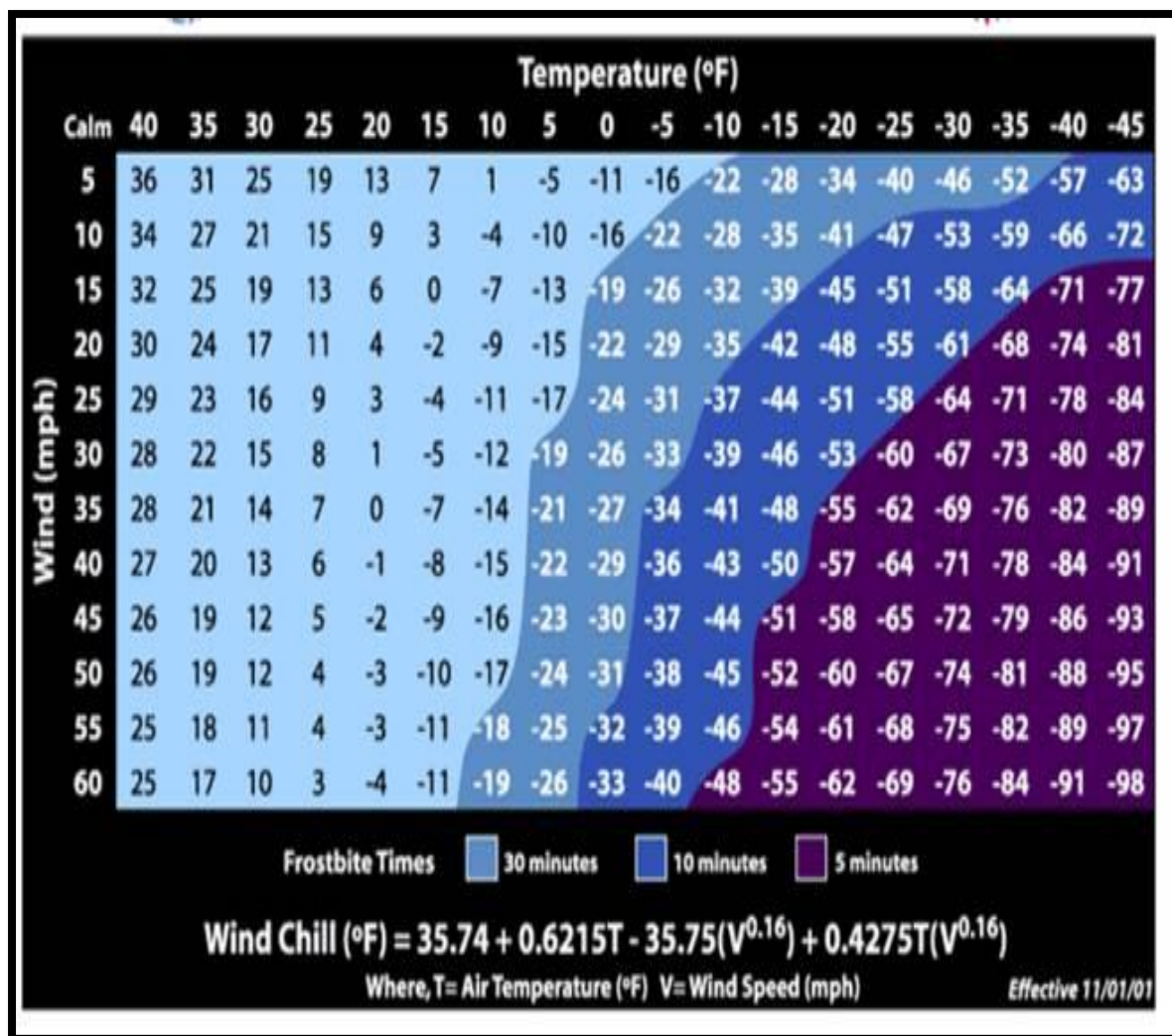


Figure 2.17: Windchill Chart(Global Standard)

For example, if the air temperature is 10°F and the windspeed is 20 mph, the windchill equivalent temperature is -9°F.

Interpretation: the rate of heat loss from exposed skin under the above conditions is the same as the rate of heat loss at an air temperature of -9°F with no wind. The windchill index will never be higher than the air temperature. Note that the windchill equivalent temperature is computed for exposed skin. Clothing reduces the rate of heat loss. The best strategy is to wear several layers of loose fitting clothing. This keeps an insulating layer of air (in the spaces between clothing fibers and layers) around your body. Again, windchill equivalent temperature is just a guide, no single chart works for all people. The rate of heat loss can be much higher if the skin is wet due to additional evaporative cooling.

The windchill equivalent temperature is a fictitious temperature. Dry objects (fingers for example) will not become colder than the air temperature. However, high winds, in below-freezing air, can remove heat from exposed skin so quickly that the skin may actually freeze and discolor. The freezing of skin, called frostbite, usually occurs on the body extremities first because bloodflow to these areas is reduced to conserve body heat for vital internal organs.

2.6. Oxygen in Closed Environmental Systems

The normal concentration of oxygen in air is approximately 21%, corresponding to a partial pressure of 0.21 ATA (Atmosphere Absolute) or 159 mm Hg. In closed systems such as pressure chambers, air craft or space craft, the partial pressure of oxygen may become increased and result in oxygen toxicity. On the other hand, there are situations in which a lowering of oxygen partial pressure may occur in all these systems, causing symptoms of anoxia. Oxygen toxicity is likely to be encountered under the following conditions:

1. For underwater swimmers using closed or semi closed breathing equipment
2. Oxygen tolerance tests used for the selection of diving personnel in the Navy
3. Saturation diving
4. Use of oxygen breathing to shorten decompression times
5. Recompression for therapeutic purposes
6. During prolonged resuscitation efforts in cases of respiratory failure
7. Prolonged exposure to increased oxygen during flights in spacecraft and aircraft

Hypoxia or anoxia may occur in:

1. Underwater swimmers having equipment problems either due to exhaustion of oxygen cylinders or faulty oxygen-nitrogen mixtures
2. Saturation excursion diving
3. Aircraft operations

Rise in oxygen partial pressure may be due to an increase in the percentage of oxygen in the ambient air or an elevation of ambient pressure, or a combination of both factors. Increases of partial pressure of oxygen at normal atmospheric pressure (1 AT A) produce effects on the respiratory and circulatory system, on erythropoiesis, and endocrine

Functions, but do not affect the central nervous system (Bean, 1945). Oxygen convulsions that involve the central nervous system, one form of oxygen poisoning, occur only under conditions in which oxygen tensions are in excess of 1 atm (2 AT A).

2.6.1. Oxygen level

At standard atmospheric pressure and temperature, dry air, by volume is approximately composed of:

- Nitrogen 78.1%
- Oxygen 20.9%
- Argon 0.9%
- Other 0.1%

Whilst the composition of air is considered to be fairly consistent, the percentage of oxygen required to support life is dependent on pressure as this leads to changes in the partial pressure of the gases. At high altitude the partial pressure of oxygen in air becomes low such that it cannot support life (for example on Mount Everest). However, underwater the partial pressure increases and below 60 metres depth oxygen starts to become toxic. As such, any discussion on the minimum concentration of oxygen required will generally refer to altitude or depth. For the purposes of this discussion, it is assumed that work is being undertaken on ships and as such relates to air at sea level. The United States Department of Labour, Occupational Safety & Health Administration (OSHA) document 29 CFR 1910.146(c) defines oxygen deficiency as 'A concentration of oxygen in the atmosphere equal to or less than 19.5% by volume'. However, it should be noted that this does not mean that an atmosphere with 19.5% oxygen is safe to enter, it only means that below this level it is not considered safe to enter based on the oxygen concentration. If an atmosphere contains 19.5% oxygen, then 1.4% of another gas has replaced it and the atmosphere is potentially deadly. For reference if this other gas was carbon monoxide, unconsciousness would occur within 2-3 breaths, and death within 3 minutes. As such, the discussion below relating to the minimum oxygen levels to support human life assumes that the air has been analysed for any potential toxic or flammable gases. The effects of low oxygen atmospheres are summarised in the table 2.1 below:

Table 2.1: The effects of low oxygen

Oxygen percentage in air ²	Effect
19.5 %	Minimum acceptable oxygen level
15 - 19%	Decreased ability to work strenuously May impair coordination and may induce early symptoms with individuals that have coronary, pulmonary, or circulatory problems
12-14%	Respiration and pulse increase; impaired coordination, perception, and judgment occurs
10-12%	Respiration further increases in rate and depth; poor judgment and bluish lips occur
8-10%	Symptoms include mental failure, fainting, unconsciousness, an ash-coloured-face, blue lips, nausea, and vomiting
6-8%	minutes -100% fatal 8 minutes - 50% fatal 6 4-5 minutes - possible recovery
4-6%	Coma in 40 seconds, convulsions, respiration ceases - death

3. STATE OF THE ART

3.1. Introduction

Conducting research, studying, and acquiring knowledge about related topics is essential for building a strong foundation for any new study. Before presenting the theoretical frameworks and key concepts, it is crucial to examine the background and related issues to understand what has already been explored in the current research field. This process helps identify gaps, trends, and key findings from previous studies, providing a context for the new research and ensuring it builds on, rather than duplicates, past efforts. By thoroughly reviewing the existing literature, researchers can position their work more effectively and advance knowledge meaningfully.

This chapter identifies the differences between the current study and prior research. It highlights how previous studies and their methodologies have contributed to the field's evolution and uses those experiences to inform and refine the current research. By analyzing past successes and challenges, this chapter acknowledges the work that has come before and lays the groundwork for innovations and improvements that can push the research forward, ensuring that it addresses gaps and opens up new avenues for exploration.

3.2. Research background

In the research (Xue & Lu, 2020), a new approach called (SDT)¹⁹ It has been presented to minimize data redundancy in BIM using Blockchain. In this model, SDT stores local changes as records and compiles them into a BIM contract (BCC)²⁰. In this way, the version history of a BIM project becomes a chain of time-stamped BCCs, and stakeholders can immediately coordinate BIM changes on the Blockchain.

¹⁹ SDT: Self-Determination Theory, [https://www.urmc.rochester.edu/community-health/patient-care/self-determination-theory.aspx#:~:text=Self%2DDetermination%20Theory%20\(SDT\),our%20habits%20and%20lifestyle%20choices](https://www.urmc.rochester.edu/community-health/patient-care/self-determination-theory.aspx#:~:text=Self%2DDetermination%20Theory%20(SDT),our%20habits%20and%20lifestyle%20choices).

²⁰ BCC: BIM contract conditions, <https://www.lexology.com/library/detail.aspx?g=c3e16cc4-f2d4-4af6-af15-9ba0781f834f#:~:text=In%20a%20nutshell%2C%20BIM%20is,planned%20building%20for%20coordination%20purposes>

This Research showed that adding a block to the Blockchain takes 0.02 seconds, significantly reducing data redundancy. One drawback of This Research is the massive amount of data stored in the Blockchain. Nevertheless, the advantage of this method is that all information and changes are recorded in the Blockchain, and the Blockchain is updated dynamically.

The study showed that building information management can be integrated into Blockchain, which can help protect the accuracy of information, which we are also looking for in This Research.

The research (Dounas et al., 2020) created a decentralized framework using BIM factors in the Blockchain platform. The software prototype was written for Rhinoceros/Grasshopper in this framework and a set of (Ethereum)²¹ Smart Contracts were developed for the project. This operating system can be scaled to thousands of participants and solves “design” problems in cooperative and competitive modes for each participant.

The results showed that the level of security created by the Blockchain for the participants was satisfied by the participants without any participant being involved in increasing the security and structure of the Blockchain. The presented BIM- Blockchain framework can record all the design efforts, including the ones that “failed” and all the positive steps in design optimization due to the scale potential, transparency, and flexibility of the results. Is. Because even unsuccessful transactions are stored in the Blockchain, we will have a large Blockchain that will take time to extract information.

Also, the Blockchain used is public; from this point of view, extracting information from it will be manual, which can be considered unsuitable for BIM in the building. However, considering that even unsuccessful transactions are stored in this chain, it is very efficient in terms of security and comprehensiveness.

The study showed that Blockchain can be used to sign contracts and that Smart Contracts are one of the tools used in This Research.

²¹ Ethereum: is a decentralized blockchain with smart contract functionality

The research (Ye, Sigalov, & König, 2020) proposed a framework for automatic payment through BIM building modeling information technology, linked data, Smart Contracts, and Blockchain. An information model called the Billing Model (BM)²² proposes integrating information with Blockchain for automatic payment. In this way, each billing unit stores one or more construction jobs with the corresponding payment and due date. Together with the rules related to the Smart Contract, BM can make the payment automatically through the Blockchain.

This Research has placed particular emphasis on digital currencies and digital currency payments. Since digital currencies still need a specific standard and a primary global standard, such as the dollar, which has yet to be determined for them and is not yet supported by some governments, this research remains within the academy's scope. Moreover, there is a long way to go before its final implementation.

The research examines the Smart Contract as an intelligent payment. Therefore, in This Research, because there is a Smart Contract, there should be a mechanism for online payment, which is only mentioned for reference and is almost outside the current research area.

In the research (Sai Erri Pradeep et al., 2020), a solution based on Blockchain technology is investigated to improve trust in data exchange in BIM following the analysis of a commercial tool called (BIMCHAIN)²³. This Research has shown eight functional requirements for a Blockchain tool that may address BIM challenges.

The results show that the proposed framework fulfills several goals, including improving data reliability, limiting the scope of responsibility, and clarifying the obligations of stakeholders. One of the positive points of This Research is determining the level of access to the Blockchain, which is also considered in the current research. Information security will increase by deterring the level of access

²² BM: Billing Model, <https://www.americanexpress.com/us/foreign-exchange/articles/blockchain-to-accelerate-payment-processing-services/#:~:text=Blockchain%20technology%20promises%20to%20facilitate,as%20correspondent%20banks%20and%20clearing>

²³ BIMCHAIN: accelerates the Building Information Modeling revolution through Blockchain Technology.

to the Blockchain and storing information by people, and the Blockchain chain will not grow significantly.

The study prevented the uncontrolled growth of Blockchain due to restrictions on Blockchain storage, which is also considered in the present study to ensure that the Blockchain used has a manageable volume and that the necessary information can be accessed as soon as possible.

The study prevented the uncontrolled growth of Blockchain due to restrictions on Blockchain storage, which is also considered in the present study to ensure that the Blockchain used has a manageable volume and that the necessary information can be accessed as soon as possible.

The research (Liu et al., 2019) examines the roles and integrated approach of BIM and Blockchain for sustainable information management in building design. For sustainable building development, an advanced transaction process in BIM is required. A Blockchain Smart Contract system can be used at the user level to increase the BIM system's contribution to the sustainable building process. Blockchain 's role is primarily in user-based Smart Contracts and the ability to exchange their record value.

The BIM user interface with Blockchain technology is for transactions in the BIM process, and the Smart Contract of BIM architecture + (BC)²⁴ This research enables the solving of BIM challenges for sustainable design. It also specializes in digital Currency and points related to digital Currency were expressed.

Shows that combining Blockchain and beam integrates the designed system and creates a systematic framework for implementation, which has also been evaluated in the present study.

The research (Shojaei et al., 2019) has discussed implementing Smart Contracts by integrating BIM and Blockchain. This Research proposes a Blockchain network to manage a sample construction project. The proposed framework does not use the cryptocurrency aspect of Blockchain as a form of payment.

²⁴ Blockchain, <https://g.co/kgs/xjV86Gm>

The results show that Blockchain is a suitable system for managing construction project contracts, which is valuable because it automates each transaction and maintains a record of project progress. The Blockchain network developed in This Research implements the Smart Contract as the logic of its network operation. As a result, thinking that we have to translate all the clauses of the traditional contract into a computer program is unnecessary and partly unsuitable for construction due to the complexity, fluidity, and high uncertainty of each project.

Has implemented a framework using digital (Currency)²⁵. Nevertheless, the remarkable thing in This Research is Smart Contracts, which have been discussed in almost all research. However, the thing to consider is preserving the history of Smart Contracts, which, although it causes the Blockchain to grow, happens. Nevertheless, it is necessary to enter into a Smart Contract. According to the research and reviews of some of the works done in this field, the necessity of Blockchain monitoring of information has yet to be raised.

Blockchain monitoring does not mean that the Blockchain as an authority monitors the correct execution of transactions because this technology does not have such a capability. The purpose of Blockchain monitoring the correct execution of transactions is to ensure that the information sent from actor x to actor y matches the transaction history information stored in the Blockchain and only stores the information in the Blockchain. Such is not a logical and efficient solution to increase security in BIM. For this reason, Blockchain is used as an interface and in a market-oriented role to improve the transfer of information and keep data safe.

Project progress and information were stored in the Blockchain, which refers to the short-term use of Blockchain. Blockchain can also be used for Martian projects, in which the implementation of projects is not evaluated but can be used for modification and repairs, which is included in the current research area.

Table 3.1 examines the recent research on integrating BIM and Blockchain, including the methods being investigated and their strengths and weaknesses. This table summarizes the research so that by studying it, we can use its strengths and

²⁵ Currency: money or official means of payment in a country or region

cover its weaknesses so that, in the end, the current research has the fewest weaknesses.

Table 3.1: Examines The Research Done In Recent Years (Author)

Author	Weak points	Strengths	Communication with research
(Xue & Lu, 2020)	Massive amount of data stored in Blockchain	Provide an appropriate method for the proposed topic	Indicates the integration of building information management with Blockchain and improving information security and accuracy
(Dounas, Lombardi, & Jabi, 2020)	A vast and extensive Blockchain	Security and community	Use of Smart Contracts
(Ye, Sigalov, & König, 2020)	Particular emphasis on digital currency	Good payment framework	The existence of Smart Contracts in research and the need to pay online
(Sai Erri Pradeep, Amor, & Wing Yiu, 2020)	Determining the level of access to Blockchain and controlled storage	Loss of information	Store the required data and refer to it when needed.
(Liu, Jiang, Osmani, & Demian, 2019)	Particular emphasis on digital currency	Community and data protection	Protection of information and comprehensiveness and accuracy of information in building
(Shojaei, Flood, Izadi Moud, Hatami, & Zhang, 2019)	Time to receive information	Ensuring the accuracy of the information	Match the information sent from user 1 to the server and match the information stored on the Blockchain.

3.3. Publications, Guides, Recommendations, Periodicals

While there's no official standard for building on Mars, researchers have been actively exploring this area and proposing architectural solutions for Martian habitats. As interest in the potential for sustaining human life on Mars continues to grow, these architectural designs are becoming more prominent. Various concepts have been developed to address the unique challenges of Martian construction, including extreme weather, radiation, and resource limitations. Notably, NASA has approved some of these architectural frameworks, acknowledging their potential to advance the goal of establishing human settlements on Mars.

These architectures aim to create self-sustaining, durable habitats that can protect inhabitants while efficiently using local resources like Martian regolith and renewable energy. The growing body of research drives innovation and paves the way for the eventual establishment of standardized building codes and practices tailored to the Martian environment.

- **Team Zopherus**

Team Zopherus from Rogers, Arkansas, is the first-place winner of Phase 3: Level 1 of NASA's 3D-Printed Habitat Challenge. Designed by a handful of Arkansas locals, it was the winner of NASA's 3D Printing Habitat Challenge. Using several resources from the Red Planet, the "huts" are put together to form a close-knit community. Construction is completed via a (3D printer)²⁶, eliminating the need for human interaction and ensuring the structure is ready for human habitation upon arrival.

A robot lander, built by robots, finds a suitable place to live in the city and then deploys a set of robots, which finally start and finish the design process (Brian Dunbar, 2018).

²⁶ 3D printer: Additive manufacturing is the construction of a three-dimensional object from a CAD model or a digital 3D model. <https://3dprinting.com/what-is-3d-printing/>



Figure 3.1: Zopherus (Brian Dunbar, 2018)

Figure 3.1 shows one of the architectures for constructing settlements on Mars. It shows how oxygen and ambient temperature are supplied and how ultraviolet radiation is protected. If this architecture reaches the final stage, This Research will be implemented to control the building using the proposed framework in this study.

- **Marsha**

Marsha is a first principles rethinking of what a Martian habitat could be – not another low-lying dome or confined, half-buried structure. So After NASA launched its 3D-printed habitat challenge in 2015, the AI Space Factory set out to design the Marsha. This egg-shaped building would serve as living quarters for possible colony residents. The double-insulated hub can handle Martian atmospheric pressure and enable complete construction on Mars, minimizing the need to transfer finished buildings on a (space shuttle)²⁷.

Materials for this construction are readily available on Mars. The researchers are developing an emulsion of basalt fibers obtained from Martian rock and renewable bioplastics from plantable plants on Mars. While these hubs are intimate rather than communal places, they readily accommodate 1-2 individuals and will provide

²⁷ Space shuttle: The Space Shuttle is a retired, partially reusable low Earth orbital spacecraft system operated, <https://www.britannica.com/technology/space-shuttle>

anyone who relocates to the Red Planet with their own space in the future (Jayakrishnan Ranjit, 2020).

Figure 3.2 shows one of the architectures for constructing a settlement on Mars. It shows how oxygen and ambient temperature are supplied and how ultraviolet radiation is protected. If this architecture reaches the final stage, This Research will be implemented so that the building can be controlled using the proposed framework in This Research after the final implementation.



Figure 3.2: Marsha (Jayakrishnan Ranjit, 2020)

- **Bamboo Colony**

Malaysian designers Warith Zaki and Amir Amzar hope to construct something akin to Ai Space using the germ of life. Using robots to weave bamboo shoots (planted on Mars after discovering a water supply), the plant is wrapped in ethylene tetrafluoroethylene (ETFE), and water is poured into the bamboo, freezing the structure and boosting protection.

For the residents of the planet's environment, this pair's design is based on choosing against 3D printing, which is the topic of most Martian constructions. While

bamboo alone may not be adequate to defend the construction, the pair feels it is a more helpful technique to develop livable structures on the Red Planet than 3D printing (Tom Ravenscroft, 2019).

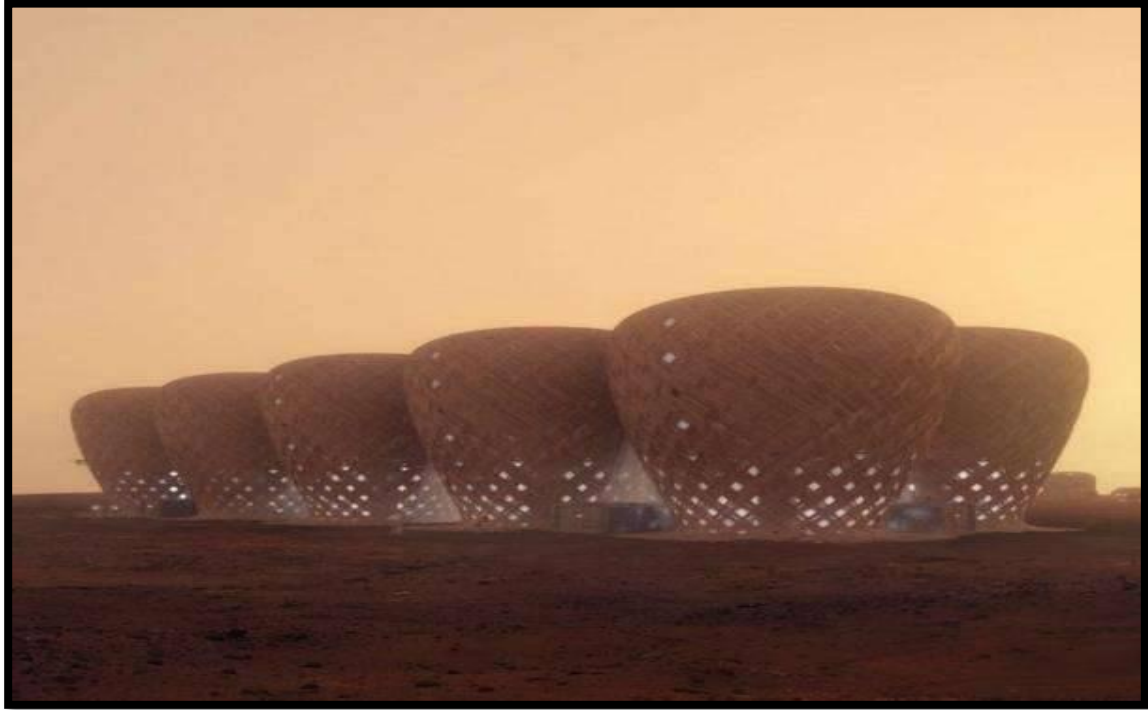


Figure 3.3: Seed of Life (Tom Ravenscroft, 2019)

Figure 3.3 shows one of the architectures for constructing a settlement on Mars. It shows how oxygen and ambient temperature are supplied and how ultraviolet radiation is protected. If this architecture reaches the final stage, This Research will be implemented so that the building can be controlled using the proposed framework in This Research after the final implementation.

- **NASA, University of Arizona: Martian Greenhouse**

While most greenhouses (on Earth) are composed of glass, NASA and the University of Arizona Department of Agriculture have developed an inflatable greenhouse for growing vegetables on other planets. To ensure that astronauts and prospective citizens may eat vegetarian in space, the 5 x 2-meter design allows for air reclamation, water recycling, trash recycling, and even capturing carbon dioxide exhaled by Repurpose astronauts.

This greenhouse has been compared to many biological systems on Earth and will undoubtedly be employed when humanity travels to the Red Planet (Pola Lem, 2017).



Figure 3.4: Martian Greenhouse (Pola Lem, 2017)

Figure 3.4 Given the atmosphere of Mars and the lack of plants to produce oxygen that can control oxygen and ambient temperature, this image shows that plants can be grown in space and that the atmosphere of Mars can help them provide ambient oxygen. However, the relationship between this and research is that one way to produce oxygen is that if it has problems, it can interfere with oxygen production, which can control plant development and production conditions.

On Mars, the structural loads and low tensile strength of in-situ Martian adhesives make existing solutions for Martian structures uneconomical, as they are based on terrestrial resources such as wind turbines. The research (Shoorshjani, 2022) has addressed this issue by introducing and analyzing three innovative structural forms according to the structural engineering point of view, using optimal symmetrical parabolic arc forms and water-free sulfur-based concrete.

These forms minimize the tensile stresses under the structural loads on Mars. Possible structural loads on Mars, including gravity, wind, Mars earthquakes, asteroid impacts, and meteor impact loads, have been investigated and calculated. The proposed models were analyzed under the structural loads of Mars using the implicit finite element method, and the results were compared with two concrete structural forms from previous studies. The proposed models can bear the structural loads of Mars with complete elastic behavior, significantly reduce the cost of Mars colonization due to the use of Mars resources, and reduce element imports from Earth.

Figures 3.5a and b show model 1, where arches are used to minimize the structure's tensile stress. The base's radius and the whole model's height are 10 meters and 9.96 meters, respectively. To consider architectural and structural limitations, the h/b ratio is 20 for walls and roofs, respectively.

An additional edge is considered to reduce and control the stresses of the rim to control the concentrated stresses caused by the deformation of the roof and tensile stress in the rim. This extra edge design acts in compression under structural loads. Also, the ratio of the top perimeter to the base perimeter was considered to be 0.88 for this model, which provides walls with approximately 82.5 degrees and applies the behavior of the structure under Martian structural loads. Despite the shallow structural wind pressure, the circular shape of the model provides an aerodynamic shape against wind loads.

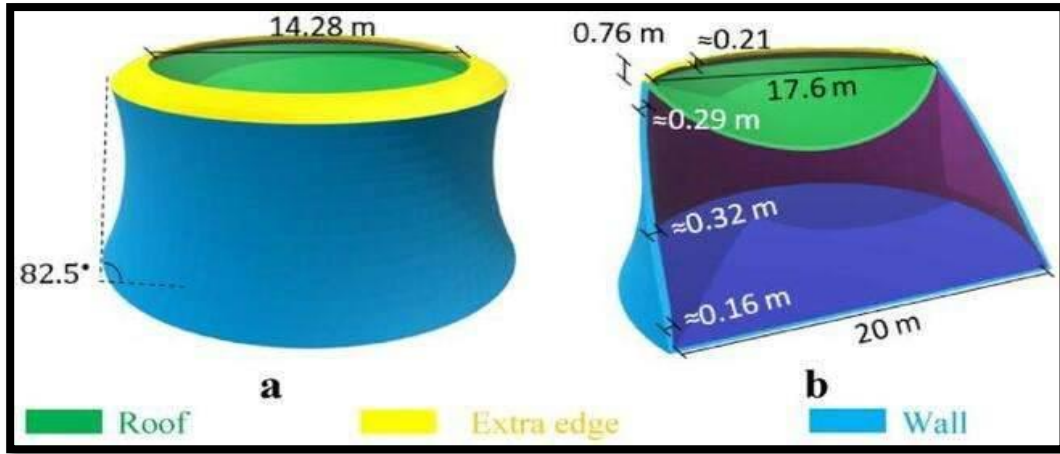


Figure 3.5: Proposed Martian Structure, Model-1. (a) 3D view, (b) elevation view.
(Shoorshjani and Masoumi, 2022)

The total height and base radius of Model 2 (Figure 3.6) are 9.01 meters and 10.00 meters, respectively. This model is designed with an h/b ratio of 0.155 and 0.17 for the wall and roof. Six columns placed at an angle of 60 degrees with a thickness of 0.20 m are used to control and transfer the ring stresses to the ground (columns surround the ring).

The columns make the wall behave as a fixed, double-ended arch. Therefore, they act as compression in the Y direction. Also, an environment was considered to control high stresses at almost the middle height of the structure.

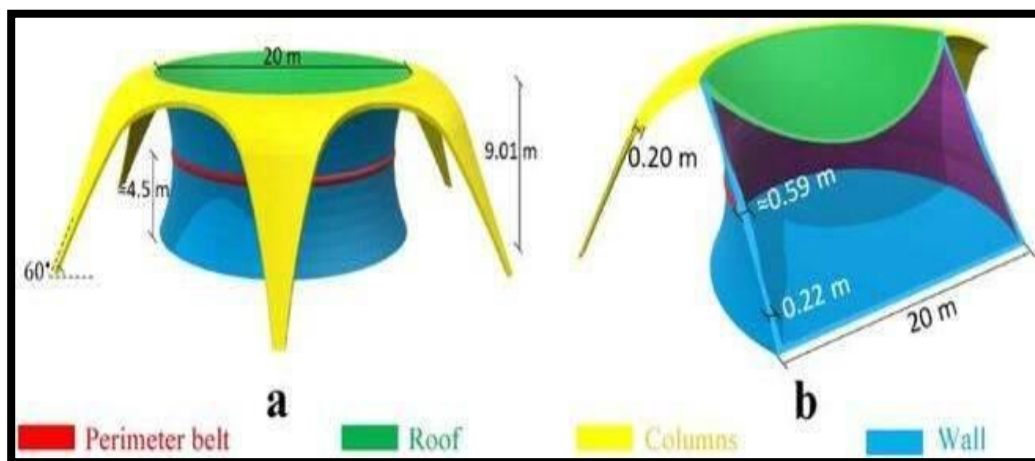


Figure 3.6: Proposed Martian Structure, Model-2 (a) 3D view; (b) elevation view.
(Shoorshjani and Masoumi, 2022)

Model 3 (Figure 3.7) uses four arches as a wall with a length of 20.0 meters and an h/b ratio of 0.15. Two 20-cm-thick supports are used on each side. This model's area and maximum height are 211.52 square meters and 10 meters, respectively. A fixed thickness of 20 cm is considered for the walls.

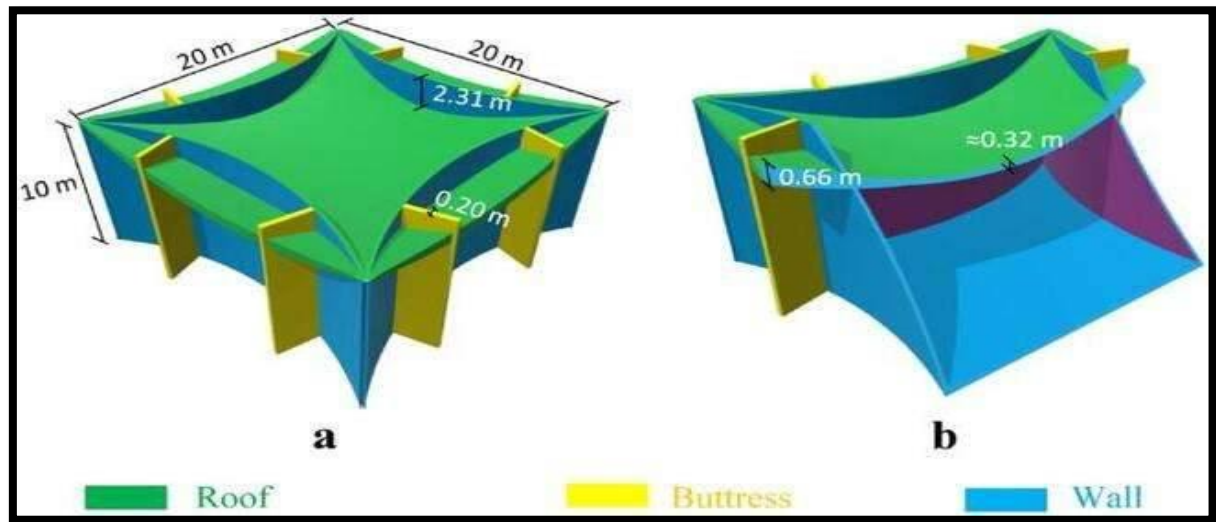


Figure 3.7: Proposed Martian Structure, Model 3 (a) 3D view; (b) elevation view.

(Shoorshjani and Masoumi, 2022)

It is also a proposed criterion and structure for Mars, which has been evaluated in terms of strength and resistance to the Martian atmosphere. Walls and roofs are of particular interest to this researcher.

Researchers calculated lateral wind and earthquake loads using information from Viking 1 and 2 landers, gravity, internal pressure, and the role of asteroids and micrometeorites. They found that the self-weight load from gravity and the difference in pressure between the inside and outside are essential for Mars structures. The proposed models show fully elastic behavior under Martian structural loads, which is necessary for the permeability of Martian structures.

While previous studies of concrete structural forms showed plastic behavior under 50% to 100% internal atmospheric pressure, Model-1 requires less concrete and less construction energy. In addition to better structural behavior and less need for concrete for construction, Model-1 has a simpler geometry than Model-2 and Model-3, making manufacturing and printing processes easier. The results showed that

the proposed models eliminate the need to import costly ground structural units, such as wind elements, from the ground. Also, these building blocks can be used for different kinds of Martian concretes in place because they behave similarly to the concretes that are already there, have meager tensile strength, almost the right compressive strength, and act in a straight line (Soureshjani & Massumi, 2022).

One day, many people hope that humans will travel to Mars. The US National Aeronautics and Space Administration (NASA)²⁸ has plans for a mission to the planet in the 2030s, and entrepreneur Elon Musk says his company SpaceX could do so by 2024. If people manage to establish an outpost on Mars, they will. There is a need to build a place for astronauts to live, sleep, and work. Nevertheless, transporting construction materials through 225 million kilometers of space—the average distance between Earth and Mars—would be a nightmare.

It costs about \$4,000 to launch a kilogram of material into low Earth orbit and several times that amount to send to Mars; therefore, sending tons of concrete would be financially devastating and logistically challenging," says senior technologist Robert P. Mueller. Advanced product development at Swamp Works, an innovation lab he founded at NASA's Kennedy Space Center. Every new inhabitant of the Red Planet must do what colonists have always done: use whatever materials they have to build shelters. The substance on Mars is lithology, a layer of dusty, crushed rock that asteroid impacts have deposited over billions of years throughout the solar system.

It is a ready-made building material—crushed rock—sitting on the planet's surface," says Müller. All we have to do is develop the technology to take that existing collection and connect it somehow. This is the goal of teams trying different methods to make materials suitable for 3D printing. This construction technique, which creates objects by layering layers of materials, allows NASA to send robots ahead of any colonists to pre-build habitats. 3D printing can also build structures

²⁸ NASA: The National Aeronautics and Space Administration

with shapes and thicknesses that may not be possible with standard concrete pouring techniques.

Part of the challenge is developing building materials that are 3D printable—in terms of consistency and hardening time—and creating sustainable structures. Some researchers have shown they could make sturdy building materials from Martian red soil. Mueller assisted in the launch of NASA's 3D Printing Habitat Challenge, which has inspired some. The challenge offers \$2.5 million in prizes to encourage industry and academic scientists to explore ways to build on Mars.

The first phase looked for new architectural concepts that take advantage of 3D printing, and the second phase awarded prizes to five teams that printed beams and other shapes from a stone simulator in August. The third phase has just begun. On land, builders work primarily with concrete. This material usually consists of crushed stone or sand mixed with Portland cement and water. Cement, made from limestone and clay heated together, reacts with water to form a paste that binds the stones together and strengthens as it hardens.

Researchers believe that rock on Mars can be an alternative to concrete components. Mars rovers have used gas chromatography, mass spectrometry, and laser spectroscopy to determine the composition of the Martian soil. Mars rock mainly comprises silicon dioxide and iron oxide and has a good amount of aluminum, calcium, and sulfur oxide. This composition varies from place to place on the planet's surface due to variations in asteroid impacts and weathering by wind and water, ancient oceans, and some modern water currents. Nevertheless, the spacecraft has yet to return to Earth with material samples.

So, scientists at NASA's Johnson Space Center have used rover data to develop the JSC Mars-1a simulator, a mixture of Earth minerals designed to match Martian soil's composition and particle size. Scientists have used this stone base to test new building materials. JSC Mars-1a is made of basalt collected from a volcano in Hawaii. Meanwhile, Muller uses another rock simulator called BP-1. It is made from a different crushed basalt from the Black Point lava flow north of Flagstaff,

Arizona. Depending on what the researchers are doing, they choose the simulator based on its mineralogical properties, particle size distribution, or other qualities.

Yu Qiao, professor of structural engineering at the University of California, San Diego, says that JSC Mars-1a is a very close copy of Martian soil. The simulator has 43.48% silicon dioxide and 16.08% iron oxide by weight, compared to average values measured on Mars of 45.41% silicon dioxide and 16.73% iron oxide. Qiao wants to see if he can develop a better replica based on more recent measurements collected by the rovers, which have found perchlorates in the soil. He wants to see if perchlorates change the behavior of the materials he is testing.

We do not just consider the soil itself; we also have to consider the impurities," he says. With the power of sulfur on the ground, concrete is cured and strengthened thanks to the chemical composition of cement, which consists of limestone and water. However, marine organisms—which Mars never had—formed the majority of the limestone on Earth. Martian soil contains calcium and carbon found in limestone, but the elements are dispersed throughout the planet. Moreover, Mars has water, but not much.

It will be a long time before we can produce cement on another planet," said Gianluca Kozatis, a Northwestern University civil and environmental engineering professor. Mars has much sulfur in its soil, and molten sulfur has been used to bond some concrete to Earth. To test the possibility of using it to make Martian concrete, Lynn Van Wendner, a Ph.D. student in Kozatis's lab, melted sulfur and mixed it with (JSC Mars-1a)²⁹ The same recipe was used for sulfur concrete on Earth in a 1:3 ratio. Then, he subjected the concrete to standard tests of its strength under pressure, bending, and splitting. This recipe uses ground sand to produce a compressive strength of about 30 MPa, similar to cement-based concrete.

²⁹ JSC Mars-1a: low-Ti lunar mare simulant, <https://ares.jsc.nasa.gov/projects/simulants/jsc-1-1a.html#:~:text=This%20low%2DTi%20lunar%20mare,as%20a%20lunar%20mare%20simulant.>

Nevertheless, Kozatis says the simulated Mars concrete was much weaker, which may be because the material is more porous than the Earth version. More porous concrete is usually the result of larger particles in the sand.

Van Wendner, a researcher at the University of Natural Resources and Life Sciences, Vienna, and his colleagues tried a 1:1 mixture of Sulfur and sand. They pressed the mixture to break up the grains and expel air bubbles. The strength of the concrete was 60 (MPa)³⁰, which was twice as strong as standard concrete. Sulfur-based concrete also hardens quickly in the time it takes for the mix to cool. Standard concrete takes 28 days to set and gain full strength fully. Cusatis says the quick setting may be an advantage for 3D printing because each material layer becomes strong enough to hold the printed layer almost immediately.

Kosatis could not explain the extra strength of the Martian concrete, so he tried changing the size of the soil grains to see if that made a difference. It did, but more was needed to double the power. He thinks the Sulfur may react with metals in the rock, particularly the iron oxide that gives Martian soil its characteristic red-orange color, to form chemical bonds within the material.

Nevertheless, Martian sulfur concrete has its drawbacks. Like standard concrete, it has poor tensile strength and easily cracks under load. On Earth, builders solve this problem by reinforcing structural concrete with steel rebars, but it needs to be clarified what kind of rebar could be built on Mars. Moreover, one of the reasons why Sulfur is not widely used in the field as an adhesive is that it is not resistant to heat. If a building catches fire, the Sulfur melts, and the concrete crumbles. As Kosatis suggests, sulfur concrete could act as a core material that provides strength and is encased in something refractory. There is another problem with its use in building materials: "Sulfur has a bad smell. You certainly do not want to avoid the smell of Sulfur in your home. You may need to cover the concrete with something to limit the smell.

³⁰ MPa: Megapascal, <https://m.convert-me.com/es/convert/pressure/megapascal.html?u=megapascal&v=1>

At NASA's Mueller Laboratory, researchers are testing polymers as a binder for rock. Mueller says it should be possible to produce polymers such as high-density polyethylene on Mars using carbon dioxide in the atmosphere and hydrogen from water in the soil. Using a 3D printer, his lab built a 1-meter-diameter dome of their simulated Mars concrete to show what they hope to do on a larger scale.

Of course, 3D printing with concrete is challenging, says Müller. The deposited material must be thick enough to hold its shape during the printing process but thin enough not to clog the machine or dry so quickly that it cracks. "The trick is to get a material that has the right consistency to be extruded and cured," he says. Mueller wants to eventually ditch the polymer glue and harden the soil by sintering—heating, and compressing it until it solidifies. This should be possible using a laser beam, solar concentrator, or microwave system. However, until researchers develop the technology, they use polymer glue to test their 3D printing ideas.

An exciting idea: Another proposal for Martian building materials removes a binder altogether. UCSD's Qiao discovered that he could turn a cobblestone simulator into bricks by rapidly compressing the material. The soil is full of iron oxide and oxyhydroxide particles with a 25 to 45 micrometers diameter. "If you squeeze the soil grains with enough pressure, you will break up the iron oxide nanoparticles," Qiao says. Fracture gives the nanoparticles clean and smooth surfaces. Under increased pressure, they rotate so that the tiny, newly split facets press against each other and form a bond. Qiao believes the nanoparticles are held together by combining van der Waals forces and atomic bonds, although he has yet to test this hypothesis.

Furthermore, the binding occurs in just about one millisecond under a pressure of 400 MPa. Qiao says that is about the same amount of pressure as when you drop a hammer on the soil, which is what his team did.

Another type of soil common on Mars is sedimentary material and clay formed in ancient oceans. Its chemical composition is similar to that of other rocks, but

weathering by water long ago means it has a fine-grained structure without nanoparticles and electrostatic surface charge. Qiao found that compressing the replica layers of this dry Martian clay under high pressure also created a solid material. The clay layers were naturally compressed; therefore, electrostatic forces held them together. Nevertheless, the researchers slowly pressed the clay layers together instead of hitting the material quickly. Qiao says the two soils produce "similarly strong solids." However, there is still a long way to go, from scientists playing in simulated Martian soil to building habitable buildings on another planet.

The third phase of NASA's 3D Printing Habitat Challenge, which requires participants to 3D print a scale model of a proposed habitat, was announced in November. Mueller hopes the competition will continue to advance the field. Nevertheless, Mueller says the goal is to prove the technology's viability rather than plan for a specific mission. "I am pretty sure there is much work to be done before we build a structure on Mars," Kozatis agrees (C&EN, 2023).

Now that the nonprofit Mars One plans to establish the first human settlement on Mars in 2025 and NASA hopes to send humans there in 2030, that fantasy is quickly becoming a reality. So, a Northwestern engineering team gets practical information about life on Mars. Gianluca Cusatis led the team that created Martian concrete using components naturally present on the planet.

High-strength concrete can be created quickly and is durable enough to withstand a meteorite impact—a key ingredient needed to develop suitable human shelters. Cusatis, an associate professor of civil and environmental engineering at Northwestern's McCormick School of Engineering, developed concrete that uses materials from Mars and the traditional ingredients of sand, cement, and water. Kosatis used a NASA-developed Mars soil simulator instead of sand. Furthermore, he used molten sulfur, abundant on Mars, instead of water.

The research is described in a paper recently submitted for peer review in *Construction and Building Materials*. It is currently available in preprint at arxiv.org. Lin Wan, a former Ph.D. student in the Kosatis lab, is the paper's first

author. Former research fellow Roman Wendner, who currently works at the University of Natural Resources and Life Sciences (BOKU) in Vienna, Austria, is also an author of the paper.

Sulfur-based concrete is a familiar idea. Highly resistant to corrosion, it is currently used in non-structural applications such as pipes and landscaping. Nevertheless, it is rarely used for larger projects because it is sensitive to heat and fire. After testing its mechanical properties, Kosatis found that his Martian concrete was more than twice as strong as conventional sulfur-based concrete. In fact, after adjusting for gravity on Mars, its strength is equivalent to the concrete used to build skyscrapers on Earth.



Figure 3.8: A Block Of Cusatis' Martian Concrete. (C&EN, 2023)

Given Figure 3.8, it can be argued that one of the important elements of managing information on Martian buildings is the control of walls and roofs and the materials used in them, which is particularly important in the present study.

"You want buildings to be fire-resistant; therefore, that can be a vulnerability on Mars," said Kosatis, a concrete expert. Nevertheless, fire will be fine for the first settlements. The issues are related to having safe shelters and durable buildings that can survive the impact of meteorites.

Kosatis believes that the strength of his concrete is due to the small size of the particles in the Martian soil, as well as the unknown chemical reaction between the

soil and sulfur. His team also found that when concrete breaks and is remelted and poured again, it becomes even more robust, likely due to a further reduction in particle size. Conventional sulfur concrete uses sand, which is ineffective. "It is just filler," Kozatis said. In our Martian concrete, sulfur is not just a glue. It reacts with minerals in the Martian soil. It completely changes the picture."

While regular concrete needs 28 hours to develop full strength, Cusatis Martian concrete takes only one to two hours. Because of this, he thinks it is a prime candidate for 3D printing. If 3D printers are sent to Mars, they could use local resources to print buildings made of Cozatis' strong concrete. This would be far more efficient and sustainable than sending material from Earth across the solar system.

Kosatis stresses that his concrete needs further research. He is interested in learning more about the chemical reactions that make it strong and wants to find ways to make it fire-resistant. However, with less than ten years to go, preparing for a mission to Mars is still early enough. "People seem curious about going to Mars now," he said. Shelter is a significant factor in these plans. Food and shelter are the two things that humans need the most (Northwestern, 2023).

In the research (Muthumanickam et al., 2021) titled Combining Artificial Intelligence and BIM in the Design and Construction of Mars Habitat, it is stated that a new connected software ecosystem using advanced developments in BIM, parametric modeling, database management, and APIs was developed to support the design of the admixture concrete construction framework. Such an integrated BIM platform enables the integration of multi-disciplinary modeling, analysis, optimization, and simulation. It considers construction and manufacturability constraints and other performance, such as structure, indoor environmental performance, and cost.

In addition to the BIM framework that enabled the simultaneous design of the entire building, along with the tool path design and the robotic manufacturing and logistics system, BIM-based digital twin models were essential in simulating the whole robotic construction work sequence. Using such a framework, it was possible

to build the world's first fully enclosed concrete structure, 3D-printed from floor to roof, tapering to its highest point, without any architectural-scale support structures or forms. With the promising trends achieved by the developed BIM framework, more robust and efficient designs can be developed by enhancing the BIM framework by integrating it with real-time feedback systems and sophisticated (CFD)³¹ Tools capable of simulating material flow.

Elan's thesis (2018), titled *Martian Buildings*, states that the possibility of sending humans to Mars is being developed. This ambitious and exciting goal requires a wide range of new technologies and innovations and a fresh perspective on the current challenges we face on Earth. This also applies to architecture and building technology.

To begin with, the need arises to build a sustainable habitat, where sustainability is defined by considering communication delay (22 minutes), travel time (at least five months), and being as rare as possible on Earth. Windows startup" that only happens once every 26 months. Therefore, stability is critical on Mars.

This aspect leads to research focusing on in-situ resource utilization (ISRU). Based on this insight, the research question was formulated: What materials and in situ forming techniques are suitable for creating an outer shell for a sustainable habitat on Mars that protects the crew from the harsh Martian environment? The Martian habitat must protect the crew from radiation and extreme temperatures (from 20°C to -153°C).

A literature study shows that ice provides an excellent shield against radiation. In addition, ice is widely present on Mars. Hence, several experiments were conducted to test the feasibility of using ice as a building material. These included a mixing test, a melt test, and a compressive strength test. Experiments were performed using different variables and environments.

³¹ CFD: Contract for difference, <https://www.investopedia.com/terms/c/contractfordifferences.asp>

The results were the same for all three experiments: adding sand or plastic did not improve the structural properties of the ice. Nevertheless, the addition of salt enhances the building's esteem. The results of the experiments show that up to 15 ppt (NaCl)³² Increases the compressive strength from an average of 1 MPa to 4 MPa. A higher percentage of sodium chloride does not affect the compressive strength.

Experiments also showed that the colder the test environment (up to -70 °C), the higher the compressive strength of NaCl ice. The warmer the environment (up to +25 °C), the more flexible NaCl ice is.

Another challenge to building a habitat on Mars is that it has to be built remotely. This thesis outlines robotic technology that can perform all the tasks necessary to create a habitat, from ice extraction to building assembly. A brief analysis shows that manufacturing has great potential for excellent assembly.

In Bsc. Layla A. van Ellen (2018) has conducted preliminary studies and experiments on additive manufacturing techniques for sodium chloride ice. The main result is that the ice structure has greater overall strength due to layer after layer of ice freezing. This technique also allows for repairs during the construction, as water fills possible cracks and expands after freezing, creating a more robust structure.

A habitat is designed to evaluate the technological findings' usefulness and compliance with the habitat requirements. "Ice Hab" uses two ice-making techniques, one almost entirely independent of earth materials and the other being earth technology for redundancy. Overall, the habitat design meets the requirements well.

Future studies should also deal with the power required for building with ice, as the design currently exceeds the requirement. This Research answered this question by discovering a new material, sodium chloride ice, and a unique technique

³² NaCl: Sodium chloride, <https://www.merriam-webster.com/dictionary/sodium%20chloride>

for processing ice through additive manufacturing. More research is needed to determine the viability of those results; however, the results appear promising (Ellen, 2018).

In a dissertation (Schmidt, 2007) entitled *The Water Cycle on Mars*, a model was built to calculate under what conditions the Arctic ice cap would be in mass balance. The study concluded that, currently, the Arctic ice cap appears to be stagnant and not flowing. Nevertheless, geological indications indicate that the ice cap has flowed in the past and investigated under what conditions it would begin to flow.

It was found that a more robust circulation of water vapor with increased evaporation at lower altitudes and latitudes and increased precipitation near the pole leads to higher flow velocities in the ice cap. The water flux in the atmosphere was analyzed using a statistical numerical method that enables the seasonal water flux to be separated into different meteorological transport modes.

This Research was based on water vapor data from Viking (MAWD)³³ and atmospheric wind speed from a climate database based on (GCM)³⁴ Results. It was found that water moves from the Northern Hemisphere to the Southern Hemisphere at low latitudes. However, there is no significant net transport at higher latitudes under the current climate scenario.

It was concluded that atmospheric water at latitudes above 30 degrees is currently limited in certain regions. Furthermore, the water flux study showed that the primary mechanism for the hemispheric transport of water is the meridional flux, which corresponds to the mean Hadley circulation.

³³ MAWD: five-channel grating spectrometer measuring solar radiation reflected from the surface and atmosphere of Mars, <https://pds-geosciences.wustl.edu/missions/viking/mawd.html#:~:text=MAWD%20was%20a%20five%2Dchannel,the%201.4%20micrometer%20spectral%20interval>.

³⁴ GCM: depict the climate using a three dimensional grid over the globe, <https://www.gfdl.noaa.gov/climate-modeling/#:~:text=Climate%20models%20divide%20the%20globe,climate%20variables%20such%20as%20temperature>.

Two new models for atmospheric transport and mixing of water vapor at different latitudes were presented. The models could not explain all the spatial and temporal details in the measured and mapped features of the vapor distribution in the Martian atmosphere. The models should be coupled with a surface exchange model representing the interatmospheric interaction surface with sources and reservoirs of water vapor.

4. THEORETICAL FRAMEWORK

4.1. Blockchain

A Blockchain is a specific type of database where information is stored. However, a series of particular features distinguish Blockchain from other databases. There are rules for adding new data to the Blockchain. Also, after adding data to the Blockchain and saving it, it can no longer be edited or deleted.

Recently, (cryptocurrency)³⁵ It has attracted extensive attention from both industry and academia. Bitcoin, often called the first cryptocurrency, has enjoyed tremendous success, with the capital market reaching 10 billion dollars in 2016 (Coindesk, 2016).

The Blockchain is the core mechanism for Bitcoin (Bitcoin is the first decentralized cryptocurrency (Hazra et al., 2024). Nodes in the peer-to-peer Bitcoin network verify transactions through cryptography and record them in a publicly distributed ledger, called a Blockchain, without central oversight). Blockchain was first proposed in 2008 and implemented in 2009 (Nakamoto, 2008).

A Blockchain might be considered a public ledger in which all committed transactions are recorded in a chain of blocks. This chain continues to develop as additional blocks are added to it. Blockchain technology offers several fundamental qualities, including decentralization, persistence, anonymity, and auditability (Xiaodong Shen et al., 2024)

Blockchain can work in a decentralized environment, integrating several core technologies such as cryptographic hashes, digital signatures (based on asymmetric cryptography), and distributed consensus mechanisms. Transactions can take place decentralized, significantly reducing costs and improving efficiency (Hazra et al., 2024)

Although Bitcoin is the most famous Blockchain application, Blockchain can be applied to diverse applications beyond cryptocurrencies. Since it allows payments to be finished without any bank or intermediary, Blockchain can be used in various

³⁵ Cryptocurrency: a digital currency, which is an alternative form of payment created using encryption algorithms

financial services such as digital assets, remittances, and online payments (Peters et al., 2015; Foroglou & Tsilidou, 2015).

Furthermore, Blockchain technology is emerging as one of the most promising technologies for the next generation of internet interaction systems, including Smart Contracts (Kosba et al., 2016), public services (Akins et al., 2013), IoT (Zhang & Wen, 2015), reputation systems (Sharples & Domingue, 2015), and security services (Noyes, 2016). Even though Blockchain technology has enormous promise for the development of future internet systems, it faces several technical obstacles.

First and foremost, scalability is a significant challenge. Bitcoin block sizes are limited to 1 MB, and a block is mined every 10 minutes. As a result, the Bitcoin network is limited to 7 transactions per second, making it unsuitable for high-frequency trading. However, more giant blocks require more storage space and propagate slower via the network. Users will want to maintain such a big Blockchain, resulting in progressive centralization (Alshahrani et al., 2023).

Therefore, the tradeoff between block size and security has become a challenge. Secondly, it has been proven that miners can achieve more revenue than their fair share through selfish mining strategies (Eyal & Sirer, 2014).

Miners hide their mined blocks for more revenue in the future. In that way, branches can occur frequently, hindering Blockchain development. Hence, some solutions need to be put forward to fix this problem. Moreover, it has been shown that privacy leakage can also happen in Blockchain s, even when users only make transactions with their public and private keys (Biryukov et al., 2014).

The user's actual IP address could even be tracked. Furthermore, consensus algorithms like proof of work (PoW) or proof of stake (PoS) face severe problems. For example, PoW wastes too much electricity, while the phenomenon of the rich getting richer could appear in the PoS consensus process. These challenges need to be addressed in the development of Blockchain technology (Pawan Golait et al., 2023)

There is a substantial body of literature on Blockchain from various sources, such as blogs, wikis, forum posts, codes, conference proceedings, and journal papers.

Tschorsch and Scheuermann (2016) conducted a technical survey about decentralized digital currencies, including Bitcoin. Compared with Tschorsch and Scheuermann (2016), our paper focuses on Blockchain technology instead of digital currencies. Nomura Research Institute made a technical report about Blockchain (NRI, 2015).

In contrast to NRI (2015), our paper focuses on state-of-the-art Blockchain studies, including recent advances and future trends. This paper is an extended version of the work published by Zheng et al. (2017), with substantial extensions on Blockchain technical details, consensus algorithms, applications of Blockchain, research challenges, and future directions.

4.1.1. Blockchain Structure

Each block contains a hash code to verify the validity of the data, and it is automatically encrypted. In each block's hash code, the previous block's hash code is also present, and a Blockchain is likewise formed as a chain of blocks connected (Zhang et al., 2024). Given that each block is connected to the previous block, it is impossible to change the data in the previous blocks, which will bring more security and trust to the data stored in the Blockchain (Lee et al., 2015).

Alternatively, it can be said in a more specialized way. Each block points to the immediately previous block via a reference, essentially a hash value of the previous block called the parent block. It is noteworthy that uncle blocks' (children of the block's ancestors) hashes would also be stored in the Ethereum Blockchain (Buterin, 2014). The first block is called the genesis block, which has no parent block.

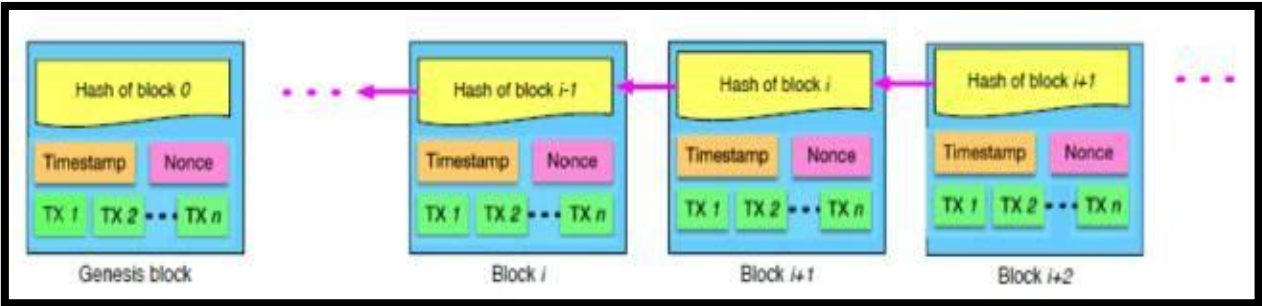


Figure 4.1: Blockchain Taxonomy (Buterin, 2014)

In Figure 4.1, each block includes items such as the hashed value, which represents the values stored in the Blockchain after being placed in the hash function used. The timestamp indicates the block creation time, and other members indicate the connection between Blockchain. Each block is connected to the previous block so the chain does not break apart.

4.1.1.1. Block

Blocks are the central part of Blockchain technology (Jhunjhunwalla et al., 2024). They can be considered the general ledger pages distributed on the Blockchain network. Each block contains specific information. This information is like the details of the transactions made on the Blockchain platform. Details such as the general address of the sender and the general address of the recipient, the dedicated hash, the hash of the previous block, and the time of the transaction are stored in these blocks permanently. They cannot be deleted or changed in any way. This feature creates a network encryption system in blocks (Monalsha Chand et al., 2023)

The Blockchain body stores the history of verified transactions on the network. When miners build a block, they validate a transaction after it is validated. To confirm these transactions, they check the amount of the transaction requested by the sender to ensure that the currency is in the sender's account. These records are stored in the block body for more accessible examination (Puwei Wang et al., 2023).

The blockhead header plays a fundamental role in the Blockchain network processes. Blocks are connected through the header and identified by the header hash in the network (Kaur Sarao et al., 2023).

The header is divided into six parts:

- Time tag
- Nance number
- Target
- Merkel tree root hash
- Program version
- Previous hash block

Let us define it in a specialized way: In building a Blockchain -based application or network, a "definition block" or "genesis block" refers to the first block created to start the chain. This block defines the network's initial state, including its protocols, rules, and parameters.

Typically, the network's creator or a group of early participants create the definition block when creating a Blockchain. The definition block also establishes the foundation for the consensus algorithm that the network will use to validate transactions and add new blocks to the chain (Kaur Sarao et al., 2023)

Once the definition block is created, subsequent blocks are added to the chain through validation and consensus among network participants. The integrity of the definition block is essential to the security and trustworthiness of the Blockchain network, as any modifications or tampering with it can compromise the entire network (R. N. et al., 2023).

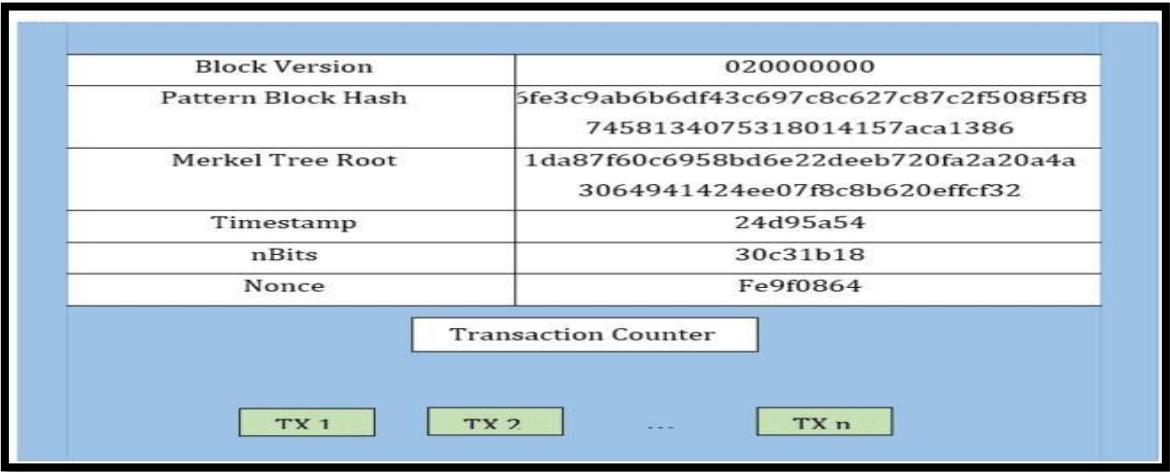


Figure 4.2: Block structure (Author)

Figure 4.2 shows how data is stored on Blockchain blocks, which will be the information and blocks of Research.

4.1.1.2. Hash

Each block has a hash, a value made from a text string using mathematical functions. Because each hash is unique, hashes can be compared to fingerprints. Their role is to identify a block and its contents (Panuntun et al., 2023).

Hashes are used in the Blockchain to indicate the current state; the function input is the entire current state, which includes all transactions made since the beginning. These transactions are hashed as input (during the hashing process), and the resulting output (Hash)³⁶ It will show the Blockchain current state. This hash is used to agree among all sectors worldwide that the current state is the only current and natural (Panuntun et al., 2023).

Let us define it in a specialized way: In Blockchain technology, a hash refers to a fixed-length string of characters representing a data block. A hash is a one-way cryptographic function that takes an input (in this case, a block of data) and produces an output (the hash) unique to that input (Sharma et al., 2023).

Hash functions are used extensively in Blockchain technology to create a tamper-proof record of transactions. When a block of data is added to a Blockchain, a hash of the previous block is included in the new block (Zhang et al., 2024). This creates a chain of blocks that are cryptographically linked together. Any changes made to a block would result in a different hash being generated, which would not match the previous block's hash. This makes it nearly impossible to tamper with previous blocks without being detected (Shakila et al., 2023).

Additionally, hashes are used to secure the network, making it computationally difficult to create a new block that matches the required hash. Miners use powerful computers to compete against each other to solve complex mathematical problems, with the winner being awarded the right to add a new block to the Blockchain. The difficulty of the issues is adjusted periodically to maintain a consistent rate of block creation (Sharma et al., 2023).

In summary, a hash in Blockchain is a unique, fixed-length string of characters representing a block of data. It is used to create a tamper-proof record of transactions and is essential to securing the network.

³⁶ Hash: a function that meets the encrypted demands needed to secure information

Figure 4.3 demonstrates the process of data hashing, which aligns with the methodology of storing data in Blockchain blocks utilizing hash functions, a methodology also employed within the framework of This Research.

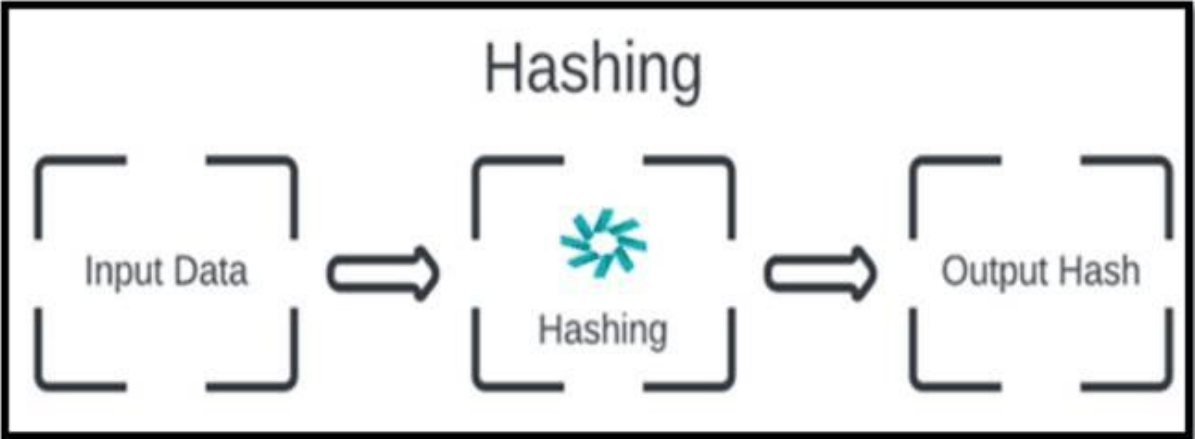


Figure 4.3: Hashing structure (Author)

4.1.1.3. Node

The word "node" is not exclusive to the cryptography industry and is usually used in other sciences (Jiang et al., 2024). In layman's definition, a (node)³⁷ A node is an intersection or connection point in a telecommunication network. It can also be interpreted as any system or physical equipment connected to a network that can perform specific tasks, such as creating, receiving, or sending data in a communication channel (Niu et al., 2023).

In cryptocurrencies, a computer node connects to a Blockchain network and performs specific tasks such as generating, receiving, and transferring data. Each protocol may provide a different definition of a node (Parab et al., 2023).

In Blockchain technology, a node refers to a computer or device connected to the network and helps maintain the integrity of the Blockchain. Nodes can be run by anyone with the appropriate software and hardware, complete or lightweight (Ghazouani et al., 2023).

A full node stores a complete copy of the Blockchain, from the genesis block to the most recently added block. This type of node is responsible for validating

³⁷ Node: a point of intersection/connection within a data communication network

transactions, enforcing network rules, and broadcasting new transactions and blocks to other nodes on the network. A lightweight node, on the other hand, does not store a complete copy of the Blockchain. Instead, it relies on full nodes to provide the necessary information to validate transactions and perform other network functions. Lightweight nodes are often used by individuals who want to participate in the network but need the storage or processing power to run a full node (Lee et al.,2024).

Nodes play a critical role in maintaining the security and decentralization of the Blockchain network. Multiple nodes that independently verify transactions and validate blocks protect the network from attacks and manipulation. Additionally, nodes can help improve the network's efficiency and speed by reducing the reliance on centralized intermediaries (Mrabet et al., 2023).

Figures 4.4-4.5 show an example of nodes for this. The thesis states that each of the building components or the buildings themselves can be used as a node in the network.

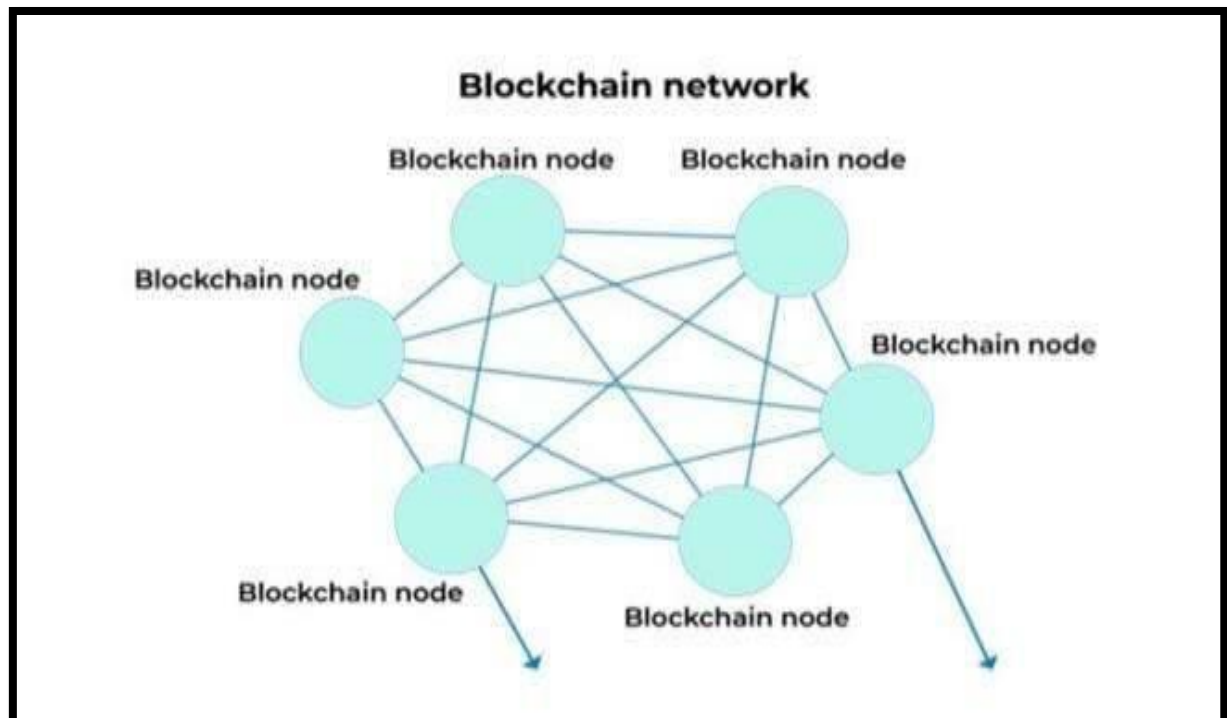


Figure 4.4: Blockchain Network (Author)

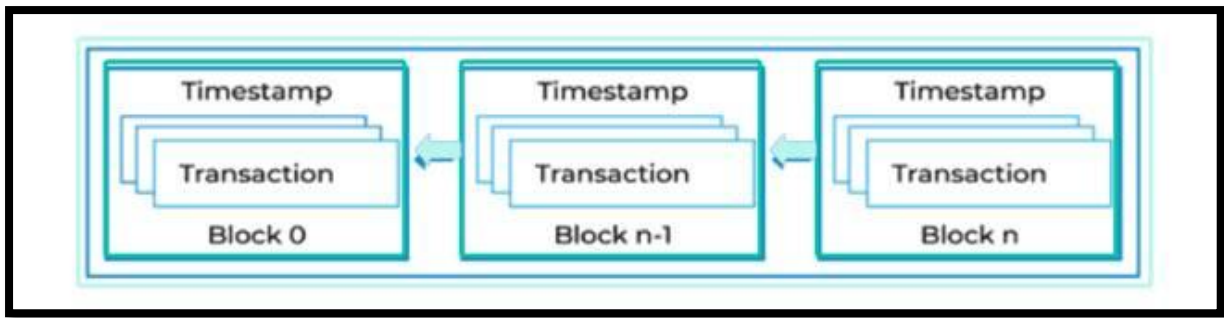


Figure 4.5: Blockchain Database (Author)

4.1.1.4. Chain

A chain consists of a Blockchain network tied to the original Blockchain via a two-way peg. A chain refers to a series of blocks that are (cryptographically)³⁸ They are Linked together using a hash function. Each block in the chain contains a hash of the previous block, which creates a continuous and tamper-proof record of all transactions that have taken place on the network (Mullegowda et al., 2024).

The Blockchain is a distributed ledger maintained by a network of nodes. When a new block is added to the chain, it must be validated by the nodes in the network to ensure that it adheres to the network's rules and protocols. Once validated, the new block is added to the chain, and the nodes on the network update their copies of the Blockchain (Raman et al., 2021).

The security and immutability of the Blockchain come from the fact that any attempt to modify a block in the chain would change its hash, which would then invalidate the hash of all subsequent blocks in the chain. This makes it nearly impossible to tamper with the Blockchain without being detected (Golait et al., 2023).

The Blockchain has many potential applications, such as serving as a platform for digital currencies, providing a transparent and secure record of supply chain information, and enabling the safe and efficient transfer of assets (Mingxiao Du et al., 2020)

³⁸ Cryptographically: the science or study of the techniques of secret writing, especially code and cipher systems, methods

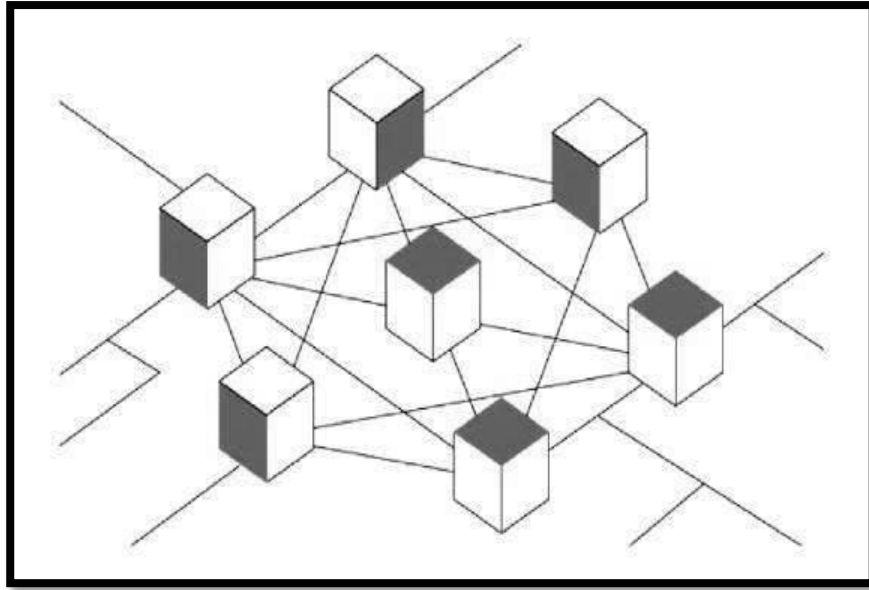


Figure 4.6: Chain Structure (Author)

Figure 4.6 illustrates how the nodes relate to each other. In This Research, all the definition nodes that can be sensors or buildings on the network are connected this way, which is why it is paid for here.

4.1.1.5. Digital Signature

Each user owns a pair of private keys and a public key. The private key is used to sign the transactions. The digitally signed transactions are spread throughout the whole network and then accessed by public keys, which are visible to everyone. The typical digital signature is involved in two phases: the signing phase and the verification phase (Rai et al., 2023).

When a user, a woman, wants to sign a transaction, she first generates a hash value derived from the transaction. She then encrypts this hash value using her private key and sends the encrypted hash to another user, man, with the original data. Men verify the received transaction by comparing the decrypted hash (using Alice's public key) and the hash value derived from the received data using the same hash

function as Alice's. Blockchains' typical digital signature algorithms include the elliptic curve digital signature algorithm (ECDSA)³⁹ (Johnson et al., 2001).

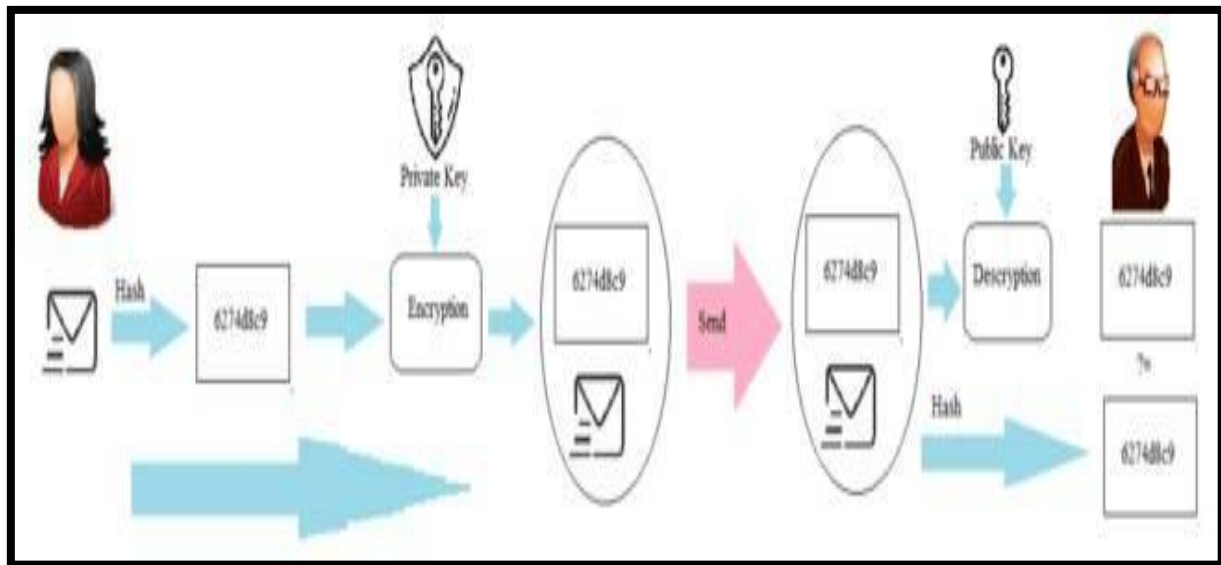


Figure 4.7: Digital Signature Used In Blockchain (Author).

Figure 4.7 examines how to encrypt and decrypt. This figure shows that in a Blockchain network, the data is first hashed by a private key, then by a public key, and finally, these steps must be reversed to decrypt. The study also used this model to send data to the server and check the accuracy of the information received from the sensors to the server.

4.1.2. Characteristics of Blockchain

Creating immutable ledgers is one of the key values of Blockchain. All centralized databases can be corrupted and usually require a trusted third party to maintain the integrity of the information. Once you have agreed on a deal and registered it, it can never be changed. The lack of centralized control ensures scalability and robustness by utilizing the resources of all participating nodes, eliminating many-to-one traffic flows, reducing latency, and solving the single-point-of-failure problem in the centralized model (Tyagi et al., 2020).

³⁹ ECDSA: a Digital Signature Algorithm (DSA) which uses keys derived from elliptic curve cryptography (ECC), <https://doubleoctopus.com/security-wiki/encryption-and-cryptography/elliptic-curve-digital-signature-algorithm/>

Anonymity provides an efficient way to hide and preserve users' identities. Blockchain provides better security because there is no single point of failure to shut down the entire network. One of the remarkable things about Blockchain technology is that it can increase the capacity of the whole network. Thousands of computers working together can be more potent than a few centralized servers (Atlam et al., 2018).

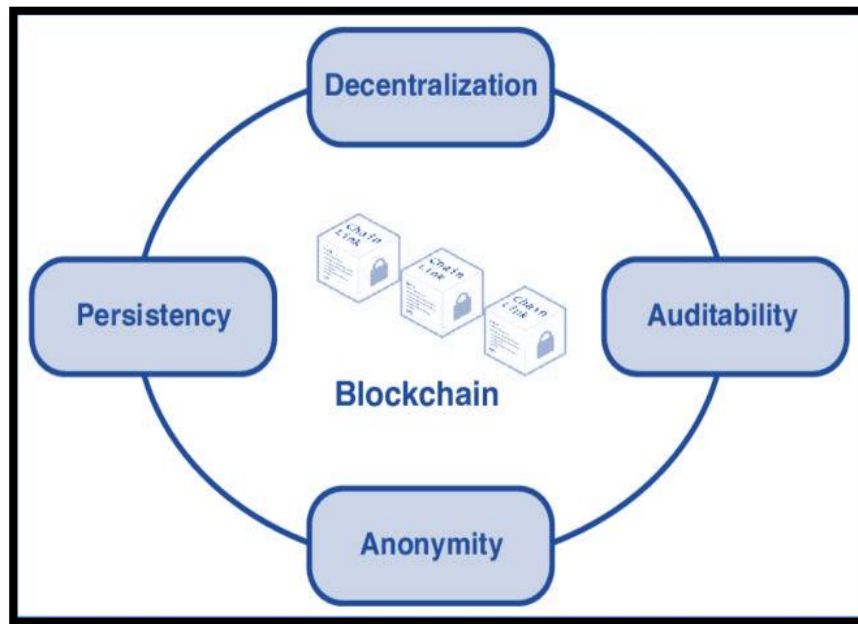


Figure 4.8: Characteristics (Author)

Figure 4.8 illustrates how data is encoded in the Blockchain. Since This Research is also a natural part of the Blockchain work cycle, it has been used.

4.1.2.1. Decentralisation

Decentralization in computer systems means distributing hardware and software resources between all network components. In this method, the calculation and management of the network are no longer done at one point but by all network components.

In conventional centralized transaction systems, each transaction must be validated through a centrally trusted agency (e.g., the central bank), inevitably resulting in cost and performance bottlenecks at the central servers. Differently, a

transaction in the Blockchain network can be conducted between any two peers (P2P)⁴⁰ Without authentication by the central agency. In this manner, Blockchain can significantly reduce server costs (including development and operation costs) and mitigate performance bottlenecks at the central server (Sun et al., 2020).

Lack of focus is one of Blockchain 's advantages that can contribute to Blockchain security in information security. In This Research, each building or sensor can be considered a ninety.

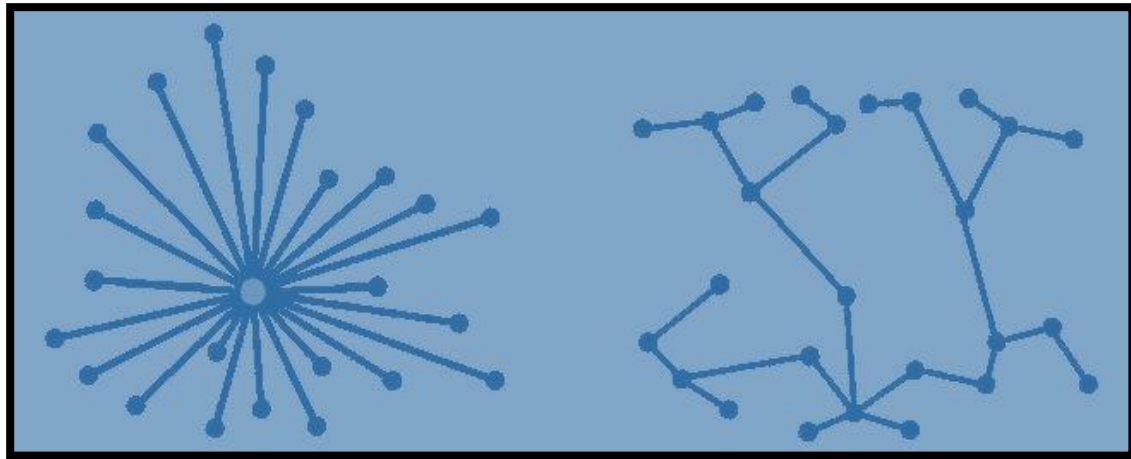


Figure 4.9: Decentralization Structure (Author)

As the graph in Figure 4.9 shows, if all the information is stored in a central location, it is easier to access. However, the intruder must access all the devices to find the information stored in a distributed system. In the worst case, it can be time-consuming, but it is also easy to identify. Therefore, storing data in distributed systems is much safer than centralized ones.

4.1.2.2. Persistency

Since each transaction spreading across the network must be confirmed and recorded in blocks distributed throughout the network, tampering is nearly impossible. Additionally, other nodes would validate each broadcasted block, and transactions would be checked. So, any falsification could be detected easily (Urien et al., 2021).

⁴⁰ P2P: Peer-to-peer, <https://www.britannica.com/technology/P2P>

4.1.2.3. Anonymity

Each user can interact with the Blockchain network with a generated address. Further, a user could generate many addresses to avoid identity exposure. There is no longer a central party keeping users' private information. This mechanism preserves a certain amount of privacy for the transactions included in the Blockchain. Note that Blockchain cannot guarantee perfect privacy preservation due to intrinsic constraints (Haro-Olmo et al.,2020).

4.1.2.4. Auditability

Since each of the transactions on the Blockchain is validated and recorded with a timestamp, users can easily verify and trace the previous records by accessing any node in the distributed network. In the Bitcoin Blockchain, each transaction can be traced to previous transactions iteratively. It improves the traceability and transparency of the data stored on the Blockchain (Appelbaum et al., 2020).

4.2. BIM

New technologies are now widely used in all aspects of society (Barrera-Vera et al., 2008). although resource scarcity, sustainability challenges, and more stringent requirements for recycling and resource efficiency in buildings motivate architecture, engineering, construction, and facility management (FM) and societies. Efficient management of resources due to the long life cycle of the building, maintenance, and renovation management are also the main levers to deal with resource efficiency and enable the closed-loop material cycle. Especially in industrialized countries with low new construction rates, construction sector activities are increasingly shifting towards building modification, retrofitting, and demolishing existing buildings (Mill et al., 2013). Also, developing and applying low-energy technologies for buildings can eliminate or at least reduce dependence on fossil fuels while providing sufficient comfort conditions in the built environment (Prieto M. et al., 2015).

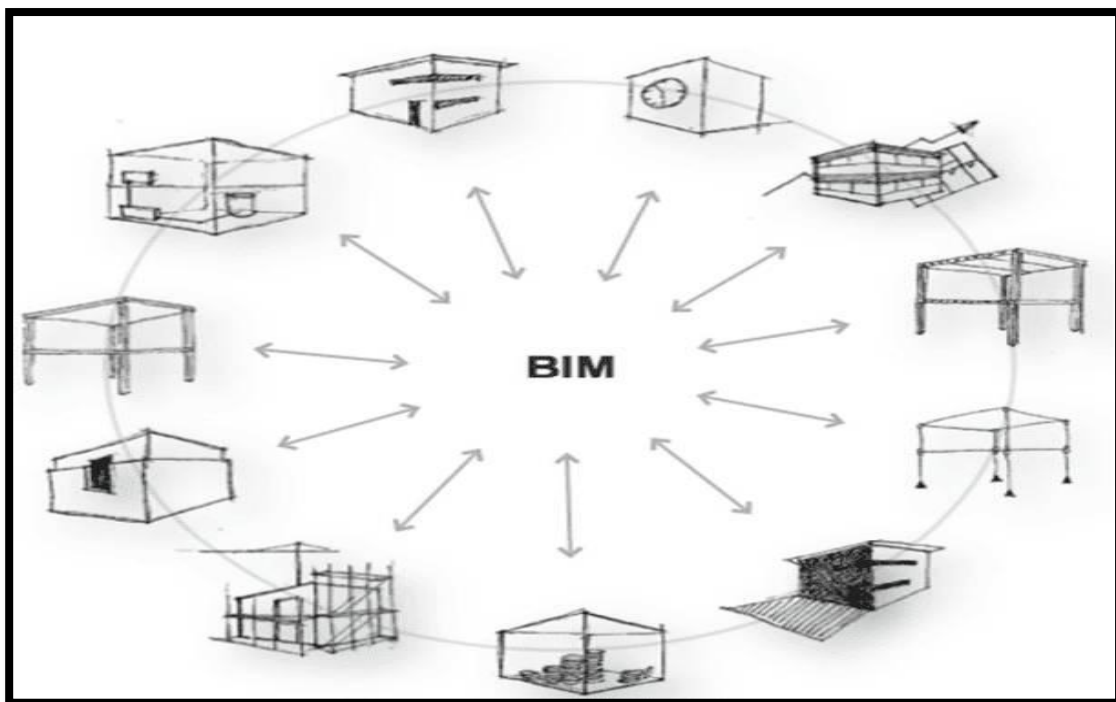


Figure 4.10: Building Information Modeling (Llorens et al. et al., 2018)

As shown in Figure 4.10, through simulation, BIM provides a virtual tour of building design and management processes before work begins and enables all involved professionals to participate actively in this process and improve

communication and error detection. In the current research, we have included this form by examining various aspects of the building and the information on Martian buildings required in the study, and the relevance of that research topic is obvious (Llorens et al. et al., 2018).

In the past decades, there has been a growing interest in the construction sector to use Building Information Models (BIM) due to the many benefits and resource savings during the design, planning, and construction of new buildings (Gray et al., 2013). The development of 3D⁴¹ Modeling began in the 1970s and was based on early computer-aided design (CAD⁴²) efforts in several industries. While many sectors developed integrated analysis tools and object-based parametric modeling (which is the core concept of BIM), the construction sector was for some time limited to traditional (2D)⁴³ Design (Sacks et al., 2018).

The construction industry now has advanced and more accurate programs that can do better detailing, such as the JACAD program, which combines descriptive geometry studies with CAD (Barrera-Vera et al., 2008).

BIM modeling was introduced in pilot projects in the early 2000s to support building design by architects and engineers (Wang et al, 2024). As a result, major research trends focused on improving planning and design, collision detection, visualization, quantification, costing, and data management (Wassouf et al., 2006). Recently, the specialized tools of the design, architecture, and engineering professions have joined essential functions such as energy analysis, structural analysis, planning, progress tracking, and workplace safety.

BIM has previously focused on planning, designing, constructing, and delivering integrated building and infrastructure projects. Although, more recently, the

⁴¹ 3D: three-dimensional graphics: height, width, and depth, <https://www.splashlearn.com/math-vocabulary/geometry/3-dimensional#:~:text=In%20geometry%2C%20a%20three%20dimensional,same%20as%20thicknes%20or%20depth.>

⁴² CAD: computer-aided design

⁴³ 2D: two-dimensional graphics: height, width, <https://divaki.com.ua/en/articles/2d-and-3d-graphics-which-style-to-choose-for-the-video/>

research focus has shifted from early life cycle (LC)⁴⁴ Phases to maintenance, renovation, demolition, and end-of-life considerations. The change is particularly complex (Becerik-Gerber et al., 2012).

Buildings and structures vary in terms of use (e.g., residential, commercial, urban, infrastructure), age (e.g., new, existing, heritage), and ownership (e.g., private owner, housing association, authorities, universities). Due to the needs of stakeholders, these different (framework) conditions affect the application of BIM, its level of detail (LoD), and its supporting functions regarding design, construction, maintenance, and deconstruction processes.

According to recent surveys, BIM is suitable for larger and more complex buildings and is used by recent survey respondents in commercial, residential, educational, healthcare, and many other building types. Although less than 10% of respondents are facility managers, owners, or builders, these trends do not necessarily reflect the current use of BIM in existing buildings (RICS, 2013).

Although BIM implementation requires profound changes in the processes of the parties involved, the benefits of new construction projects for both private and institutional owners are diverse and often acknowledged by the stakeholders involved. Significant benefits include design consistency and visualization, cost estimation, collision detection, lean construction implementation, and improved stakeholder collaboration. Essential challenges in new buildings refer to the shift from design-bid-build processes to integrated project delivery (IPD)⁴⁵ Moreover, it increased the time and knowledge required to use BIM.

BIM is in the building and construction industry, which faces significant challenges and obstacles to increasing productivity, efficiency, quality, and sustainable development (Llorens et al., 2018). The potential benefits of BIM in FM appear significant, such as valuable 'as-built' (legacy) documentation, warranty and service information maintenance, quality control, assessment and monitoring, energy and

⁴⁴ LC: life cycle

⁴⁵ IPD: integrated project delivery, <https://leanconstruction.org/lean-topics/integrated-project-delivery-ipd/>

space management, emergency management, or retrofit planning. Decontamination or demolition processes can also benefit from up-to-date building structural information to reduce errors and financial risk (Volk et al., 2014).

Several types of information are necessary to manage a facility or perform retrofitting measures on buildings. Apart from contact and general building information, detailed information about installed parts and equipment, such as service areas, date of installation, type of installation, vendor or manufacturer, exact geometry and location, materials and compositions, physical properties, warranties, and maintenance of the item, is needed.

History since completion When LC construction is completed, more information on occupancy history, actual and detailed (hazardous) material information, component mass and connections, recycling or disposal options, potential recycling quality, load-bearing structures or demolition techniques with time and The costs associated with each component are relevant for planning demolition. Multiple responsible stakeholders and subcontractors are involved during a building LC, and their expertise is often outsourced. In the installation of parts (Cheng & Ma, 2012).

Since the Building Information Model (BIM) is a tool to manage detailed building information in the whole LC, it is sufficient to support the data of maintenance and construction processes. Since BIM was initially intended to support the design and construction processes, some information, such as load-bearing structures, is already recorded in the existing BIM. In contrast, others, such as (LCA⁴⁶) information, may be added or added for a required function. Since introducing the (COBie⁴⁷) international standard, stakeholders can store maintenance information in BIM in a structured way and so in a valuable form of facility documentation (Liu et al., 2012).

In many existing buildings, incomplete, outdated, or fragmented building information prevails. Missing or obsolete building information may lead to

⁴⁶ LCA: Life Cycle Analysis, <https://sphaera.com/resources/glossary/what-is-a-life-cycle-assessment-lca/>

⁴⁷ COBie: Construction Operations Building Information Exchange, <https://www.thenbs.com/knowledge/what-is-cobie>

inefficient project management, uncertain process results, and wasted time or increased maintenance, retrofit, or modification costs. As existing buildings often need more as-built documentation due to omitted upgrades, limitations to using BIM in existing buildings and research challenges are expected (Gursel et al., 2009).

4.2.1. Definition Building Information Modeling

Building Information Modeling (BIM) is defined by international standards as "a common digital representation of the physical and functional characteristics of any built object that forms a reliable basis for decisions." BIMs originate from product models widely used in the petrochemical, automotive, or shipbuilding industries. BIM enables the study of actual buildings almost across LC and all its metric issues. Also, nowadays, they allow us to study both their quantitative and qualitative features and show enriched and compatible digital building models (Chias P. et al., 2019).

BIM is realized with object-oriented software and consists of parametric objects representing building components. Objects may have geometric or non-geometric features with functional, semantic, or topological information (Lu et al., 2021). For example, functional characteristics can be installation time or costs, such as storing semantic information. Connection, aggregation, containment, or intersection information and topological features are provided as examples. Information about objects' location, proximity, coplanarity, or perpendicularity (Ali et al., 2022).

BIM can be seen from a narrow and broader perspective. BIM in the narrow sense ("small BIM," "tool") only includes the digital building model itself in the mind of a central information management center or repository, its issues, and model creation (Donath, 2009). In a broader sense, this tool enables you to create a clone of the managed world and experiment with it before developing it at full scale. These programs, including design, create a little virtual reality in which predictions are made using numerous recommendations (Raposo et al., 2008).

Commercial BIM platforms offer integrated data management, component libraries, and generic functions. Broad distinctions of BIM include 3D (spatial model

with quantitative take-off), (4D)⁴⁸ (plus construction planning), and (5D)⁴⁹ (calculation plus cost) BIM (Cerovsek, 2011).

In Figure 4.11, BIM's functional, technical, organizational, and informational issues are displayed. These are some of the main criteria in This Research and have been addressed. All dimensions of technology must be evaluated before it can be used, and its connection with the current study is quite clear.

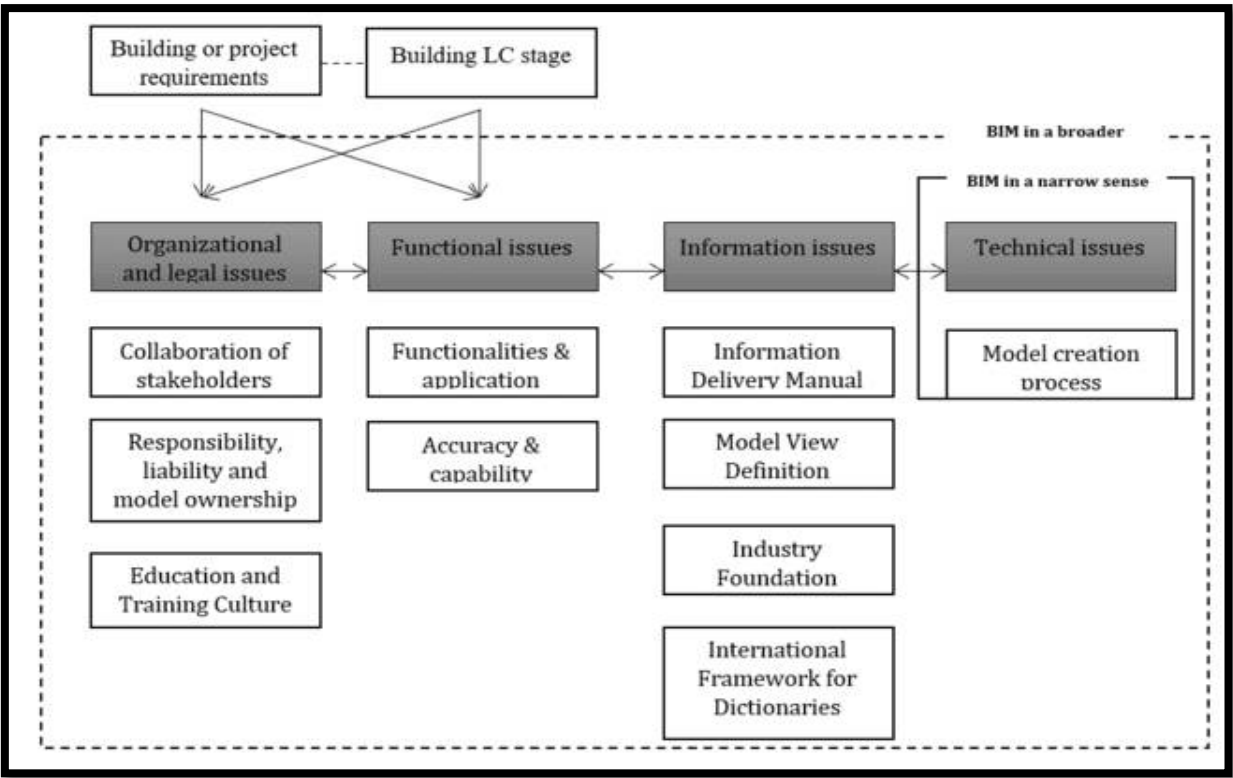


Figure 4.11: Relationships Between The LC Phase As Well As The Functional, Informational, Technical, And Organizational Issues of BIM (Author)

BIM is developed in several LC stages for new buildings, from inception, brief, design, production (Case I), and part of project delivery. Because BIM is sometimes

⁴⁸ 4D: four-dimensional space of length, width, and height, plus time, <https://www.merriam-webster.com/dictionary/fourth%20dimension>

⁴⁹ 5D: five-dimensional way of showing the physical & functional aspects of any project, <https://www.letsbuild.com/blog/5d-bim-in-construction>

only used by some (AEC/FM⁵⁰) stakeholders in a building LC, some of whom create isolated BIMs for a specific purpose.

Depending on the availability of pre-existing BIM in existing buildings, the BIM can be updated (Case II) or recreated (Case III). In Europe, more than 80% of residential buildings were built before 1990, and most still need construction documentation in BIM format (Eldeep et al., 2022). So, if implemented in practice, costly and primarily manual reverse engineering processes ("points to BIM," "scan to BIM") (Case III) help to recover building information.

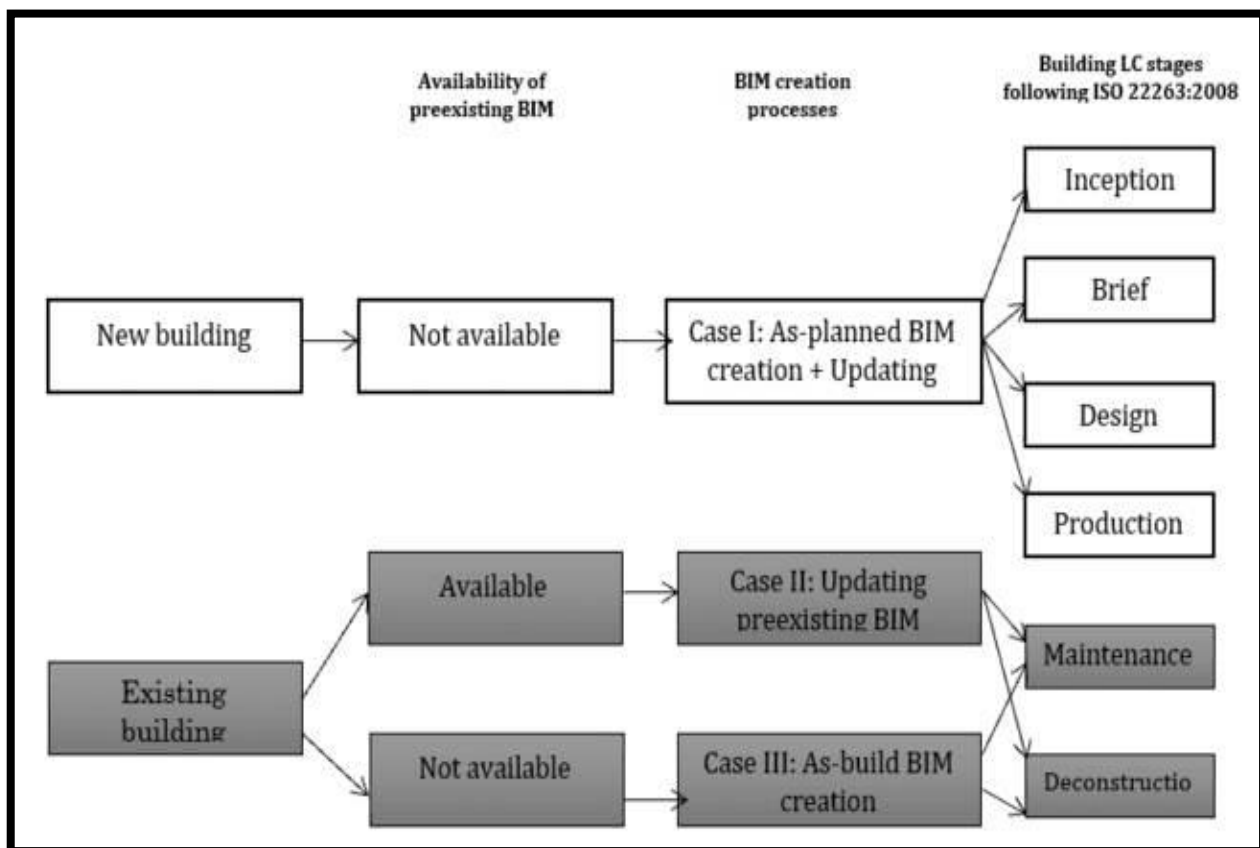


Figure 4.12: BIM Model Creation Processes In New Or Existing Buildings Depending On Existing, Pre-Existing BIM And LC Phases With Relevant Requirements (Author)

Figure 4.12 shows the BIM creation process. The formation of any building must be evaluated to determine whether BIM is to be used. This Research should explain

⁵⁰ AEC/FM: Architecture/Engineering/Construction (AEC) and Facilities Management, <https://www.trade.gov/architecture-and-engineering-services#:~:text=Overview,multi%2Dbillion%2Ddollar%20projects.>

this picture because a building information control model based on BIM is being prepared and formed for Martian buildings.

In a broader sense, BIM can be divided into related functional, informational, technical, and organizational/legal issues. Depending on the needs of the stakeholders and project requirements, a BIM model is used to support and perform specialized services for buildings, such as energy or environmental analysis. Therefore, two types of expert software may interact with a BIM model: (1) data entry applications that provide services for importing, recording, and monitoring data, processing data, or converting captured data to BIM, or (2) applications that Report or technical data output. Analyzes include structural and energetic analysis or collision detection (Begić & Galić, 2021).

4.2.2. BIM Implementation And Research Approach In Existing Buildings

This section explains BIM in a broader sense, with its functional, informational, technical, and organizational/legal issues in building maintenance and demolition. Apart from depicting state-of-the-art implementation, we present current research approaches and identify future research areas.

4.2.3. Functional Issues

Functional difficulties in Building Information Modeling (BIM) present substantial barriers to its adoption and practical implementation in the architectural, engineering, and construction (AEC) industry. Key obstacles include interoperability between software platforms, a need for defined methods resulting in inconsistent workflows, and worries about model complexity, expertise shortages, legal uncertainty, and cost-effectiveness. To address these problems, coordinated efforts must improve interoperability, promote standardization, and invest in industry professionals' education and training programs. Clear contractual agreements and regulatory frameworks are also required to reduce the risks associated with BIM deployment. The AEC sector will fully realize BIM's potential for improving project collaboration, efficiency, and innovation in the built environment by addressing these functional concerns.

4.2.3.1. Applications of BIM on Construction

Due to the numerous designs, engineering, construction, maintenance, and demolition services involved in building LC, BIM's potential applications and required functions in buildings and infrastructure are diverse. Depending on the needs of the stakeholders and the project, BIM, architectural, construction, plumbing, electrical, structural, construction, or supervisory functions are required.

Functions are either inherent in 3D, 4D, or 5D BIM (such as quantity takeoff, scheduling, or costing) or are attached to BIM as standalone expert applications. Expert capabilities use the underlying BIM data to support, extend, calculate, or simulate specific business requirements (such as performing structural analyses). The results are either integrated back into the BIM or reported separately. Functions are based on process maps that describe the logical flow of information and activities as well as the role of stakeholders in a specific function (Wei et al., 2021).

Due to the primary application of BIM in new construction, functional functions are focused on design and visualization, procurement, construction, construction management, and coordination rather than commissioning, facility management, or demolition. However, recently, the planning and handover processes have changed from design-as-built to integrated project delivery (IPD) in a collaborative environment, considering the value of "as-built" BIM information for FM, retrofit, and renovation processes (Becerik-Gerber & Rice, 2010).

With the stagnation of the rate of new construction in industrialized countries, planning and implementing renovation and retrofitting measures in existing buildings has become more critical. Various digital tools, such as 2D/3D geometric maps, accelerometers, laser scanning, and automatic image location, are available for building recording and auditing. However, they require increased modeling and planning efforts by skilled personnel.

Existing maintenance functions—so-called computerized maintenance management systems (CMMS)⁵¹ or computer-aided facility management (UniClass⁵²) focus on data management, maintenance schedules, and equipment warranties for complex buildings, but are rapidly developing. have found that Due to deterioration and cause-effect relationships, some FM systems include laser scanning of existing facilities and two-way information flow between geographic information systems (GIS)⁵³ And maintenance data (Wei et al., 2021).

While there have been many research efforts on FM and BIM-related topics, industry-wide implementation still needs to be done. As mentioned earlier, most of the FM's renovation and deconstruction research approaches require an existing BIM for a recently constructed building. If there is a BIM of the designated structure, the functions and processes of planning and carrying out conversions, renovations, and demolitions may be performed with more minor adjustments. However, only an old or no BIM is available. In that case, processes begin with a building audit, document review, and analysis of previous and current building features to provide an in-depth basis for planning and cost estimation.

Although digital cost estimating, quantity surveying, data management, and reporting tools are used in the construction industry, BIM functions include deconstruction, vulnerability and collapse analysis, emergency management, localization or documentation of hazardous or polluting materials, and planning. Risk scenarios are still rare in the literature.

Other potential BIM functions such as demolition execution planning and progress tracking, recycling and rubble management, auctioning of secondary parts and raw materials, recycling network logistics, monitoring hazardous components, or automatic reporting to authorities still need to be covered. One reason may be the

⁵¹ CMMS: Computerized maintenance management system, <https://www.ibm.com/topics/what-is-a-cmms>

⁵² UniClass: Computer Aided Facility Management, <https://www.thenbs.com/knowledge/what-is-uniclass#:~:text=Uniclass%20is%20a%20unified%20classification,by%20NBS>

⁵³ GIS: Geographic information systems, <https://education.nationalgeographic.org/resource/geographic-information-system-gis/>

low participation of facility, retrofit, and demolition managers in developing BIM functions (Lee & Chong, 2021).

Another reason may be due to the COBie and (OmniClass)⁵⁴ Standards define several properties and attributes to support maintenance processes but only partially enable deconstruction and recycling capabilities (such as destruction date, recycling date, ease of relocation, or removal). Materials Specifications). Analysis of the OmniClass properties showed that many of the properties defined for constructors and their processes can be easily adapted to the destructor requirements, e.g., lead times and idle times, remanufacturing and shipping costs, remanufacturing and recycling methods, or resource constraints for deconstructors. However, the deviations, damages, or effects of deterioration have yet to be depicted and require further research (X. et al., 2021).

As functions require detailed information about objects, relationships, and attributes in BIM, maintaining and updating information in BIM remains a significant challenge and research area. Due to the long lifespan of buildings and infrastructure, recent research also addresses BIM model evolution, continuous model maintenance, temporal data management, and interoperability with BIM development and specialist software.

4.2.3.2. Accuracy and Capability

BIM functions require accuracy, information richness, and realism in the underlying data to realize their goals. A concept often mentioned to describe the information richness of BIM objects is called "level of detail" or "level of development" (LoD). LoD defines the geometric and non-geometric characteristics of information a model component provides, often referred to as a point in time, an LC step, or a contractual responsibility.

To enable, for example, analysis or scheduling functions, the required LoD of object attributes and relationships must be defined, such as durations, dependencies, or priority information (Koo & O'Connor, 2022). LoD increases during the LC phases

⁵⁴ Omniclass: facilities management, and to provide a classification structure for databases, software, and building information modeling (BIM)

from initiation to production/construction in new construction projects, depending on changing requirements and modifications from draft to execution.

The literature defines performance-related LoDs for general modeling, 3D imaging, and energy performance. In existing buildings, it determines the performance requirements of the LoD and the cost and effort involved in creating BIM. For maintenance functions, the Construction Operations Building Information Exchange (COBie) standard defines a LoD for technical equipment concerning type and location, make, model and serial number, label, installation date, warranty, and scheduled maintenance requirements. Slow (Klein et al., 2012) defines a 2% geometric deviation for maintenance plans, but LoD does not provide non-geometric information.

Adequate LoD has yet to be defined for demolition functions (including rubble management). Beyond LoD, several BIM evaluation frameworks, such as CMM6, CMMI, PCMM, Object/Element Matrix, or ISO/IEC 15504 (SPICE), are under development (Bedrick & Davis, 2012). As ISO/IEC 15504 formulates process evaluation in general, the Capability Maturity Model (CMM)⁵⁵ It is used in BIM contexts to assess whether BIM projects or processes reach the desired performance level.

The CMM assessment framework assesses the minimum capabilities and requirements of the BIM model and process maturity, with ten BIM maturity levels defined for the categories (Cirillo et al., 2024): spatial capability, roles and disciplines, data richness, delivery method, change management or maturity assessment, business process, information accuracy, cycle views, lifetime, graphical information, timeliness, and responsiveness, as well as industry-class interoperability and support (Ganah & Lea, 2021).

Professional associations try to define and harmonize related concepts and ratings to measure BIM data needs and capabilities. Although, a standard evaluation framework for BIM for new and existing buildings has yet to emerge.

⁵⁵ CMM: Capability Maturity Model,
<https://www.techtarget.com/searchsoftwarequality/definition/Capability-Maturity-Model>

4.2.4. Information and Interoperability Issues

Expert functions are linked to a BIM model through the Information Delivery Guide (IDM)⁵⁶ and Model Display Definitions (MDV)⁵⁷ Frameworks by providing relevant information, facilitating data exchange, and avoiding ambiguities. The IDM and MVD frameworks specify the storage, transformation, and exchange of information in BIM and so form the link between functional, technical, and organizational issues.

The Exchange Requirement Model (ERM)⁵⁸ Describes information flows concerning requesting users in their roles, information related to a defined process, information flow moment, content, and user/recipient role. Non-proprietary standards such as the Industrial Foundation Classes (IFC)⁵⁹ (ISO/PAS 16739) and the International Framework for Dictionaries (IFD)⁶⁰ (ISO 12006-3) enhances data exchange between different BIM systems at the object level, reducing information loss.

Schemes such as UniClass and OmniClass structure and unify the information content of organizational roles, project steps, services, or component attributes. The following sections detail the related information issues (Bastos et al., 2021).

4.2.4.1. Information Delivery Manual (IDM) framework

The IDM framework defines the exchange of performance-related process information in BIM through process maps, interaction maps, and the associated Exchange Requirement Model (ERM). Process maps describe the flow of activities

⁵⁶ IDM: Information Delivery Guide, <https://www.thenbs.com/knowledge/what-is-an-information-delivery-manual-idm#:~:text=It%20is%20the%20Information%20Delivery,processes%20to%20be%20carried%20out.>

⁵⁷ MDV: Model Display Definitions, <https://www.degruyter.com/document/doi/10.1515/jib-2018-0010/html?lang=en>

⁵⁸ ERM: Exchange Requirement Model, [https://www.investopedia.com/terms/e/exchange-rate-mechanism.asp#:~:text=An%20exchange%20rate%20mechanism%20\(ERM\)%20is%20a%20way%20that%20governments,or%20the%20influence%20of%20inflation.](https://www.investopedia.com/terms/e/exchange-rate-mechanism.asp#:~:text=An%20exchange%20rate%20mechanism%20(ERM)%20is%20a%20way%20that%20governments,or%20the%20influence%20of%20inflation.)

⁵⁹ IFC: Industrial Foundation Classes, <https://www.buildingsmart.org/standards/bsi-standards/industry-foundation-classes/>

⁶⁰ IFD: International Framework for Dictionaries, <https://atlan.com/what-is-a-data-dictionary/#:~:text=A%20data%20dictionary%20includes%20technical,setup%20process%2C%20and%20best%20practices.>

on a specific topic, the roles of actors, and the information needed, created, and consumed, while interaction maps define the roles and transactions for a particular purpose or function. ERM is the technical solution that represents “a set of information to be exchanged to support a specific business need” or function and is related to (MVD) (Jeon et al., 2021). However, IDM frameworks are not yet defined for maintenance or deconstruction processes.

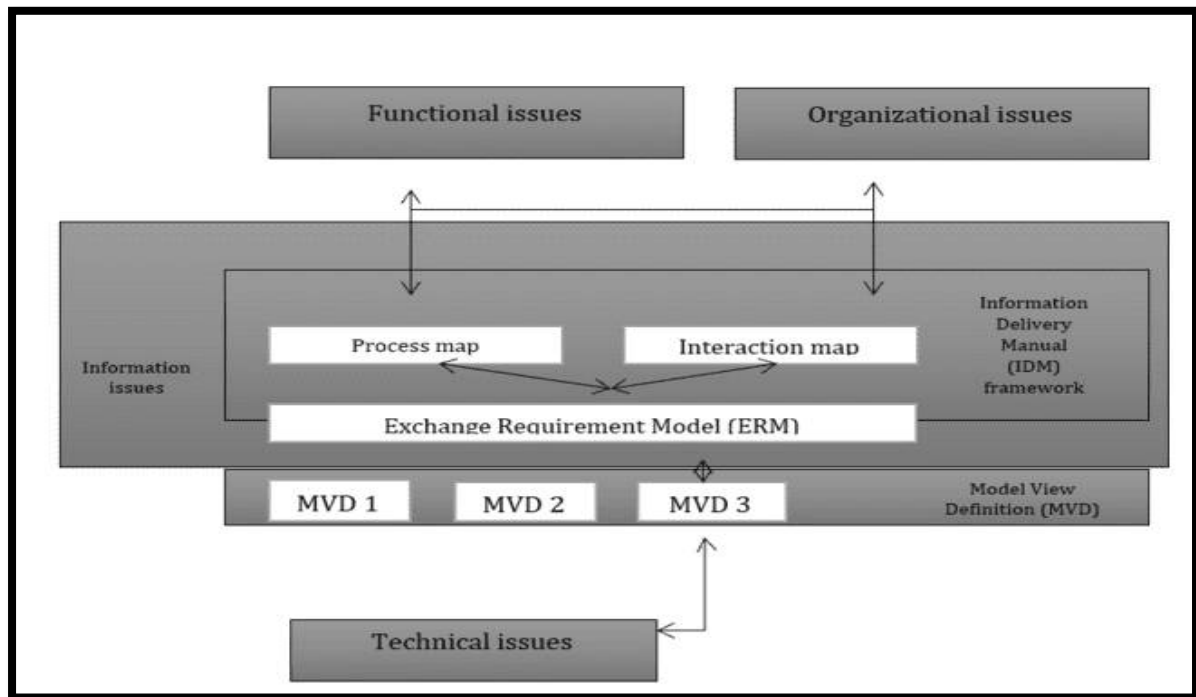


Figure 4.13: Information Delivery Guide (IDM) Framework (ISO 29481-1:2010⁶¹) And Its Relationships With Functional, Technical, And Organizational Issues in BIM (Author)

Figure 4.13 shows the relationship between information and functional and technical developments in BIM. It is constantly changing, and this subject must be transformed in BIM. Due to the atmospheric conditions of Mars and the many changes in the environment around the buildings, you have to build the BIM and, therefore, realize that this image is fully functional now.

⁶¹ ISO 29481-1:2010: Organization and digitization of information about buildings and civil engineering works, including building information modeling (BIM)

4.2.4.2. Model View Definition (MVD)

A Model View Definition (MVD)⁶² The IFC View Definition defines "a subset of IFC required to meet one or many of the AEC industry's interchange requirements" (Gan, 2022). An MVD structures the relevant information for the efficient flow of information between stakeholders in building-related processes, for example. The energy or structural analysis of the MVD definition depends on the performance required and the BIM objects and features referenced in the process and interaction maps.

For maintenance purposes, COBIE MVD is the dominant, vendor-neutral international standard for exchanging contact information and public facilities and information about spaces, floors, areas, components, technical systems, and equipment.

Recently, this standard has been supplemented with a responsibility matrix that assigns the required data types to responsible individuals or roles. Because COBie contains general building information, spaces and areas, and equipment-related information such as geometry, location, certificates and warranties, performance data and test results, preventive maintenance, safety, and emergency plans or instructions, On/off, it can be seen as a core model with domain-specific exchange requirements and extensions.

For example, As shown in Figure 7.5, the development of WSie is planned to provide performance information about flow rates or other control information (Pinheiro et al., 2018). Since many MVDs refer to the requirements of new buildings, the mentioned MVDs are only partially relevant and adequate in maintenance processes due to different needs and information structures.

⁶² MVD: Model View Definition, <https://technical.buildingsmart.org/standards/ifc/mvd/>

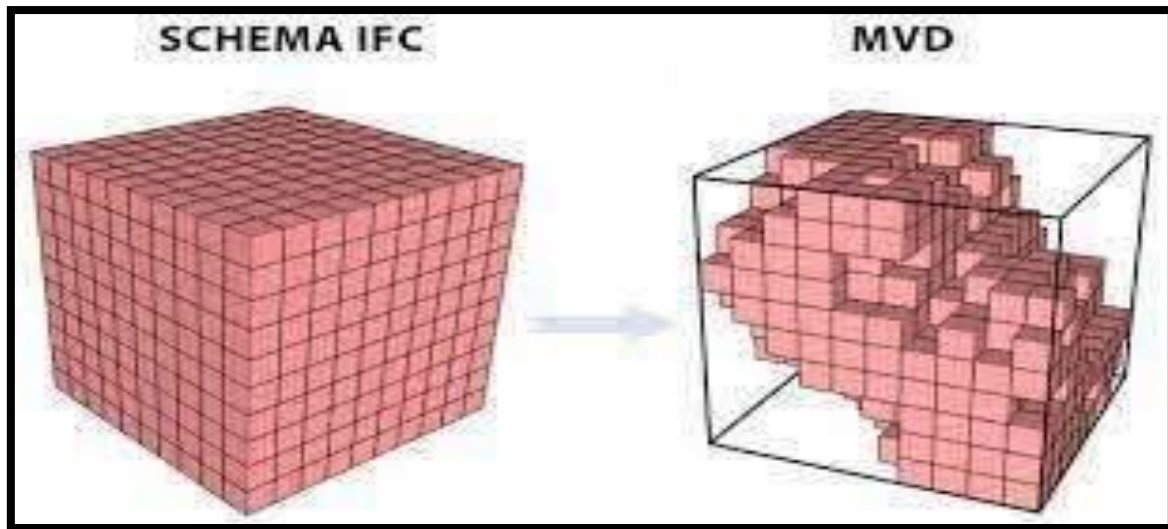


Figure 4.14: Model View Definition (MVD) (Pinheiro et al., 2018)

4.2.4.3. Industry Foundation Classes (IFC)

Data exchange is possible directly or through proprietary or non-proprietary exchange formats. (IFC) defined in ISO/PAS 16739, is the dominant non-proprietary interchange format for building information between AEC/FM software. It was developed to display building information on whole buildings (excluding demolition) and to facilitate data transfer between BIM modeling software (such as Autodesk or Bentley), IFC viewers (such as IFCStoreyView), and expert software programs (such as "Model"). Data exchange between source and receiving software systems is done mainly through proprietary translators with their data structures. Certifications such as openBIM⁶³ software solutions buildingSMART and NBIMS⁶⁴ With high interoperability IFC (Vieira et al., 2020).

BIM interoperability in different LC phases and functions still needs to be improved due to incomplete, other, or ambiguous IFC features, symbols, or contents. Expert applications often use one-way interfaces from the BIM model. Recent developments focus on implementing SPie.⁶⁵ Semantic Web technologies in open

⁶³ OpenBIM: collaborative process that is inclusive of all participants, promoting interoperability to benefit projects and assets throughout their lifecycle

⁶⁴ NBIMS: industry-consensus standard for the creation and use of building information models, <https://www.nibs.org/nbims/v4#:~:text=The%20purpose%20of%20the%20National,fostering%20streamlined%20communication%20among%20owners%2C>

⁶⁵ SPie: Society of Photo-Optical Instrumentation Engineers, https://spie.org/about-spie#=_

formats and ontologies such as HTML, XHTML, bcXML, gbXML, eCOGNOS, COBie, IFCXML, IFC, ifcOWL,⁶⁶ or CIS/2 to enable expert software. Although, most applications are still limited to academic use (Vieira et al., 2020).

4.2.4.4. International Framework for Dictionaries (IFD) Library

BuildingSMART Data Dictionary (bSDD⁶⁷) The International Framework for Dictionaries (IFD), defined in ISO 12006-3 and recently renamed BuildingSMART Data Dictionary (bSDD), is a terminological standard for BIM libraries and ontologies (Shayeghanfar et al., 2008). It is an object-oriented database of multilingual terms that define concepts used in the construction industry and related IFC properties, such as symbols for objects, parts, attributes, units, or values. Regional adaptations and customization of IFC are possible due to globally unique ID (GUID⁶⁸) tags defined by an international working group. IFD supports the interoperability of BIM content via GUIDs between BIM and project- or product-specific data (Jönsson, 2015).

ISO 12006 parts 2 and 3 structure BIM content, while OmniClass™ specifies BIM content based on AEC requirements in construction outcomes, construction resources, and construction processes (OmniClass, 2006). An in-depth analysis of OmniClass features revealed that some features representing existing buildings and related processes are still missing.

In Table 4.1, an MVD, or "Model View Definition," is a specific implementation level of IFC to describe a particular ease of use or workflow. The IFC scheme is designed to accommodate various configurations. For example, a wall can be represented as a line (or curve) segment between two points, as a type of 3D geometry for visualization and analysis (such as extruded solids or triangular surfaces), as simple forms or with specific construction details (taking individual studs, pipe joints, wiring, etc.), along with data such as engineering specifications, responsible parties, schedules, and cost information. Since software vendors implement an

⁶⁶ ifcOWL: International Finance Corporation OWL, <https://technical.buildingsmart.org/standards/ifc/ifc-formats/ifcowl/#:~:text=ifcOWL%20provides%20a%20Web%20Ontology,and%20XSD%20schemas%20of%20IFC>.

⁶⁷ bSDD: Building SMART Data Dictionary

⁶⁸ GUID: Globally Unique Identifier

MVD, MVDs are the basis for certification of MVD-based software. The software implementation is checked against the implementation agreements of an MVD. Therefore, it has been mentioned in this research because Martian buildings must comply with this structure.

Table 4.1: Model View Definitions (Author)

Model View Definitions (MVD)	Acronym
BIM Service interface exchange, (web services and server-client communication)	BIMSie
Building Automation Modeling information exchange (control and building automation systems)	BAMie
Electrical System information exchange (delivery of electrical power within facilities)	Sparkie
Equipment Layout information exchange	Elie
IFC2x3 Coordination View Version 2.0 (optional with Quantity Takeoff, Space boundary or 2D Annotation add-on view)	-
IFC2x3 Structural Analysis View (released)	-
HVAC (Heating, Ventilation, Air-conditioning, Cooling) information exchange	HVACie
Life-Cycle information exchange, with the refinement of Building Programming information exchange	LCie BPie
FM Basic Handover with Construction-Operations Building information exchange	COBie
Quantity Takeoff information exchange	QTie
Spatial validation	-
Water System information exchange	WSie

To explain Table 4.2, for a long time, everyone could build their own MVD and go to software vendors to implement it. This created a situation where multiple MVDs created are not interoperable and require more effort to implement in software tools. Software that supports example 1 (reference display) cannot automatically support example 2 (prefab). Software tools must update and extend their code to support multiple MVDs.

Table 4.2: IFC's Own Texts And Proposals Attribute Extensions To Describe Inaccuracies, Uncertainties, Or Future Processes And Treatments That Occur In Existing Buildings. (Author)

Areas	Potential IFC attribute extensions	
	(main category)	(subcategory)
Existing building audits and surveys	Uncertain/lacking information in captured data	• Clutter, measurement errors • Trees, shrubbery etc • Ground conditions like sloping ground • Damages, defects, or deterioration of building elements • Deviations in geometric or topological object information like uneven floors/walls or non-orthogonality; • Concealed and so assumed components and components' physical properties like detailed layers, structure, or (hazardous/contaminant) material composition • (Non-)loadbearing structures, containing relation, adhering relation, etc.
	Vegetation and site conditions	
	Uncertain/lacking information on BIM objects	
	Uncertain/lacking information on BIM relations	
Maintenance- and Deconstruction-related information	Location Properties	• Locations of sorting, recycling/reprocessing and disposal facilities, temporal storage facilities • Deconstruction lead and idle times • Deinstallation/dismantling costs • Object treatment costs, e.g., for reinforcement, repair, decontamination, reprocessing, recycling, disposal • Shipping costs to recycling/disposal facilities or other construction sites • Source limitations for deconstructors and decontaminators, like required operating and storage spaces • Methods of deconstruction or recycling • Equipment with their characteristic durations, costs, resources (personal, machines) • Dependencies and precedences in maintenance and deconstruction processes • Deconstructors' certifications • Consultant and authorities' properties, e.g., information requirements • Disassembly types and groups • Possible future or performed object treatments, e.g., reinforcement, repair, decontamination, reprocessing, recycling, disposal options • Structural behavior during deconstruction • Properties of sustainability, e.g., recycling material quality, recycling and disposal rates of building components, hazardous materials • Safety plans and prevention measures or deconstruction progress tracking • Noise, dust, or vibration emissions from deconstruction processes or other emissions according to LCA information with related prevention measures and costs
	Properties of time and money	
	Source properties	
	Product properties	
	Process planning	
	Possible future emissions	

Three (base) MVDs are IFC implementation levels: coordination view (IFC 2x3 and reference view (IFC 4.*), alignment-based reference view (IFC 4.3), design transfer view (IFC 2x3, IFC 4.*) Exchange requirements can be defined on top of the MVD (base). This increases interoperability between domains. There are several ways to describe computer interpretable exchange requirements. The buildingSMART IDS standard works hand in hand with IFC to define computer interpretable exchange requirements in each case. According to the above definitions and tables, it can be imagined that Martian buildings are also considered smart buildings, and these factors must be observed in them.

4.2.5. Technical Issues

As BIM is modeled in a limited sense to perform the functions required, for example, in maintenance or demolition, the technical issues depend on the LoD needed for the specified function. So, when applied to existing buildings, the performance-related LoD specifies the technical specifications for data collection, processing, and BIM model creation.

The BIM creation process can be differentiated between new buildings and existing buildings due to different building information quality, information availability, and functional requirements. For new buildings, the creation of an "as-planned" BIM model is an interactive and iterative process with commercial design or planning software, allowing for an update to an "as-built" BIM (Case I). As many of the existing buildings are relatively inadequate, pre-existing building documents or pre-existing BIM are updated (Case II), or a "point-to-BIM" process (Case III) is performed to collect and model the actual conditions of the building.

To create a built-from-scratch BIM (Case III), the geometric and topological information of the building elements must be manually collected, modeled, and supplemented with semantic property information. Existing buildings can benefit from using BIM if a reliable data collection technique can provide a built-in BIM at a reasonable time and cost regarding documentation, visualization, or facility management (Huber et al., 2011).

In Figure 4.15, for new buildings (Mars buildings are considered new buildings) and existing ones, there are different processes for creating BIM in those buildings that

should be investigated, and it is a requirement of This Research that they know (even if they are not related to the topic).

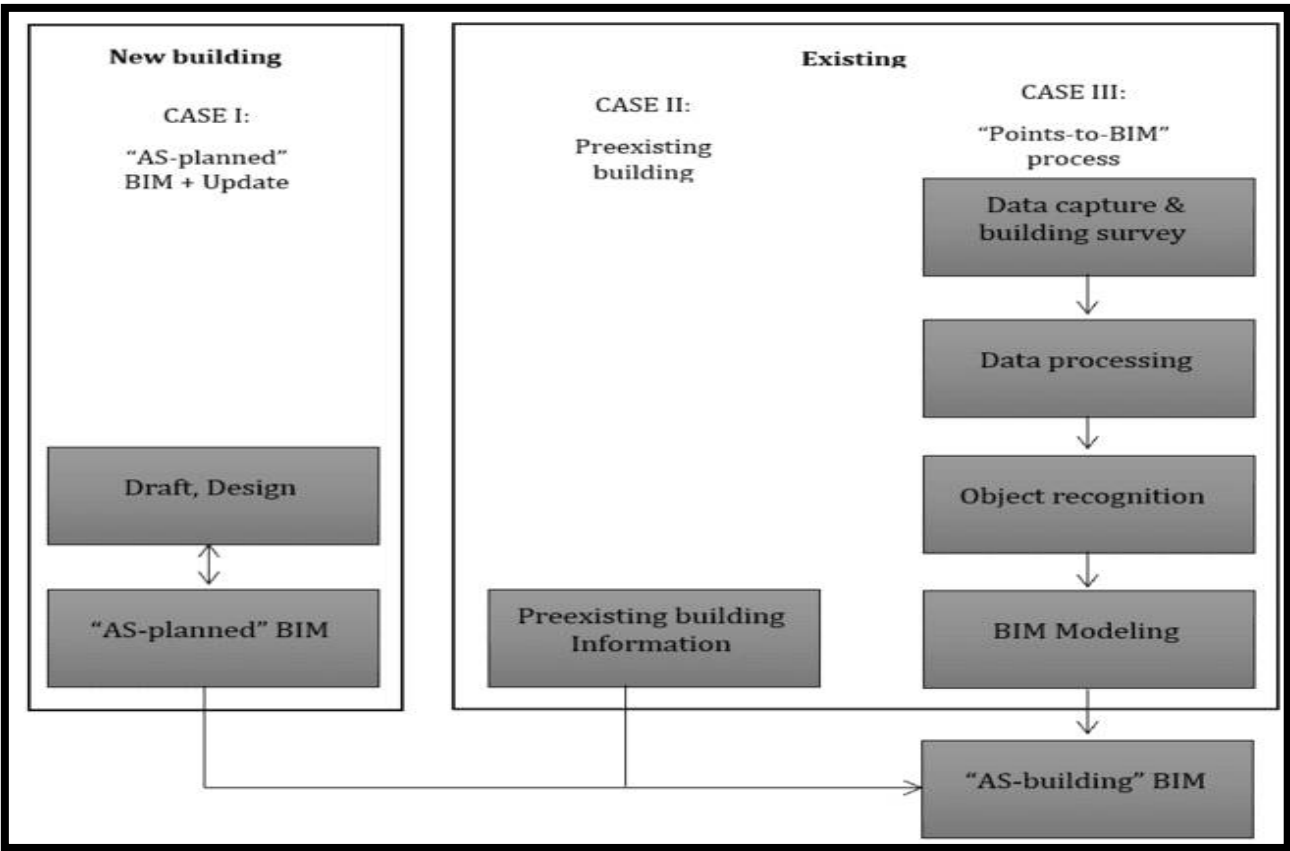


Figure 4.15: BIM Creation Processes For New And Existing Buildings (Author)

These three cases differ significantly in their potential modeling efforts. In most existing buildings, insufficient building information and the lack of pre-existing BIM lead to the use of Case III, which is discussed in more detail below.

4.2.5.1. Collecting Data

Data collection or survey techniques are used if building information is insufficient for the required functions. The required LoD determines all the following steps, from technique selection to model creation, due to its high impact on required data quality, data volume, and processing effort (Donath, 2009).

Figure 36 shows non-contact techniques further differentiated into image-based, range-based, hybrid, or other techniques. Contact methods include manual or other techniques. Image-based and range-based techniques mainly extract spatial, color, and reflectance information. In practice, semi-automated laser scanning is standard

with total stations. However, it has disadvantages such as high equipment cost, fragility, and difficulty scanning reflective, transparent, and dark surfaces. Furthermore, this technique requires more extensive data modeling and processing steps on conventional computers, and current approaches have relatively minor LoDs (Tzedaki & Kamara, 2013).

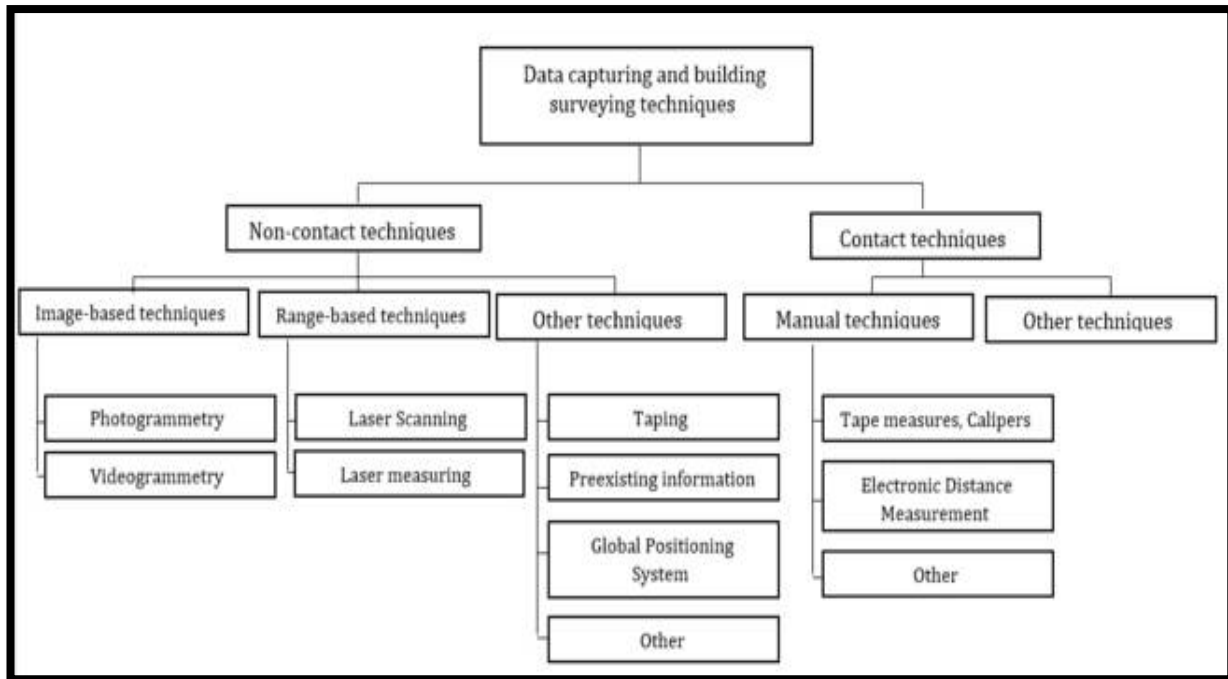


Figure 4.16: Systematic Review Of Data Collection And Analysis Techniques For Collecting Existing Building Information. (Author)

In Figure 4.16, the tools and methods that exist for collecting and analyzing information in BIM are discussed. It is obvious and evident that these steps should be studied so that a solution can be provided to create a proposed framework for collecting information and how to analyze it.

Manual techniques mainly record spatial and other information about the component. A few approaches focus on methods, such as tagging or using pre-existing building information to collect additional information, such as component dimensions, materials, textures, functions, connections, positions, or maintenance periods. RFID, or barcode tags, are primarily installed in new buildings because, in existing buildings, tagging is limited by installation effort (e.g., for retrofitting), readability range, and interoperability (Motamedi & Hammad, 2009).

This paper summarizes the main laser scanning, photogrammetry, and tagging data collection techniques relevant to research (Clemen & Grundig, 2009) and the defining characteristics for technique selection. The main factors are cost, time, LoD, and environmental conditions during data collection (e.g., light, weather, vegetation, concealment, and clutter). A combination of techniques is common and tries to overcome the drawbacks of individual imaging techniques (Frahm et al., 2010).

In practice, laser scanning is widely used to measure the dimensions of infrastructure and buildings and register and update city surfaces (Golovinskiy et al., 2009).

Table 4.3. Characteristics of the Main Data Collection Techniques In The Construction Sector (Author)

Decisive features	Data capturing techniques			
	Laser scanning	Photogrammetry	RFID tagging	Barcode tagging
Applicability in existing buildings	Yes	Yes	Limited	Limited
Cost	High	Medium	Medium	Low
Time	Medium	Fast	Fast	Fast
Spatial accuracy, Level of Detail (LoD)	High	High	Medium	Medium
Influence of size and complexity of the scene	High	High	Low	Low
Influence of environmental conditions	High	High	Low	Low
Import ability into BIM	Yes	Yes	No	No
Data volumes	High	Medium	Low	Low
Degree of automation	Medium	Medium	Low	Low
Operability	Low	Medium	Medium	Medium
Equipment portability	Low	High	High	High
Equipment durability and robustness	Medium	High	High	Medium

One of the essential points in Table 4.3 is that much of the information required in BIM must be collected during construction. It is obvious—quite obvious—that not much information may be available after the completion of a structure. Therefore,

this information should be collected while constructing Mars buildings, a significant and vital project. These techniques are also mentioned in the above table and are essential for this research.

Maintenance functions require a high LoD of parts, installed equipment, services, and appliances. Therefore, tagging for maintenance applications needs to be improved in terms of spatial accuracy, LoD, and degree of automation. Time and cost constraints are the primary determining features in deconstruction processes, but an associated LoD and appropriate recording technique have yet to be defined.

Recent research has focused on capturing geometric rather than semantic representations of buildings and feeding point cloud data in BIM software. However, new developments are heavily researching process models for automated BIM modeling from captured data ("scan to BIM") and improvements in LoD to increase applicability in existing buildings (Xiong et al., 2013).

To perform a comprehensive audit on existing buildings, the mentioned data collection techniques may be combined with other non-destructive testing methods to analyze materials and properties. Possible methods include material- or texture-based detection and detection of structure beyond the surface through ground-penetrating radars, radiography, magnetic particle inspection, sonars or electromagnetic waves, or tags installed during retrofitting.

4.2.5.2. Data Processing

As performance requirements determine the required LoD (Level of Development Specification) and so the data collection technique, performance affects data volume, processing, and associated time and effort. Data processing is performed to detect functionally relevant BIM objects in previously captured building data, e.g., identifying installations or connections for maintenance purposes.

Image and domain based point cloud data are registered, aligned, and integrated into a coordinate system during processing. This is mainly done interactively through defined coordinates or identified attributes such as descriptors or anchor points. Then, the data are cleaned of noise, irrelevant information, and clutter and are often detrended to improve computation time.

Data collected by other techniques is processed based on the data format, required functionality, and object detection method. Data processing to meet the functional requirements of maintenance or deconstruction of complex structures may take reasonable computing times due to increased LoD, high data volume, or the limited computing capacity of mobile devices.

Further advances in mobile device computing performance and research into outsourcing computing processes to cloud servers may speed up data processing (Ignatova et al., 2018).

4.2.5.3. Object Recognition

Collected and processed building data is used to identify building components and features related to required functions. Object recognition includes object identification, relational and semantic information extraction, and remaining concealments and clutter treatment. Object detection methods and tools vary due to the geometric complexity of the building, required LoD, applied imaging technique, data format, or processing time (Wu & Zhang, 2019).

Figure 37 shows data-based, model-based, and other identification methods. Data-driven approaches extract building information from captured and processed data and can be differentiated into feature-, shape-, material-based, and statistical matching methods. Model-driven approaches are primarily based on a predefined structure, like relationships or topological constraints, and perform data matching through background knowledge or information. Other methods include manual identification or tags. Some publications combine data- and model-based approaches to overcome the drawbacks of individual techniques.

Coarse, predominantly planar building components such as walls, roofs, floors, doors, windows, and clutter are detected in small single—or multi-room scenes with detection rates between 89% and 93%. However, research approaches try to improve LoD and detection rates further and manage data uncertainty through statistical (thresholds), contextual (semantic networks, relationships), or interactive (machine learning) methods.

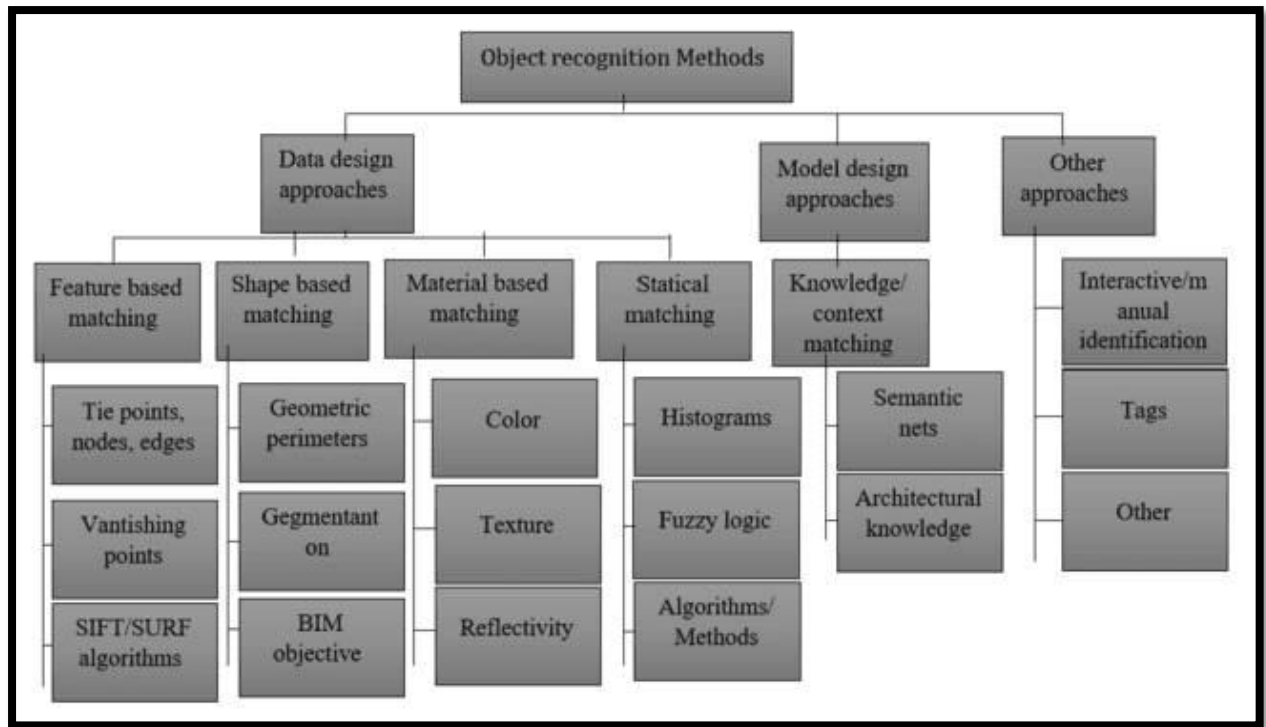


Figure 4.17: Systematic Review Of Object Recognition Approaches Used In Existing Buildings (Author)

Based on Figure 4.17, it can be concluded that the building's examination of walls, roofs, facilities, and other objects is part of BIM. In This Research, walls, roofs, and facilities have been investigated as objects entered into BIM in Martian buildings, and based on the shape, it can be understood that this is correct and should be considered more in a Martian building.

To enable maintenance functions, detailed information, e.g., in technical equipment (HVAC/MEP), such as the route of the ducts, installation date, and layers of materials or composites, is necessary. This information is not automatically detected in buildings with current approaches but requires intensive user input and interaction (Dickinson et al., 2009). however, other industries may offer promising approaches.

Recent research on deconstruction-related LoD focuses on structural components that may be identified in image—or range-based data. However, a higher LoD is required for complex functions, e.g., due to component connections, hazardous

components, component layers, or recycling quality, which requires high analytical testing efforts and user inputs.

4.2.5.4. Modeling

Modeling means creating BIM objects representing building components, including geometric and non-geometric properties and relationships. Suppose BIM is modeled based on previously captured building information. In that case, previous data collection, processing, and identification methods will affect the data quality through the established technique and LoD provided.

The generated models may be evaluated as examples to compare approaches and their modeling capacities. No standard BIM evaluation method has been developed to compare model quality according to modeling or diagnosis accuracy, LoD, or CMM6 (Zabin et al., 2020).

In practice, "as-built" BIM modeling is done interactively in a time-consuming and error-prone process, e.g., with BIM modeling software from several major vendors: Autodesk Revit and Navisworks, Bentley Architecture, Graphisoft ArchiCAD, Tekla, or Nemetschek Allplan. Although some allow rapid generation of building floor plans or offer BIM integration, the software solutions shown need to be more automated or semi-automated.

4.2.6. BIM Modeling In Automation Of Existing Buildings

In research, automated BIM modeling, or the transformation of surface models into volumetric, semantically rich entities, is in its early stages. Many reviewed publications deal with the semi-automatic modeling of building surfaces or components concerning their geometric representation. However, they still do not consider component features or semantic information. If non-geometric features such as functional, relational, economic, or semantic information of existing buildings are integrated into BIM, it is done interactively or semi-automatically (Xiong et al., 2013).

For example, Hidden building components such as ducts, pipes, or plumbing (HVAC/MEP) can only be modeled with top-user input. Due to the laborious BIM creation process, the creation of existing building models either focuses on coarse

building components or still needs to be implemented. In addition, high LoD, e.g., the requirement for specific maintenance considerations, is incompatible with current time and cost constraints in the (AEC/FM/D)⁶⁹ Sector. Furthermore, our review shows that object properties and relationships related to maintenance and deconstruction capabilities still need to be widely modeled, partly due to undefined properties, inaccessible object libraries containing older building components, or uncertain LoD.

Since skilled personnel and much effort are necessary for BIM modeling existing buildings, further research in automated recording, processing, and modeling can reduce the cost of building audits and increase productivity in BIM-based maintenance and renovation processes—Increase (Dickinson et al., 2009).

The concept of BIM and integrated product delivery (IPD) requires profound process changes in new construction. This also applies when using BIM in maintenance and renovation processes. This section discusses organizational issues that affect the implementation of BIM in existing buildings, such as stakeholder collaboration, contractual relationships, or liability (Sacks et al., 2018).

4.3. BIM Security

The security of BIM platforms is essential in collaborative project environments because sensitive project information is stored and distributed through them. Inappropriate sharing, leakage, or loss of sensitive project information, such as intellectual property, financial information, and client personal information, from shared BIM platforms may lead to severe consequences, such as economic loss and loss of trust and reputation.

In addition, security for BIM projects of buildings of national importance, such as military institutions, police departments, prisons, significant bridges, power plants, government buildings, and industrial buildings, is essential to prevent political and commercial espionage. However, the existing literature needs a comprehensive

⁶⁹ AEC/FM/D: Architecture/Engineering/Construction-Facility Management – Design, <https://www.trade.gov/architecture-and-engineering-services#:~:text=Overview,multi%2Dbillion%2Ddollar%20projects.>

study on BIM security that identifies the security requirements of common BIM platforms.

Figure 4.18 shows the essence of Blockchain technology and whether it can be combined with BIM. As mentioned many times in the previous chapters, we are looking for this issue in This Research.

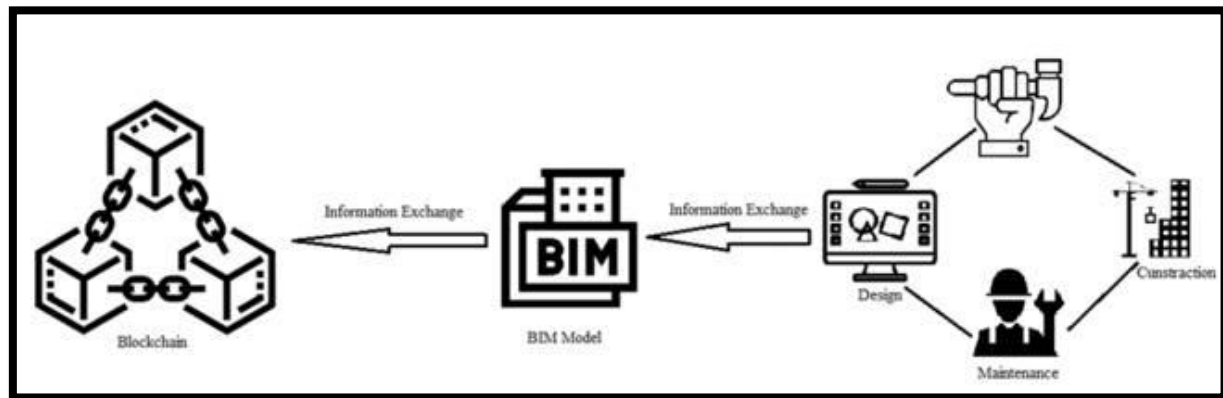


Figure 4.18: Blockchain + BIM (Author)

4.3.1. Common BIM Platforms

Due to their interdisciplinary nature, multiple data contributors and consumers, geographically separated stakeholders, network-based communication, and decentralized project organizational structure inherited from construction projects, they have special security requirements. Therefore, specific security risks or requirements arising from common BIM platforms' functional characteristics must be identified in order to design cybersecurity strategies for BIM security.

In the last decade, cloud-based services with standardized cybersecurity policies have gained popularity in various fields, including the construction industry for BIM. However, generic security solutions are unsuitable for addressing specific security requirements of common BIM platforms. The British Standard, ISO 19650⁷⁰, sets out recommendations on policies, people, processes, and technologies to secure data sharing in construction projects via shared platforms. However, it

⁷⁰ ISO 19650: international standard for managing information over the whole life cycle of a built asset using building information modeling (BIM).

does not explicitly address the cybersecurity requirements of common BIM platforms.

Research articles on BIM security should be more extensive in the available academic literature. Singh, Gu, & Wang (2011) introduced the concept of BIM security and argued in favor of considering cybersecurity principles, namely confidentiality, integrity, and availability (CIA)⁷¹, in the design of BIM servers. Olatunji (2011) has discussed the legal implications of cyber security breaches in sharing BIM data across different geographies and recommended that appropriate customized security strategies be developed.

(Afsari, Eastman, & Sheldon, 2016) Have identified security-related challenges such as liability and ownership in cloud-based BIM platforms. (Skandhakumar, Reid, Salim, & Dawson, 2018) have proposed an access control policy language called "BIM-XACML" to automatically link people, BIM objects, security violation conditions, and their corresponding consequences. However, their research should have included essential areas of BIM security, such as data integrity and data privacy for sharing multi-party BIM models and the impact of the distributed architecture of shared BIM platforms on their security.

(Parn & Edwards, 2019) presented a study on the cybersecurity of built environments and discussed the motivations of hackers to steal information related to the built environment. A comprehensive study that identifies and evaluates BIM security from the perspective of cybersecurity principles and characteristics of distributed environments, BIM practices, and the nature of construction projects still needs to be improved.

The current adoption of security practices and technologies for common BIM platforms is low and not systematic. Due to their system architecture and functional requirements, common BIM platforms have specific data security-related features necessary to devise cybersecurity management strategies for BIM (Ameen et al.,

⁷¹ CIA: confidentiality, integrity, and availability ,
<https://www.techtarget.com/whatis/definition/Confidentiality-integrity-and-availability-CIA#:~:text=In%20this%20context%2C%20confidentiality%20is,that%20information%20by%20authorized%20people.>

2024). For example, federated BIM model generation is one of the critical functional requirements of common BIM platforms to support various quality assurance requirements and standard procedures. Creating federal BIM models requires the aggregation of BIM data from multiple data owners, which ensures data privacy (protecting sensitive BIM data from unauthorized persons) and data transfer security (protecting data from interception and abuse during transit) and is confirmed. (version integrity and data freshness)-related requirements.

Therefore, shared BIM security requirements should be clearly and thoroughly defined to assess the current state of BIM security and serve as a road map towards achieving secure and functional shared BIM platforms in the future (Xue & Lu, 2020).

4.3.2. Security of BIM

This section presents the methodology adopted to extract literature from academic publications, standards, and guidelines related to the security of common BIM platforms. The review aims to identify the security requirements of common BIM platforms based on functional and user needs. Academic articles from two areas, namely (i) security-related features and processes of common BIM platforms and (ii) distributed system security, were extracted from Scopus, Web of Science, and Google Scholar.

4.3.2.1. Level I - Common BIM Features and Processes

Popular protocols for BIM-based collaborative design and management were reviewed, including (1) Framework Alliance Agreement, (2) BIM Coverage to the RIBA Outline, (3) UK BIM (CIC⁷²) Protocol, and (4) ConsensusDocs. In general, the primary purpose of these BIM protocols is to provide a high-level guide map to facilitate the use of BIM models and reduce the possibility of conflicts in construction projects.

Most existing BIM protocols include principles and guidelines on maintaining IP rights, setting specific deadlines, mandatory allocation of BIM deliverables from project participants, managing collaborative change, managing risk, and resolving

⁷² CIC: Construction Industry Council, <https://www.cic.org.uk/>

disputes. However, existing protocols need more detail and guidelines for project-level implementation.

Although the protocols lack definitive guidelines on information security, they address areas relevant to the security requirements of BIM-based collaboration, such as data ownership and transparency. Therefore, the guidelines in the protocols above require security requirements such as access control and data ownership in BIM models (Das, Tao, & Cheng, 2021).

4.3.2.2. Level II - Security of Distributed Systems

This section presents a two-step method for reviewing academic publications and identifying security-related characteristics of distributed environments. This process also identifies technologies commonly used to secure distributed systems.

In the first step, a search was conducted using the keywords "distributed system security" and "collaborative security" to identify the most common terms related to cyber security in distributed environments. As a result of this search, four popular technologies, namely (1) cloud computing, (2) encryption, (3) distributed database systems, and (4) Blockchain, were identified.

In the second stage, another round of keyword searches was conducted using the combination of the keyword "distributed system security" and keywords related to security technologies, namely "encryption," "cloud computing," "distributed database," and "Blockchain" (Das et al., 2021).

4.3.3. Security Components of BIM

This section presents BIM security components based on cybersecurity principles, drawn from features of common BIM platforms and distributed environments in general that are relevant to security. Data in distributed environments, such as shared BIM platforms, is exposed to cyber security threats and should be protected according to classical cyber security principles and existing BIM security standard specifications, including (1) confidentiality and (2) integrity. (3) availability, (4) originality, and (5) severability of BIM (Zhang, 2020).

The concept of "confidentiality" refers to the need to prevent access or use of data by unauthorized users, that is, to enforce data privacy in "storage" and during

"transmission" between system components in a distributed environment. Data privacy may be established by data access rights or data encryption protocols. "Integrity" refers to data integrity and immutability, meaning that data received by an end user in a distributed environment is incomplete (not partial) order and has not been tampered with. Data integrity may be implemented by managing data modification rights to restrict unauthorized users from modifying data.

"Authenticity" includes the authenticity of the data and the authenticity of the user, which refers to the assurance of the authenticity of the data and the authorization to create or verify the data, respectively. Data "availability" or availability is the guarantee that data is always available to its authorized users and is prevented from being hidden by malicious processes. The term "severability" refers to the cybersecurity considerations required to support confidentiality and integrity in processes that require the division and distribution of partial BIM models and data. Several methods, such as information validation workflows that require the distribution and validation of partial BIM models to various project participants, are necessary for the lifecycle of BIM models. Separability is strongly related to "data granularity," the smallest unit of BIM models that can be shared, updated, and encoded.

Therefore, the requirements of confidentiality, integrity, availability, authenticity, and severability of data for the characteristics of shared BIM platforms and distributed environments are applied to define the seven components of BIM security.

(1) Security "Data ownership" refers to the security measures required to ensure that the ownership of a piece of data in a BIM model is securely maintained with its creator throughout the BIM model's life cycle. A BIM model may have different contributors and consumers of data. Therefore, to facilitate data ownership on shared BIM platforms, security measures are needed to establish data modification rights to limit the ability of users other than the data owner to modify the data (Garzia & Lombardi, 2018).

(2) Security "Data Sharing" refers to the security measures required to facilitate sharing partial or complete BIM models with authorized participants. Therefore,

data sharing security requires that the data remain selectively private (data privacy) among its users, that end users do not receive incomplete data (data integrity), and that the data is always shared between users. Be available (data availability). For secure data sharing, project participants must have "domain-level access" to the data, i.e., full access to the data from their domain or organization and no access to other domains or organizations. However, the right to read or modify data may be granted to different end users within the same domain (Wang et al., 2022).

(3) Security "Model federation" refers to the security measures required to collect relevant BIM model information from different domains securely. The creation of federated BIM models is needed in construction projects to support various processes such as conflict detection, design coordination, and cost estimation [97]. Creating a federated model involves collecting data from different data owners and aggregating it. Therefore, end users must have "cross-domain level" access to selected data from other domains; so, that data can be aggregated as needed. So, security strategies are required to aggregate the latest relevant data from different domains by enforcing data integrity (data completeness), data privacy (cross-domain level read access), and data validity (data correctness in terms of "freshness" and version). Data severability and data availability (Tao et al., 2023)

(4) "Information workflow" security refers to the security measures required to assign and revoke permissions to project participants to review, approve, and discard data at various stages of a BIM model's life cycle. Information workflows in the context of BIM models are sequential processes that maneuver the movement of BIM data through multiple stages—Being 'created,' reviewed,' 'validated,' and 'archived.' Therefore, to facilitate workflow effectively, BIM data must be available for verification by end users (data availability). In decentralized environments such as shared BIM platforms, reliable approvals from authorized project participants are necessary to ensure the validity of information workflows (user authenticity). The reliability of the confirmations depends on the effectiveness of the security measures used to confirm the identity of the project participants. A security

strategy to facilitate consistent audit trail recording and change (data immutability) is also essential for shared BIM platforms (Erri et al., 2019).

(5) "Data security" refers to the security measures required to protect data regarding privacy and data integrity when stored on storage devices. "Data security" is influenced by the choice of storage technologies, such as block-based, file-based, and object-based storage systems. Block-based storage systems such as (Amazon EC2⁷³) store data in fixed-size blocks with block-level metadata for data access and updates. File-based storage systems store data in the form of files. On the other hand, object-based storage systems (e.g., Amazon S3) store data as discrete objects with object-level identifiers and metadata. From a security point of view, an object-based storage system provides rich metadata that can be used to categorize data into sensitive and non-sensitive groups at a finer level and use protocols (such as encryption) to protect data privacy, integrity, and data. Possession of sensitive objects (Nawari & Ravindran, 2019).

(6) "Network security" refers to the security measures required to ensure that complete (data integrity) and correct (data authenticity) data is sent by authorized participants (user authenticity) during data transmission. Network security is affected by the choice of security protocols used to protect data in transit and can be broadly classified as (1) perimeter security, (2) connection security, and (3) authentication security.

- "Perimeter security" refers to network security systems such as firewalls that monitor and control incoming and outgoing network traffic based on predetermined security rules. It acts as an intermediary between a network and a computer to prevent the execution of unwanted or malicious requests, ensuring data integrity.
- "Connection security" refers to network protocols such as Transport Layer Security (TLS⁷⁴) that ensure security in connection channels for data transmission. Network security protocols may also facilitate data privacy through encryption.

⁷³ Amazon EC2: Amazon Elastic Compute2

⁷⁴ TLS: Transport Layer Security, <https://www.internetsociety.org/deploy360/tls/basics/>

- "User authentication" refers to network protocols that verify the identity of the sender and receiver of data (the authenticity of the user) during data transmission and are of two types:
 - (a) one-way authentication and
 - (b) two-way authentication.

One-way authentication verifies the sender's identity, while two-way authentication adds another layer of security and authenticates the sender and receiver during data transfer (Peng et al., 2020).

(7) "System security" refers to security measures that maintain data integrity through predefined data structures and predefined rules for structured and unstructured data. System security can be facilitated through cryptographic checksums and database properties such as atomicity, consistency, isolation, and durability (ACID⁷⁵) for unstructured and structured data (Garzia & Lombardi, 2018).

4.3.4. BIM Security Levels

In this section, three levels of BIM security are defined based on the selection of BIM security components. The three levels of BIM security are (Figure 39):

- (1) level 1—unstructured file servers
- (2) level 2—structured file servers
- (3) level 3—structured database servers

The critical point is that BIM's security and security level should be evaluated in This Research. This research aims to determine the security and accuracy of information in Martian buildings. Figure 8.2 references security levels in BIM, and each of the levels is explained below.

⁷⁵ ACID: Advanced Construction Information Development,
<https://www.inmoley.com/NOTICIAS/2012345/2020-1-inmobiliario-urbanismo-vivienda/010-20-inmobiliario-022-20.html>

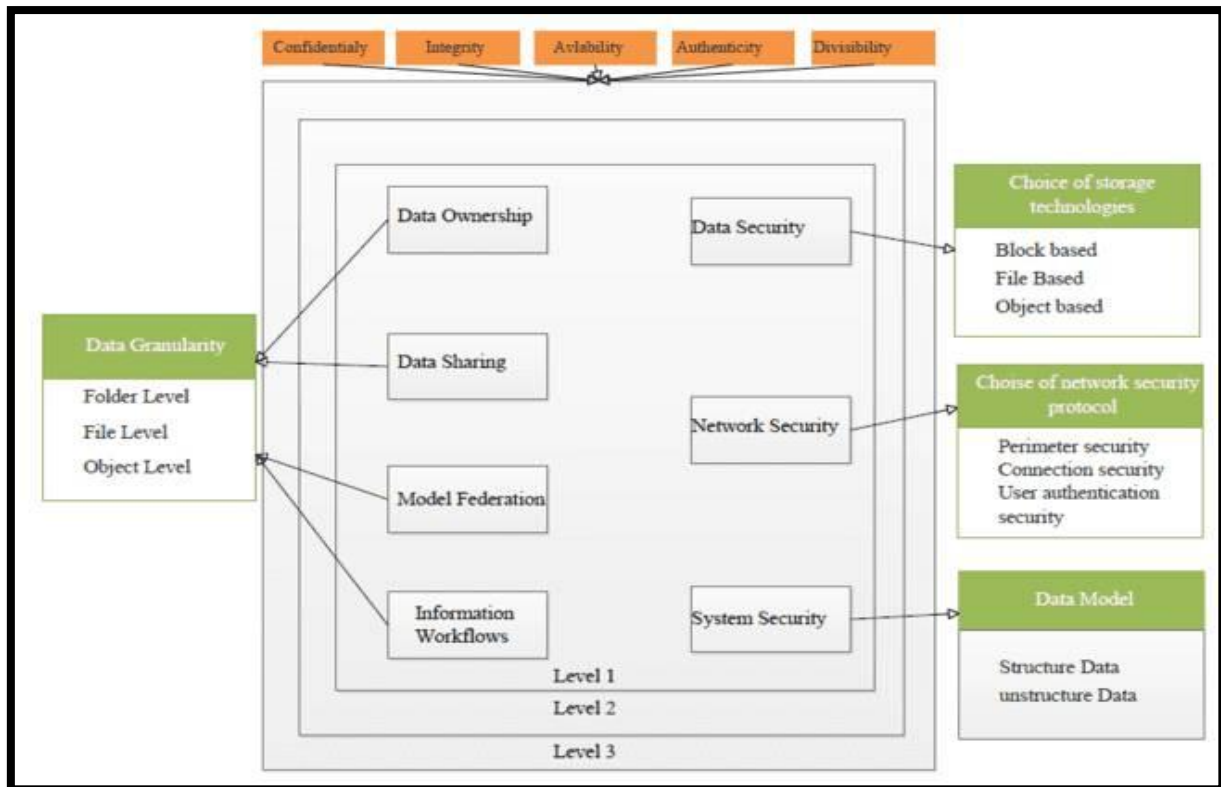


Figure 4.19: BIM Security Levels (Author)

4.3.4.1. Level 1 - Unstructured File Servers

Examples of unstructured file servers are file repositories, such as Dropbox, and internal files, which use file systems or similar technologies to store BIM models. A fundamental characteristic of unstructured file servers is that information needs to be organized according to a data model. At the application level, data is stored as BIM files and classified into sub-folders based on criteria such as data context, creation date, and ownership. For storage, data is usually aggregated into fixed-size blocks and dumped into storage devices. Unstructured file servers are very popular among small and medium-sized construction companies due to their low cost and ease of implementation.

However, from a BIM security perspective, unstructured file servers do not provide the necessary performance and security. Public, unstructured, or cloud-based file servers share physical storage units with organizations or departments. Separation is facilitated through logical units, which could be a more effective way to reduce data privacy. In addition, it is not easy to maintain system security due to the need for an application-level data model. For example, if a file is accidentally

or maliciously deleted, it is not easy to track the subsequent impact on resources related to the deleted file. In addition, it is challenging to facilitate information workflow and automatic model federation based on relationships between data units from multiple domains due to the need for a data model (Das et al., 2021).

4.3.4.2. Level 2 - Structured File Servers

Structured file servers store BIM data according to a predefined data model. The basic unit of data on such platforms is a "file." The (NBS BIM Toolkit⁷⁶) is an example of a structured file server where BIM files and project documents are linked and stored on a central server. Unlike unstructured file servers, structured file servers maintain relationships between files. Nevertheless, since the smallest unit of information is a file, such platforms need more functionality in facilitating information workflows or generating different combinations of federated models. For example, a subcontractor responsible for bricklaying may need to produce a federally detailed BIM model consisting of information such as geometry, location, schedule, and cost related to bricklaying. To do this, he needs to extract the geometry of building elements, such as walls and fireplaces, along with timing and cost information that may belong to different parties. However, unstructured file servers cannot facilitate optimal data reuse due to low granularity. Therefore, processes such as information workflow can only be facilitated at the file level. Structured file servers can implement data integrity through the ACID (atomicity, consistency, isolation, and durability) transaction properties inherent in most modern databases (Das et al., 2021).

Figure 4.20, like Figure 4.19, shows security levels in BIM. As mentioned, we often seek information security and accuracy in This Research. The difference between Figure 4.20 and Figure 4.19 is this. In Figure 4.19, all the levels are described in detail, and in Figure 4.20, the executive structure of these levels is displayed.

⁷⁶ NBS: National Building Specification, <https://www.nabicvalves.com/nbs/>

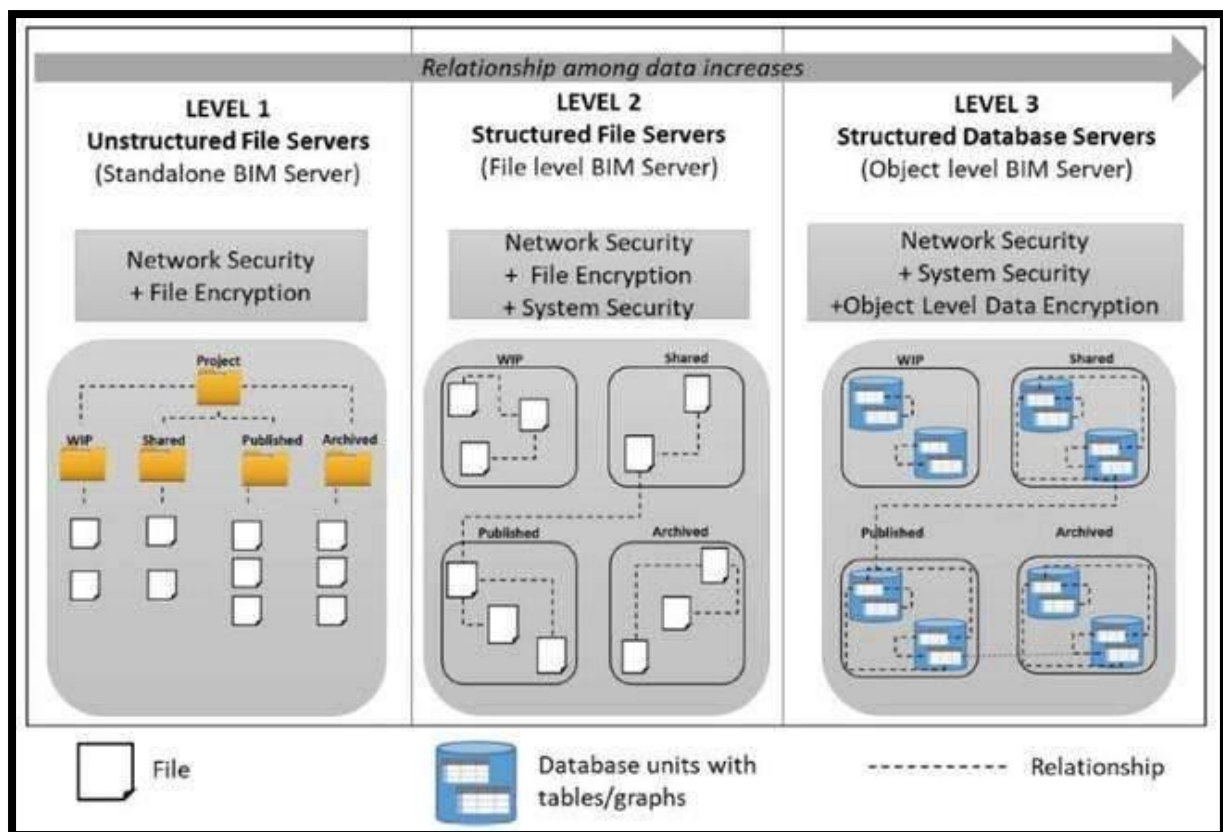


Figure 4.20: Levels of BIM Security (Das et al., 2021)

4.3.4.3. Level 3 – Structured Database Servers

A third type of common BIM platform is structured database servers that facilitate the storage and exchange of BIM and related project information at the object or element level (e.g., building element, material, and task) based on a predefined data model. Many existing BIM collaborative platforms, such as Autodesk 360, BIMServer.org, IFCServer, and Social BIMCloud, are examples of structured database servers. High data granularity is one of the features of these platforms that effectively facilitate detailed access and modification of BIM models.

Structured database servers perform highly through object-level data ownership and data sharing security. For example, information about a building element, such as a “wall” in a structured database server, may belong to multiple project stakeholders. An architect may own geometric information, a contractor may own task and schedule information, a material supplier may own material price information, and cost information may belong to a cost estimator. So, a structured database server enables ownership of individual objects (such as building element

materials and schedules) and facilitates access and manipulation of individual objects without affecting related objects belonging to different owners. Data reuse is optimized and secure as federated models are generated, and information workflows are facilitated by securely separating high-detail information while maintaining data ownership.

Although BIM security level 3 is the most optimal in terms of BIM security and performance for common BIM platforms, the difficulty of deploying BIM security increases in terms of cost and technical expertise. Therefore, individual projects may weigh the security vulnerabilities (resulting from the nature and value of their projects) against the costs and choose the appropriate level of BIM security that meets their security needs (Das et al., 2021).

4.3.6. Proposed Frameworks for BIM Security Implementation

Encryption and Blockchain -based conceptual frameworks are proposed to facilitate BIM level 3 security on common BIM platforms. As discussed in Section 4, encryption protocols combined with distributed database technology can facilitate data sharing, model federation, network security, data security, and system security. Nevertheless, for Level 3 BIM security, segmentation strategies are required for BIM deployment at the object level for data sharing and model federation.

4.3.6.1. Encrypted BIM Server Framework for BIM Security

Data in BIM models is generated by various stakeholders, such as architects, structural engineers, cost estimators, and facility managers in construction projects. IFC, where the data representation for the architecture and cost estimation domain is shown. For a construction project, it is assumed that data from different domains is owned and hosted by stakeholders. For example, data belonging to architecture and cost estimation areas are hosted by the respective architecture and cost estimation companies, respectively.

Project participants from architectural and cost-estimating firms have full access rights ("domain-level access") to their respective data. At the same time, some project participants may need to integrate data from multiple domains to meet the

needs of tasks such as cost estimation. For example, an estimator may need geometric details of a building element and standard rates for materials and labor to prepare an estimate. Hence, he must have access to more than one domain.

Therefore, the estimator in this example should be allowed access to multiple pieces of data required explicitly for his task while being denied access to any other sensitive data unrelated to his task.

4.3.6.2. System Structure

The general architecture of the proposed coding-based conceptual model of a common BIM platform. This architecture includes (1) a distributed relational database that stores BIM model data and (2) an encryption strategy to facilitate secure data sharing at the domain level and across domains. Methods for storing BIM models with high data granularity in databases such as relational (NoSQL⁷⁷) and graph databases can be found in the existing literature.

The proposed encryption-based framework deploys relational databases due to their high performance with structured data, such as BIM models. Relational databases are systems that organize data into tables of rows and columns. For example, relational tables, such as building elements, may describe BIM data through columns representing building element properties, such as unique identifiers, dimensions, materials, and specifications, and rows representing records. According to the proposed encryption strategy, the data in the application is encrypted using a symmetric encryption algorithm, such as the (AES⁷⁸) algorithm before being stored in relational tables. In this encryption strategy, different encryption keys encrypt different columns of relational tables so that columns are the smallest unit of information that can be shared securely.

Various keys, such as data encryption, key encryption, and user encryption keys, are deployed hierarchically to facilitate secure domain and cross-domain level access.

⁷⁷ NoSQL: an approach to database design that enables the storage and querying of data outside the traditional structures found in relational databases.

⁷⁸ AES: Advanced Encryption Standard,

<https://www.techtarget.com/searchsecurity/definition/Advanced-Encryption-Standard>

4.3.6.3. Implementation of the Framework

The proposed Blockchain framework is a distributed collaborative BIM platform where the BIM model is stored and modified locally but through the automatic consensus of project participants. The consensus mechanism is based on voting and is similar to the open-source permissioned Blockchain framework, Hyperledger Fabric. The consensus mechanism facilitates nodes voting for or against a proposed change by locally simulating it in their respective databases. Each node implements the pre-agreed Smart Contract conditions and sends a response (R) in approval or rejection of the proposed change. There may be three outcomes of consensus:

- (1) Positive consensus: If the proposed change passes all Smart Contract preconditions in most nodes, it is finalized and deployed in the BIM DB of all nodes. A record of this change is added to the Blockchain ledger of all nodes.
- (2) negative consensus. If positive consensus cannot be achieved through this framework, a record of negative consensus is created in the Blockchain ledger. Project participants may evaluate the proposed change manually through inter-organizational discussion and make necessary modifications to make it acceptable to all project participants.
- (3) No consensus was reached. If consensus is not reached, it indicates a security breach. All nodes' Blockchain ledgers and databases are synchronized and must have the same information. Therefore, the failure to reach a positive or negative consensus indicates the presence of the enemy.

5. MARS

5.1. Introduction

Building a house on Mars has long occupied the minds of researchers and scholars. Meanwhile, in the recently held challenge, NASA displayed the design of houses for future immigrants to Mars. According to Delta Magazine, the NASA space organization, in collaboration with Bradley University, organized a competition to develop housing for astronauts on Mars, and five finalists were chosen as the best designers among them. In this multi-stage challenge, designers and engineers designed houses built with the help of a 3D printer and materials found on Mars. The winning teams successfully presented a digital design of the physics and performance characteristics of a home on Mars (Brasser, 2013).

Knowing the Martian buildings is essential because the designs and architecture presented for Mars and its history, present, and future are very important for human life. Accurate knowledge provides a framework for these buildings. What are these buildings considered, and what points should they observe? What are their shortcomings, and what points should we believe in in this research? Therefore, this season is essential.

Mars is the fourth planet from the sun. Its diameter is only half that of the Earth. Nevertheless, many characteristics of the Earth lead us to believe that there is life on Mars. It is even possible that intelligent beings live on Mars. These ideas should be confirmed after unmanned space probes pass Mars and send information to Earth. These probes revealed that Mars is a cold and dry planet similar to the Moon and Earth (Benaroya, 2016).

Large areas of the surface of Mars are covered with holes. The density of the Martian atmosphere is incredibly low, like the Earth's atmosphere at an altitude of 50 km above sea level. This atmosphere mainly comprises carbon dioxide and a small amount of water. Oxygen and nitrogen have not been found, although there is probably a tiny amount of them. Because the air is so thin, ultraviolet radiation, which is dangerous to most living things, quickly reaches the surface of Mars from space. At one time, large parts of the surface of Mars were covered with water, and the polar caps were composed of frozen water. The samples taken by explorers from the Martian soil were returned after the water warmed up. Among the planets,

Mars has attracted the attention of scientists more than others. There are two main reasons for this (Liebske & Khan, 2019).

Among the planets far from the Sun, Mars is the closest to the Earth. Mars sometimes comes relatively close to the Earth in its orbit, is located about 56 million kilometers from it, and is one of the brightest. The objects of our night sky The color of this planet is red-orange, which can be seen easily with the naked eye. Mars is called the red planet.

Mars and Earth are similar in several ways: A Martian day is only about 40 minutes longer than our day. Mars has an atmosphere. Like the Earth, it has seasons and an ice cap on its poles. Many scientists once believed there might be a yard on this planet. Since then, several unmanned space probes have gone to Mars, and reports have sent many pictures back to Earth. These documents assure us that there is no life on this planet, but maybe the previous climate of Mars was more suitable for life.

Unfortunately, the atmosphere of Mars is not breathable for humans and consists of carbon dioxide and a little water vapor. It should also be said that the atmosphere of Mars is fragile, and the average atmospheric pressure there is only about one-hundredth of the pressure on Earth (Liebske & Khan, 2019).

As shown in Figure 5.1, humanity has long imagined itself on the red planet Mars. With the ambitious goal of creating human habitation on Mars shortly, numerous alternatives emerge. Among the numerous topics surrounding this endeavor is the complex task of managing Martian infrastructure, which includes designing, constructing, and maintaining buildings customized to the Martian environment's specific challenges and conditions.



Figure 5.1: Mars (Liebske & Khan, 2019)

5.2. History of the discovery of Mars

The very similarity of Mars to Earth is the main reason for researchers' curiosity in reaching more definitive results about the existence of life on this planet. In the middle of the 17th century, observing ice fragments was one of the first discoveries of similarities between Mars and Earth. In the 18th century, a person named William Herschel (William Herschel) mentioned in a report the change in ice volume due to the changes in the atmosphere of each hemisphere of the planet in the summer and winter seasons.

By the middle of the 18th century, astronomers were talking with complete confidence about the similarities between Earth and Mars, such as the length of the day on Mars being almost the same as on Earth. They also knew that the similarity of the axial angle of Mars with the Earth suggests a variety of seasons, just like on Earth, but twice as long. These observations increased the confidence factor about the existence of water and land on this planet. Consequently, the possibility of a species of living organisms increased significantly.

At the end of the 19th century, several theories about life on Mars were presented through telescope observations. In 1854, William Whewell from Cambridge University officially proposed the hypothesis that there is land, sea, and most likely life on Mars (Vago et al., 2013). In 1895, an American astronomer named Percival Lowell published a book called "Mars" about this planet and the water channels observed in it, stating that these channels indicate the existence of a very ancient civilization on Mars. This opinion prompted the English writer H. G. Wells to write "The War of the Worlds" in 1897, concerning the unknown and strange creatures living on Mars who were forced to leave it and turn it into writing.

In 1965, more explicit and more detailed images taken by the Mariner 4 spacecraft showed Mars without any rivers, seas, or signs of life. Investigations carried out in the Viking projects to photograph and test the presence of microbes on Mars also remained inconclusive. Finally, in 1990, during a project called "Mars Global Surveyor," it was proven that Mars, unlike Earth, does not have a magnetic field, and therefore radiation can reach the planet's surface. In addition, scientists emphasized that the absence of a magnetic field caused the solar winds to destroy most of the air on Mars over billions of years (Perminov, 1999).

In recent years, following the studies conducted on the celestial rock ALH84001 and the discovery of fossilized microbes, various discussions about life on Mars have again been discussed and caused disagreements in the scientific community.

Figure 5.2 illustrates the presence of water on Mars in bygone eras. Delving into the planet's historical records reveals valuable insights that can significantly inform the establishment and administration of a human settlement. Understanding Mars' past provides crucial data for devising strategies to address water resource management, environmental conditions, and other essential factors pivotal for the sustainable construction and effective management of a Martian habitat.

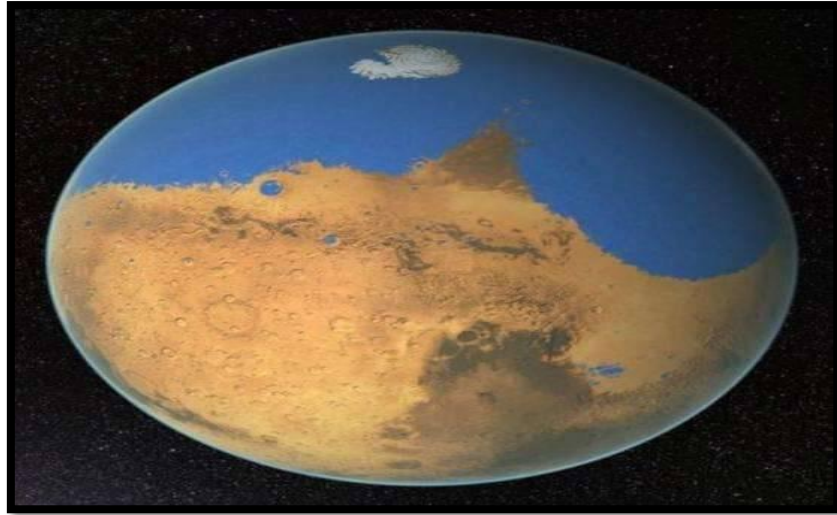


Figure 5.2: History of Mars (Perminov, 1999)

Mars is the fourth planet in the solar system. Its diameter is half that of the Earth, and its area is equal to its land area. In the following section, you will learn about this red planet.

Mars revolves around the Sun in a longer and slower orbit than Earth. Each rotation of this planet around the sun is equivalent to 687 days and nights, and the length of the night and day is slightly longer than that of Earth. The diameter of Mars is almost half of the diameter of the Earth and equal to 6790 km. (The diameter is also the earth: 12756 km).

The atmosphere of Mars is red and can be seen from Earth in the night sky. Mars has two small moons, Phobos and Deimos, with irregular shapes. These two moons may be meteorites trapped in the orbit of Mars. If a person is on Mars, he will see that Phobos rises and sets three times in one day. Deimos is half of Phobos; if we look at it from Mars, this moon will be more like a star than a moon. The solar eclipse on Mars is not complete due to the small size of its moons. The moons of Mars are close to its surface, and its largest moon is Phobos, whose rotation around the mother planet is nearly 7 hours, 39 minutes, and 27 seconds. The Deimos orbital period is one day, 6 hours, 21 minutes, and 16 seconds (Shayler et al., 2005).

Mars is less dense than Earth, with 15% volume and 11% mass. Its surface area is slightly less than the earth's total land surface. Compared to Mercury, Mars is more

prominent and has more mass, which makes it denser. This field has caused a greater force of gravity on the surface of Mars. Mars is the eighth body in the solar system regarding volume and mass. In terms of size, mass, and surface gravity, Mars is between the Earth and the Moon (Earth's Moon). The Moon has a diameter equal to half the diameter of Mars, while the diameter of the Earth is about twice the diameter of Mars. The Earth has a mass about ten times that of Mars, while the mass of the Moon is ten times less than that of Mars. The red-orange color of Mars is due to the presence of iron (III) oxide, more commonly known as hematite or iron rust (NASA, 2023).

Paying attention to the duration of the Martian year (689 days) and the Earth year (365 days) shows that the time interval of both confrontations is about two years and two months. However, due to the elliptical orbit of both planets, it can be expected that the distance between Earth and Mars will be different in each confrontation (NASA, 2023). The shortest distance occurs when the Earth is at its zenith and Mars is at the perigee of its orbit. In this case, Earth and Mars will come closer to each other by up to 56 million kilometers. The farthest distance between two opposing planets can increase to 240 million kilometers. The minimum distance between Earth and Mars occurs in confrontations repeated in 15–17-year years. Nevertheless, what is essential is to pay attention to the point that the distance between two planets in close encounters is not necessarily the same, and that is why the closest encounters (such as the one that happened on August 27, 2003) occur at very long intervals. The orientation of the orbit of Mars in space during a close encounter is such that Mars is in the direction of the Aquarius constellation or near the Capricorn constellation. On the other hand, the Earth passes through this place every year. At this time, Mars is located south of the celestial equator; therefore, these types of confrontations are better observed from the southern latitudes of the Earth. The reverse of this article is accurate in distant confrontations because these types of confrontations occur in the constellation of Leo and the months of Bahman and Esfand; therefore, they are better seen from the earth's northern hemisphere (NASA, 2023).

All previous observations by satellites and Mars rovers have indicated that the Red Planet was once covered with a thick layer of gases that allowed liquid water to exist on the surface. This impression (the presence of surface water) is evident in the characteristics of the surface of Mars, such as the works that resemble the beds of rivers, deltas, and lakes.

However, the air pressure on Mars today is less than 1% of Earth's, meaning that if you pour liquid water on the surface (depending on where it is), it will either boil and vaporize or freeze. In April 2015, NASA's Mars rover, which has been exploring the planet for about three years, discovered soil moistened with salt water, which lowers the freezing point. Then, in September, the rover found rocks beneath the Martian surface that were four times wetter than previously thought. In addition, the satellite images of the pebbles on the planet's surface showed that there was once a water flow.

By studying the pictures taken by the Mars rover of the basalt and dark rocks on the surface of Mars, there were speculations that this planet was covered by water in distant years. In a press conference on September 28, 2015, NASA confirmed the existence of water on Mars and announced that there is flowing water on this planet during the warm months. Photographs of Mars that have reached Earth clearly show how dark streaks on a Martian slope change with the seasons. These streaks, called recurrent slope lines, stretch down to the bottom of the slopes in the warmer months, but they disappear during the colder seasons. NASA scientists announced that the dark streaks are flowing water, seen in the summer and disappearing in the Martian winter. It should be noted that the discovered water is not pure, and some salt in it makes it possible for this water to flow at the usual temperature of 50 degrees Celsius below zero on Mars. This could mean the existence of some life on Mars.

On July 25, 2018, Italian scientists found a lake of liquid water in the South Pole of the Red Planet by examining the data of the Mars Orbiter (Express Orbiter) radar instruments. This lake is hidden 1.5 km below the surface of the ice peak at the South Pole of Mars. According to the research group, this enormous lake is 20 km wide. The discovery of liquid water on this planet increases the possibility of life.

Italian researchers say that the Martian Lake resembles the lakes trapped under the ice masses at Earth's north and south poles. Since there is life in terrestrial sub-
iconic lakes, signs of life may also be discovered in a Martian Lake (NASA, 2023).

5.3. Orbital Characteristics of Mars

Like other planets in the solar system, the orbit of Mars is also elliptical. Nevertheless, the elongation of the elliptical orbit of Mars is greater than that of all the planets. The distance between Mars and the Sun is 20,662,000 km at its minimum and 2,492,300,000 km at its maximum. Mars makes one complete revolution around the sun every Earth Day. This period is one year on Mars. The distance between Mars and Earth depends on the position of both planets in their orbits. The minimum distance between these two neighboring planets is 54,500,000 km, and the maximum is 4,013,000,000 km.

Like Earth, Mars also moves around its longitudinal axis from west to east. The solar day of Mars lasts 24 hours, 39 minutes, and 35 seconds. This is the period when Mars completes a complete revolution around its axis concerning the Sun. The longitudinal axis of Mars is not perpendicular to its orbital plane but has an angle of approximately 19.25 degrees. The deviation of this planet causes the sunlight to vary in certain parts at different times. As a result, we see the change of seasons on Mars and Earth (Ehlmann et al., 2008).

Figure 5.3 delineates Mars' orbital dynamics with Earth and the Sun. This critical data furnishes essential insights for foundational understanding and developing an appropriate framework tailored to Mars' unique characteristics. By comprehending Mars' orbital parameters, such as its distance from the Sun, orbital period, and axial tilt, scientists and engineers can craft precise models and blueprints conducive to designing and implementing adequate infrastructure and operational protocols for Martian exploration and colonization endeavors.

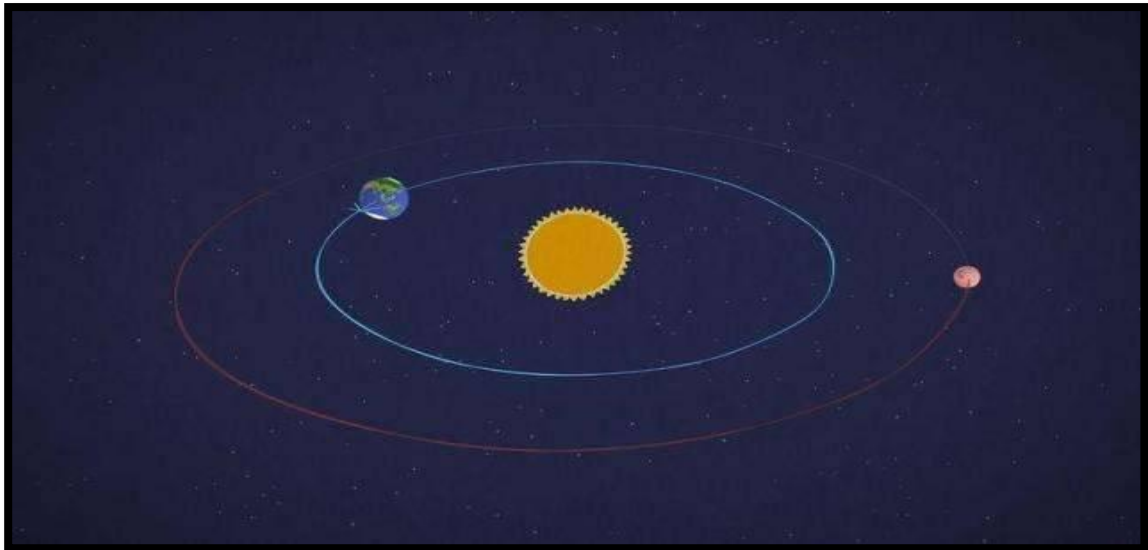


Figure 5.3: Orbital Characteristics of Mars (Ehlmann et al., 2008)

5.3.1. Atmosphere

The oxygen content of Mars's atmosphere is shallow compared to Earth's. This gas constitutes only 0.13% of the total atmosphere of Mars, while 21% of our Earth's atmosphere consists of oxygen. Carbon dioxide comprises 96% of the atmosphere on this planet. Other gases include nitrogen (1.9%), argon (1.9%), carbon monoxide (0.7%), and water vapor (0.3%) (Zurek et al., 1992).

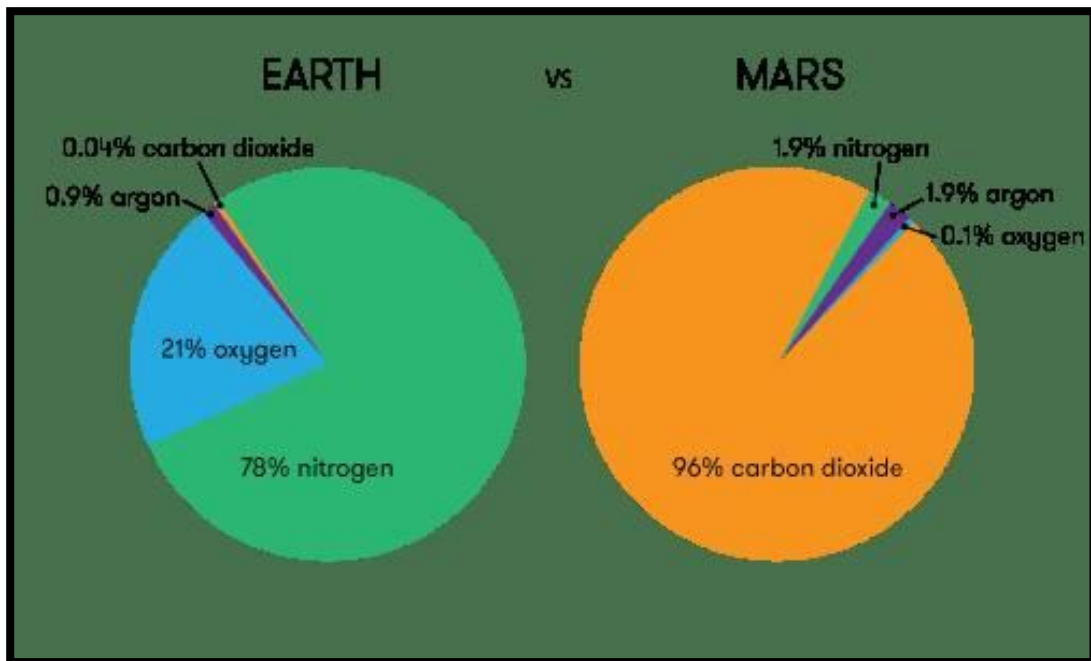


Figure 5.4: Atmosphere Between Mars And Earth (Zurek et al., 1992)

Figure 5.4 depicts the differing atmospheric compositions of Mars and Earth, an essential factor in the attempt to support life and develop livable colonies on the red planet. Mars's thin atmosphere, primarily made of carbon dioxide with trace amounts of other gases, poses a substantial hurdle to human existence. Understanding these atmospheric inequalities is critical for developing novel solutions, such as oxygen-generating systems, to support life and aid in creating viable dwellings on Mars.

5.3.2. Clouds

In the Martian atmosphere, clouds made of frozen carbon dioxide particles form at high altitudes. In addition, the formation of clouds and fog with water ice particles is widespread. The foggiest time is in the early morning. The cold air makes the water vapor dense (James, 1978).



Figure 5.5: Clouds on Mars (James, 1978)

Figure 5.5 captures the mesmerizing imagery of clouds observed on Mars by rovers, offering valuable meteorological insights essential for establishing a Martian settlement. Weather data, including cloud formations, are pivotal in shaping habitat design, resource management, and operational planning on the red planet. By analyzing Martian weather patterns, scientists and engineers can optimize

infrastructure designs, develop robust contingency plans, and ensure the resilience of future Martian colonies against dynamic and sometimes harsh atmospheric conditions.

5.3.3. Wind

Mars' atmosphere, like Earth's, has a general cycle and wind pattern that sweeps across the planet. On Mars, the concentration and evaporation of carbon dioxide gas in the poles significantly impact the overall cycle. With the onset of winter, the carbon dioxide in the atmosphere is concentrated between the two poles. As a result, more carbon dioxide flows towards the poles to fill the void of this gas. When spring arrives, the frozen carbon dioxide evaporates, and as a result, this gas flows in a direction away from the poles. The winds that blow on the surface of Mars are primarily calm and have a speed of about 10 kilometers per hour (Fenton & Michaels, 2010).

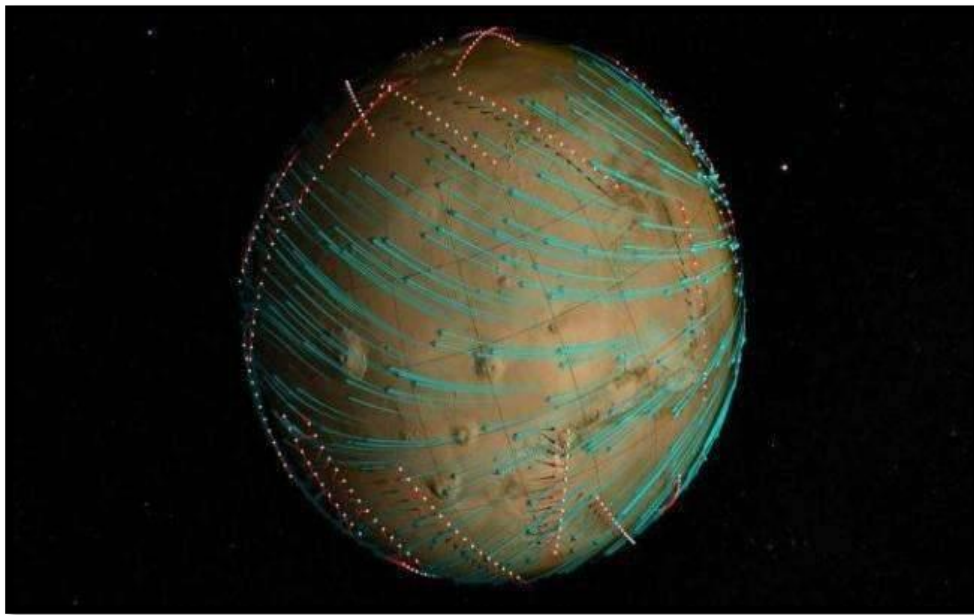


Figure 5.6: wind on mars (Fenton & Michaels, 2010)

Figure 5.6 presents a comprehensive overview of the diverse types of winds observed on Mars, a crucial aspect necessitating an in-depth understanding of the subject of this thesis. Martian winds, ranging from gentle breezes to powerful storms, significantly influence various elements of Martian exploration and settlement endeavors. By delving into the intricacies of Martian wind patterns,

researchers can glean essential data vital for designing resilient infrastructure, optimizing energy systems, and mitigating potential risks associated with Martian atmospheric dynamics, so advancing the objectives of this thesis.

5.3.4. Dust storm

One of the most apparent effects of the weather on Mars is blowing winds accompanied by dust. Similar to terrestrial tornadoes, small tornadoes can temporarily lift soil from the planet's surface.

Severe dust storms start when the wind carries dust up into the atmosphere. At this time, the air around the soil particles is heated due to the absorption of sunlight. When warm air rises, the wind becomes more robust and carries more dust. As a result, the storm gets stronger and stronger. On more severe scales, a dust storm can cover an area of more than 320 km or even several thousand km. More giant storms can cover the entire surface of the planet. Such storms are uncommon but can last for months (Leovy et al., 1973).

The strongest storms can make the entire surface of the planet invisible. Such storms blew once in 1971 and again in 2001. Sandstorms occur mainly when the distance between Mars and the Sun is small. The sun heats the atmosphere more during those times (Kass et al., 2020).

Figure 5.7 captures the occurrence of a Martian storm, emphasizing the critical importance of understanding and preparing for such atmospheric phenomena in the context of settlement construction and management on Mars. Martian storms, ranging from dust devils to planet-spanning dust storms, pose significant challenges to infrastructure, resource management, and human safety. By gathering and analyzing data on Martian storm behavior, scientists and engineers can develop robust strategies for designing resilient habitats, implementing emergency protocols, and safeguarding the well-being of future Martian inhabitants against the disruptive forces of these storms.



Figure 5.7: Dust Storm on Mars (Kass et al., 2020)

5.3.5. Mass and density

Mars's mass equals 42.6×10^{20} tons; this number can be expressed as 642, along with 18 with a zero in front of it. The mass of Earth is about ten times that of Mars. The density of Mars is 3.933 grams per cubic centimeter, which is approximately 70% of the density of the Earth (Smith et al., 2008).

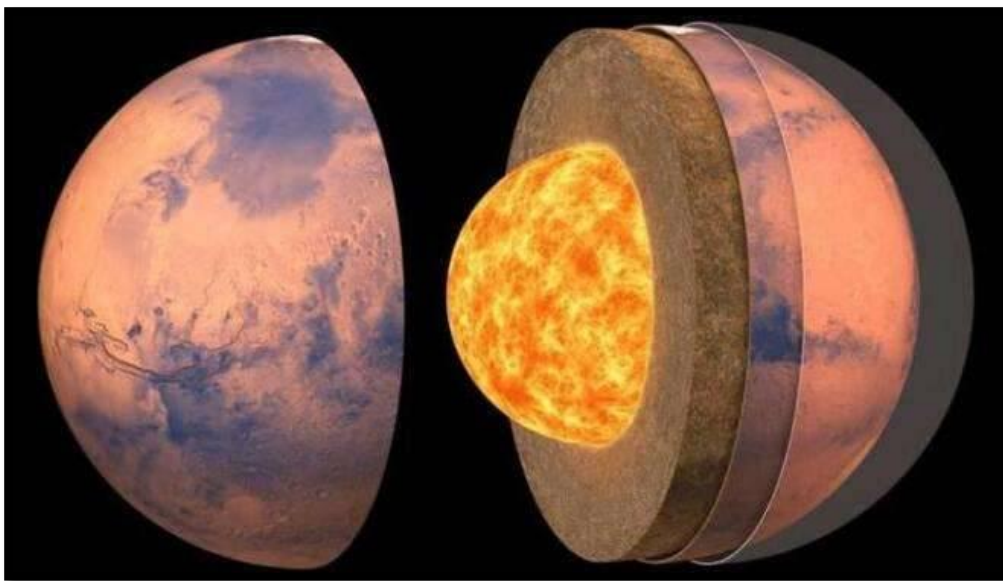


Figure 5.8: Mass and Density (Smith et al., 2008)

Figure 5.8 provides valuable insights into the mass of Mars and the characteristics of its core, essential information for assessing the viability of potential settlement sites and understanding the planet's surface behavior. Mars' mass and core composition directly influence gravitational forces, geological activity, and magnetic fields, profoundly impacting surface conditions. By scrutinizing this data, scientists can identify stable regions conducive to human habitation, evaluate geological stability, and mitigate potential risks associated with settling on Mars, ensuring future Martian colonies' safety and sustainability.

5.3.6. Force of Gravity

Since Mars is much smaller and less massive than Earth, its gravity is weaker than Earth's and only 38% of Earth's gravity. Therefore, if a person stands on the surface of Mars, he will think he has lost 62.5% of his weight. Likewise, if a rock is dropped on Mars, it will reach its surface much slower than Earth (Cavagna et al., 1998).

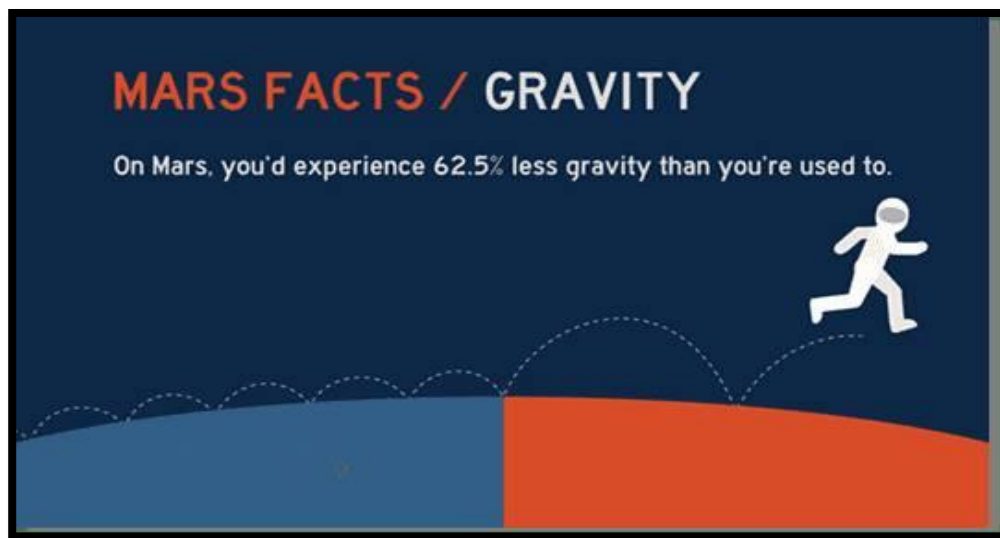


Figure 5.9: Force of Gravity (Cavagna, Willems, & Heglund, 1998)

Figure 5.9 offers a comparative analysis of the gravitational forces exerted by Earth and Mars, a fundamental component of the essential information necessary for establishing settlements on the Martian surface. Understanding the gravitational disparity between the two planets is paramount for designing infrastructure, developing transportation systems, and ensuring the well-being of inhabitants in

the Martian environment. By comprehending these gravitational differences, engineers can tailor construction techniques, optimize resource utilization, and devise ergonomic solutions to mitigate challenges Martian gravity poses, so facilitating the construction and sustainability of Martian settlements.

5.3.7. The Rocky Crust of Mars

- A front composed of dense rocks is placed under the crust.
- a nucleus that consists primarily of iron.

The average thickness of the crust of Mars is about 50 km. Since the higher altitudes are located in the southern hemisphere, it is possible, as a result, that the thickness of the crust of the northern hemisphere is less. Most of the crust is probably composed of volcanic rocks called basalt. In addition to Mars, basalt is also found on the surface of the Earth and the Moon. Some other stones on the surface of Mars, especially in the northern hemisphere, are called andesite. Andesite is also a type of volcanic rock that is found on Earth. The amount of silica in this stone is higher than in basalt. Silica is a combination of silicon and oxygen (Cathcart, 2021).

5.3.8. Plains of Mars

Many areas of Mars are plains, most of which are located in the northern hemisphere. In the parts of the north of the northern hemisphere, the flattest and smoothest regions of the solar system are located. The smoothness of these areas is most likely due to the sediments that created them. There are many reasons why water once flowed on the surface of Mars. The presence of water has caused the formation and accumulation of sediments (Tanaka et al., 2005).



Figure 5.10: Plains (Tanaka et al., 2005)

Figure 5.10 depicts the Martian plains in realistic detail, highlighting their harsh and rocky environment. Investigating these plains is critical for determining acceptable areas and developing strategies for establishing colonies on Mars. Understanding the Martian plains' topography, composition, and geological features is essential for site selection, land use planning, and infrastructure construction. Scientists and engineers can successfully limit risks, maximize resource use, and assure the robustness and endurance of Martian communities in this harsh climate by undertaking detailed evaluations of such terrain features.

5.3.9. Valleys on Mars

Along the equator, there is a striking symbol on this planet. an extensive collection of valleys called Martian valleys. The Mariner 9 spacecraft discovered this phenomenon on the surface of Mars in 1971. The valley stretches from east to west, and its length is about 4000 km, the width of Australia or the distance between Philadelphia and San Diego. Scientists believe this system was created due to cracking a part of the crust. The unique valleys in the Martian valleys have a width

of 100 km. The valleys connect in the central part, which is 600 km wide. The depth of the valleys reaches 8 to 10 km in some places (Group, 1983).



Figure 5.11: The Valleys On Mars (Group, 1983)

Figure 5.11 visually represents the valleys on Mars, providing crucial locational information for settlement construction endeavors. The study of Martian valleys, alongside plains and other geological features, is indispensable for site selection, infrastructure planning, and habitat design on the red planet. By examining Martian valleys' morphology, composition, and spatial distribution, scientists and engineers can identify potential settlement sites, assess accessibility, and develop tailored strategies to navigate and utilize these terrain features effectively, ensuring the success and sustainability of Martian colonies.

5.3.10. Volcanoes on Mars

Mars has the most prominent volcanic mountains in the solar system. The tallest of them, Olympus, has a height of 27 km and a diameter of 600 km and is surrounded by flat plains. The other three enormous volcanoes on Mars are Arsia, Askreus, and Paonis, located in a high area called Tharsis. All these volcanoes, like the volcanoes of Hawaii, have a slope that gradually increases. Mars also has many other types of volcanoes. Scientists have yet to learn when the last volcanic eruption

occurred on Mars, from small conical hills to plains covered with frozen molten material. Nevertheless, minor eruptions may still happen (Carr, 1976).

Figure 5.12 showcases Mount Olympus on Mars, surrounded by sedimentary materials that hold significant potential as resources for settlement construction. Such geological formations provide an opportunity to obtain essential materials for building and sustaining Martian settlements. By leveraging the resources available in the vicinity of Mount Olympus, such as sedimentary rocks, scientists and engineers can develop innovative extraction and processing techniques to acquire construction materials, minerals, and other vital resources required for infrastructure development and habitat construction on Mars, thereby enhancing the self-sufficiency and resilience of future Martian colonies.

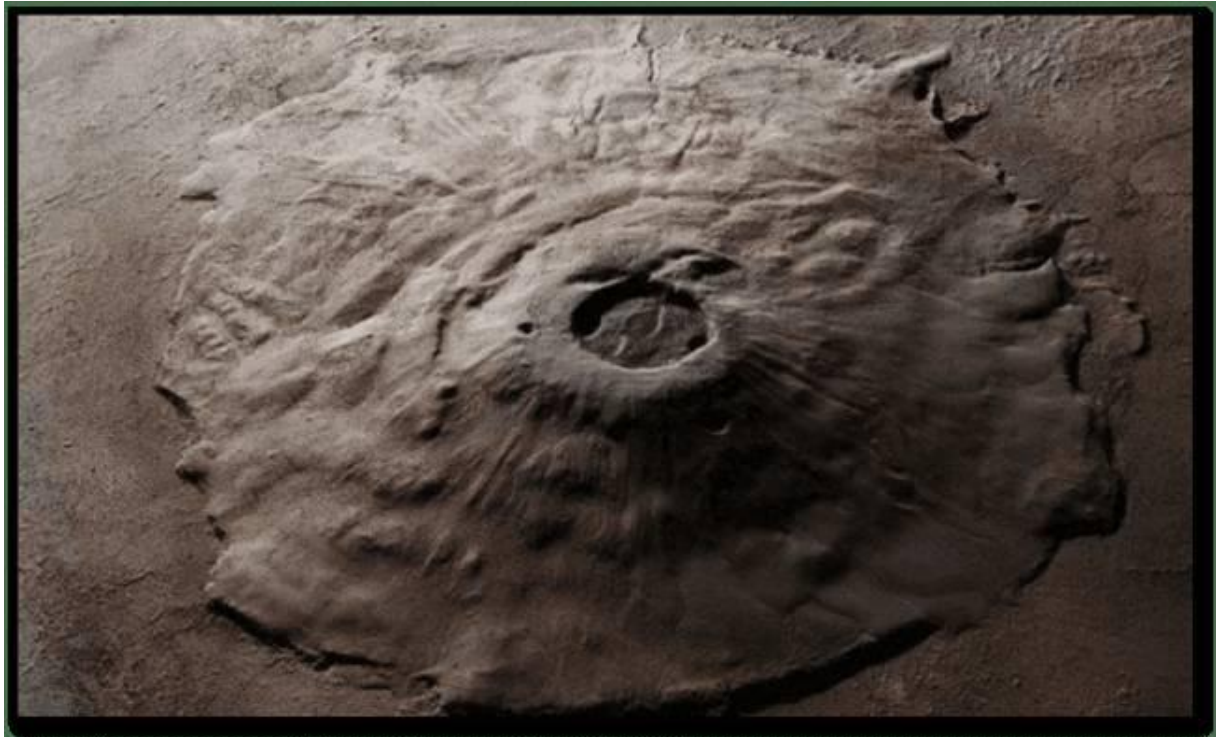


Figure 5.12: Volcanoes on Mars (Carr, 1976)

5.3.11. Craters and impact areas on Mars

Many celestial rocks that have collided with Mars throughout its history have created holes in the surface of this planet. These impact pits are very few in the ground for two reasons: 1) The pits created before have been lost due to erosion. 2) Earth's dense atmosphere prevents rocks from colliding and forming holes.

The holes on the surface of Mars are very similar to the holes on the moon, Mercury, and other solar system objects. The pits are deep and bowl-shaped. Larger craters can have central peaks that are formed by post-impact crustal rebound.

On Mars, the number of craters varies significantly from place to place. The surface of Mars in the southern hemisphere is ancient and, therefore, has many craters. Other areas, especially in the Northern Hemisphere, are younger and have fewer craters. Some volcanic mountains also have craters, indicating that only a little time has passed since their eruption. The molten material of volcanoes can cover all existing holes. So, only a little time has passed since the last eruptions because otherwise, the number of craters on volcanic mountains would be higher.

Abnormal deposits can be seen around some holes. These sediments are materials thrown out of the hole formed when the meteorite hit. This form of sediments can indicate that the meteorite encountered water or ice underground (Sharp, 1973).



Figure 5.13: Pits and Impact Areas (Sharp, 1973)

Figure 5.13 delineates the regions impacted by meteorite strikes on Mars, underscoring the importance of understanding such occurrences in managing Martian construction projects. Knowledge of meteorite impact sites is crucial for assessing potential risks to infrastructure, evaluating structural vulnerabilities, and implementing mitigation measures to safeguard Martian buildings and habitats. By identifying and analyzing these impact areas, engineers can incorporate robust design features, develop resilient materials, and establish

contingency plans to minimize the impact of meteorite strikes on Martian construction projects, ensuring the safety and longevity of Martian settlements.

5.3.12. Polar deposits on Mars

The most interesting phenomenon in the polar regions of Mars is thick masses of sedimentary layers of material. A combination of water, ice, and soil particles forms these layers. These sediments have extended up to 80 degrees from each pole. The atmosphere has led to the deposition of layers over a long time. These layers document the activities and seasonal changes in the weather during very long periods.

One possibility of climate change on Mars is the change of its longitudinal axis. These changes lead to a change in the amount of sunlight on different parts of the planet and, as a result, general changes in the weather on Mars. The amount of sediment the atmosphere creates is directly related to past changes in climate.

On top of the sedimentary layers in both hemispheres, water ice caps remain in the form of ice throughout the year. These layers and the cap on them are several kilometers thick. In winter, seasonal caps that are formed from frozen layers also appear. These caps are well visible with telescopes on the ground. Seasonal caps consist of frozen carbon dioxide or dry ice formed from carbon dioxide in the atmosphere. In the coldest days of winter, these layers extend up to 45 degrees toward the equator (Thomas et al., 1992).

Figure 5.14 depicts Mars' polar regions, including a small fraction of ice, which is critical for sustaining life and supporting human operations on the red planet. The presence of water ice near the Martian poles provides a significant resource for future civilizations, as it might be used for drinking, cultivation, and industry. Understanding the distribution and composition of ice at the Martian poles also provides essential information for planning resource utilization, housing construction, and long-term sustainability measures for human settlement attempts on Mars.

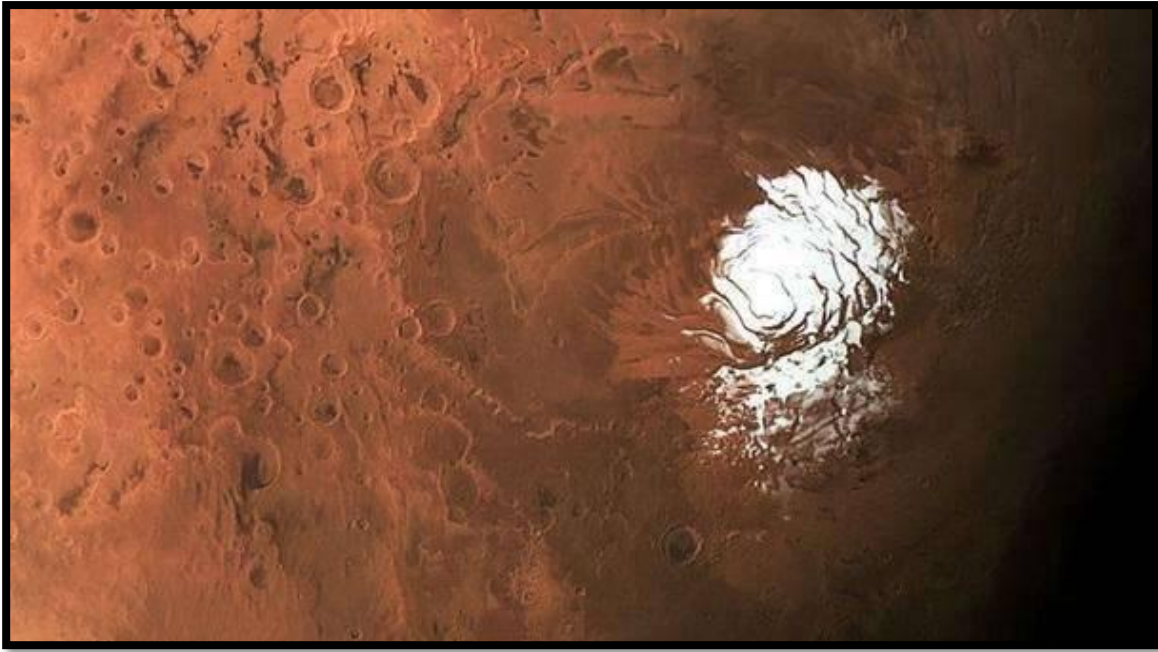


Figure 5.14: Polar Sediments (Thomas et al., 1992)

5.3.13. Formation of Rock on Mars

Viking landers landed on Mars in 1976. They photographed a dry surface with large boulders among gravel, sand, and mud. These were basalt stones. Some contained small holes from which gas was released. On Earth, such basalts originate from volcanic lava filled with foamy gas. The rocks of Mars also probably had such a source. The soil of Mars is similar to the hardened soil of Earth's deserts (Rogers & Nekvasil, 2015).

Figure 5.15 depicts one of the Martian stones, representing a potential resource that could be instrumental in sustaining human life on Mars. Understanding the composition and properties of Martian stones is crucial for identifying and utilizing them as valuable resources for future Martian settlements. These stones may contain minerals, metals, or other materials essential for construction, manufacturing, or even as a source of nutrients in farming endeavors. So, comprehensive knowledge of Martian stone formations is indispensable for resource assessment, extraction techniques, and developing self-sufficient habitats on the red planet.



Figure 5.15: Formation of Rock On Mars (Rogers & Nekvasil, 2015)

5.3.14. The Cause of Red Mars

This entire planet is a vast desert. There is no water flowing on its surface, nor is there any water in its atmosphere. The color photos show an arid and barren landscape covered with scattered rocks. The red color of this planet is due to the rocks with iron oxide (iron rust). Some of these stones are also found on the ground. Only the surface of Mars has this color because the Viking ships excavated it and showed that there are dark-colored rocks under the red dust. Due to the presence of red dust, even the sky of Mars can be seen in this color. Sometimes, big dust storms appear, and almost every ten years, a considerable tornado engulfs the entire planet (Ezell & Ezell, 1984).

Figure 5.16 depicts Mars' typical reddish tone, emphasizing the importance of acquiring information about the planet's soil as a valuable resource for settlement development. Martian soil, commonly known as regolith, has enormous promise as a source for various building materials, including bricks, ceramics, and concrete. It may also contain vital ingredients for agricultural and manufacturing activities required to support human life on Mars. As a result, extensive investigation and

understanding of Martian soil composition are critical for optimizing resource usage and promoting the formation of self-sustaining settlements on the red planet.

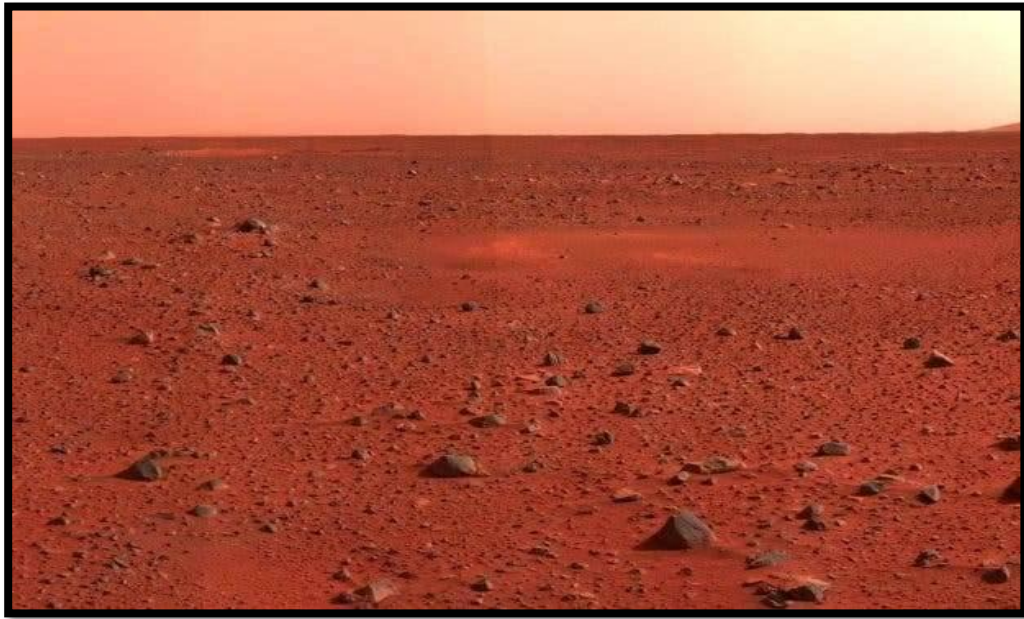


Figure 5.16 The Cause Of Red Mars (Ezell & Ezell, 1984)

5.4. Phobos of Mars

1877, when Schiaparelli was carefully drawing the channels on his maps, an American astronomer named Asaph Hall was also observing Mars. He used a new type of 66-cm reflecting telescope at the US Naval Observatory in Washington. Astronomers have been looking for the moons of Mars for years. Johann Kepler announced in the 17th century that Mars must have two moons. He believed that there was a mathematical pattern behind the solar system. According to this pattern, the number of moons on the planets after the Earth should increase. In such a way that their number should be doubled every time. Considering that the Earth has one moon and, at the time of Kepler, it was thought that the planet Jupiter has four moons, according to the mathematics governing this theory, Mars must have two moons.

At the beginning of August 1877, Asaph Hall began the grueling observations to find the moons of Mars. At that time, the proximity of Mars to the Earth caused problems. Mars was so close that, when viewed through a telescope, its remarkable brightness caused problems in observing this planet. By August 11th, Hall was

convinced he could find nothing. However, his wife insisted he look again. Finally, that night, he realized something. That celestial body was tiny. However, there was. Then, the sky became cloudy. On the 16th of August, the sky cleared again, and Hall could see the moon of Mars. On the 17th of August, Hall was excited to find the second moon of Mars. In this way, the theory of the doubling of the moons seemed correct.

Scientists still thought Jupiter had four moons and Saturn had eight. However, they discovered the fifth moon of Jupiter in 1892 and the ninth moon of Saturn in 1898, making Kepler's theory forever obsolete.

Asaph Hall observed the moons of Mars as luminous and moving points. Nevertheless, images sent by the Mariner spacecraft in 1969 and by Viking in 1975 showed that the twin moons of Mars have a very irregular appearance. Hall named these moons in honor of the chariot horses of the god of war in Greek mythology, Phobos (meaning fear) and Deimos (meaning terror).

Phobos and Deimos's motions from the surface of Mars appear very different from those of our moon. Swift Phobos rises in the west, sets in the east, and rises again only after 11 hours, while Deimos rises in the east as expected but very slowly. Despite its 30-hour orbit, it takes 2.7 days to set in the west as Deimos descends more slowly than Mars rotates and so takes longer to rise again.

As seen from Mars, Phobos has an angular diameter of 8 minutes (at sunrise) and 12 minutes (overhead), while Deimos has an angular diameter of 2 minutes. The angular diameter of the sun, taking into account the difference in intensity of burning, is about 21 minutes. Both satellites are death-locked. They always present the same face to Mars.

Since Phobos orbits Mars faster than its planet, the gravitational forces are less, but its orbital radius decreases steadily and uniformly. In other words, in the future, when Phobos gets close enough to Mars, he will be crushed by these deadly forces. Several pits lined up on the surface of Mars suggest there may be other small moons that have succumbed to the fate that awaits Phobos. On the other hand, Deimos is far enough away that its orbit slowly opened, as with our moon.

The latest image sent by MGS shows the shadow of the potato-shaped Phobos moon on Mars (Lawrence et al., 2019).

Figure 5.17 captures a detailed view of Mars from a distance of 250 km, employing both red and blue filters to capture distinct features. Utilizing these filters allows for differentiating surface characteristics based on color variations. Subsequently, combining these filtered images provides a comprehensive depiction of Martian terrain, enhancing our understanding of its geology, atmosphere, and potential resources. Moreover, a wide-angle camera system enables the capture of expansive vistas, facilitating comprehensive analysis and exploration of Martian landscapes essential for future settlement planning and scientific research endeavors.

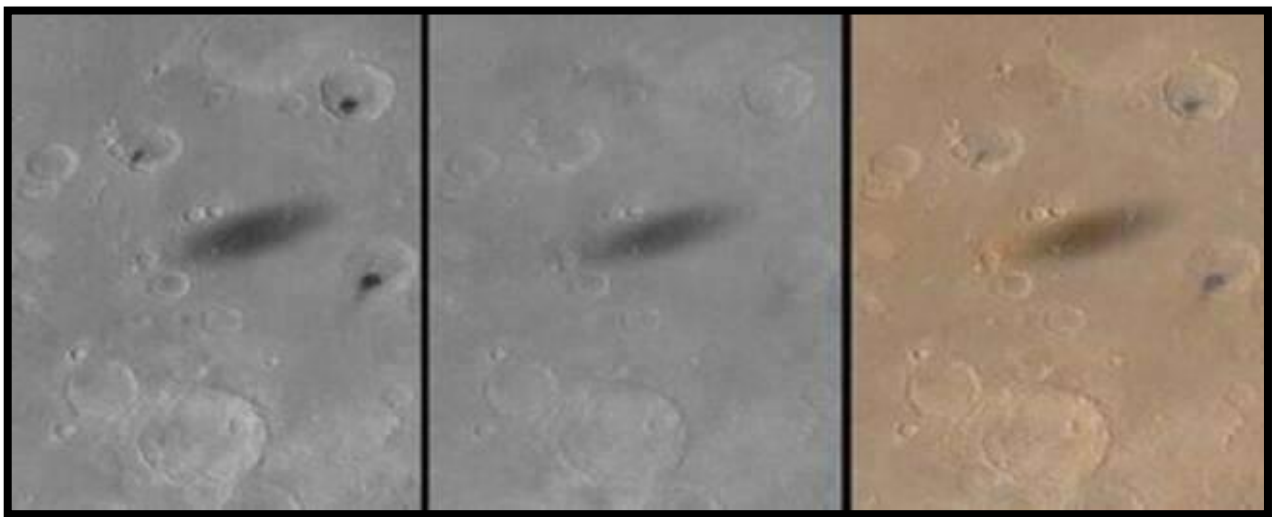


Figure 5.17: Phobos On Mars (Lawrence et al., 2019)

The Soviet Union sent the first probe to Mars in 1960, none of which reached orbit. After many Soviet failures, the United States sent the Mariner probe to Mars in 1964. On July 4, 1965 (Mariner 4), he took vital images and measurements over Mars. It revealed that the planet's atmosphere is thinner than expected, and its surface is similar to the surface of the moon.

In 1971, the Soviet Probe Gars Go dropped a capsule on the surface of Mars and made the first landing on this planet. Of course, this capsule could not prepare and send usable information. In 1976, the American probe Anir 9 reached Mars and took pictures of the planet's entire surface. They landed, measured the Martian climate for years, and conducted complex experiments to detect traces of life.

In 1992, the United States sent the Mars Observer probe. In 1993, the probe contacted NASA three days earlier. It was broken when the probe reached orbit. This connection was never established, and the probe must be recovered in sequence.

The United States sent the Path Finder probe in December 1996, which landed on the surface of Mars on July 4, 1997. Two days later, the six-wheeled rover named Sojourner was sent to Mars with the help of a ramp from the probe. The length of this car is 62.33 cm, and its weight is equivalent to 1.5 kg on the ground. This car is equipped with a device called an X-ray spectrometer. Alpha Proton was to collect information on the chemical structure of the soil and rocks on Mars. Sojorand sent this information to Penfinder, which sent them back to Earth. Scientists on Earth controlled Joe Renner, but since it takes 10 minutes for radio signals to reach Earth from Mars, scientists installed automatic devices to prevent the car from falling into danger.

In 1996, the United States sent a probe called the Mobs Global Surveyor to map the planet's surface. The probe used a laser device to detect Martian ridges and elevations. With the precision of this device, a map was obtained, and the heights with a minimum height of one meter were specified. The other equipment in this probe was to identify minerals on the planet's surface, the presence of sediments that were probably formed in liquid water, and the corroded aqueducts that appeared to have been created by the flow.

In 2001, the United States sent the Mars Odyssey probe to the planet, carrying equipment that helped identify the minerals on the surface of the earth, find evidence for the existence of water and ice in the lower layers of the planet, and measure the amount of harmful radiation for the presence of humans on Mars in 2002 (Edition of Mars). Large amounts of ice were discovered at a level about one meter near the planet's pole.

In 2003, one probe from ESA and two from the United States were sent to Mars. Mars Express, which ESA sent to Mars in December 2003, sent terrific images of the planet's surface to Earth, confirming the presence of ice near the planet's south

pole. He discovered methane in the atmosphere of Mars, which is proof of the existence of life.

5.4.1. Legendary Mars Rovers

Spirit and Opportunity rovers were launched to Mars on June 10 and July 7, 2003, respectively, to pursue the following goals on Mars:

- searching and identifying a group of rocks and soils that contain evidence of ancient aquatic activities. Determine the spatial distribution and type of minerals, rocks, and soil around the landing sites.
 - finding the origin of mineral masses and textures of different types of rock and soil on the surface of this planet and placing them in their geological context.
- Spirit landed on the surface of Mars on January 4, 2004, and Opportunity on January 25, 2004. Although the mission of these two Mars rovers was planned for three months, after two years, they continued to operate on the surface of Mars, which is why they have earned the title of legendary Mars rovers (Tao et al., 2016).

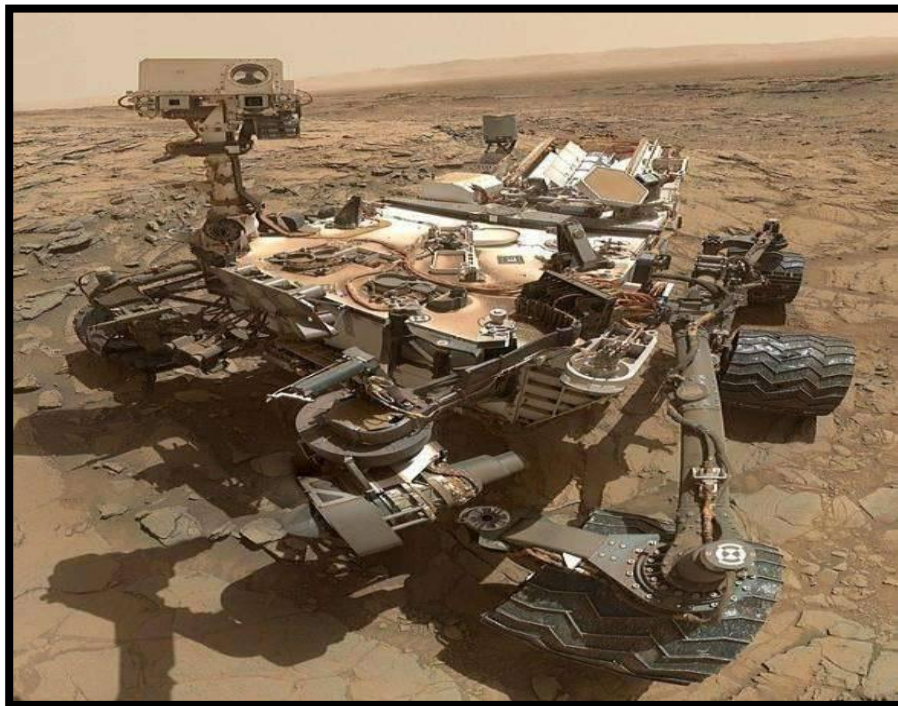


Figure 5.18: Legendary Mars Rovers (Nasa)

Figure 5.18 depicts one of the Mars rovers diligently collecting information and transmitting data back to Earth. The data gathered by these rovers is invaluable

for assessing environmental conditions on Mars, including atmospheric composition, temperature variations, radiation levels, and soil properties. This information is crucial for informing the Red Planet's house construction and building management strategies. By analyzing data from Mars rovers, scientists and engineers can design habitats resilient to the Martian environment's unique challenges, ensuring the safety and well-being of future inhabitants.

5.4.2. Tools On The Rover's Arm

A microscopic imager is a combination of a camera and a microscope. This tool produces very close-up views in black and white (at a scale of 100 microns). It also helps to identify sedimentary rocks that have formed in water. Alpha Particle X-Ray Spectrometer (Alpha et al.) accurately determines the identifying elements of rocks and soil. The tools on the arm are supported by the Rock Abrasion Tool; this tool uses an emery stone to roughen the dust and can create a 4.5 cm intact surface. Each rover uses three magnetic arrays to collect air dust for analysis. Calibration targets are points that help scientists make correct observations. The Mossbauer spectrometer is designed to accurately determine ferrous minerals' composition (Trebi-Ollennu et al., 2005).

Figure 5.19 shows a close-up of one of the rover's arms, which was precisely built and equipped to capture vital data from the Martian surface. These specialized robotic arms have various sensors, devices, and tools for scientific experimentation, soil sample analysis, and high-resolution landscape imaging. By using these advanced robotic arms, Mars rovers can collect critical data on geological features, atmospheric conditions, and possible resources, which will help us comprehend the Martian environment and assist future exploration and colony efforts.

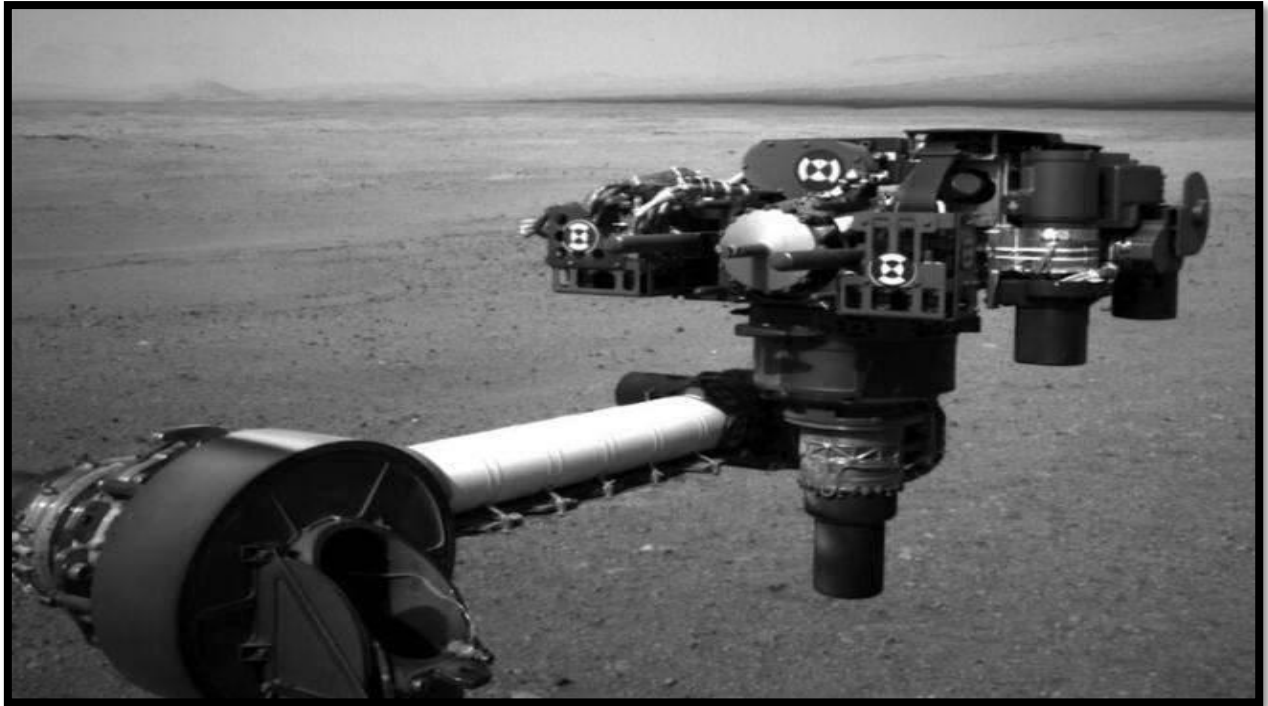


Figure 5.19: Tools On The Rover's Arm (Nasa)

5.4.3. Rover Auxiliary Equipment

Hazard-identification cameras are used in pairs to create three-dimensional information about the rover's front and rear surface effects.

The Navigation Camera is another pair of black-and-white cameras. Like the open horizon camera, it is in front of the rover and provides wider-angle images. This tool does not have a filter to create color images and provides a general picture of the surrounding environment for navigation.

In addition to driving the rover, wheels may be used to dig large shallow pits to evaluate soil properties and create new soil (Tian et al., 2021).

Figure 5.20 illustrates extensive information about the Mars Rover's components, which will be extremely useful to civil engineers building and sustaining settlements on Mars. These painstakingly built rovers are loaded with several sophisticated sensors and equipment, including cameras, spectrometers, drills, and communication devices, allowing them to gather a wealth of data about the Martian landscape. Civil engineers can use the knowledge provided by these rovers to make informed decisions on settlement design, construction methods, and building management practices that are tailored to the Martian landscape's distinct issues.

This collaborative effort by Mars rovers and civil engineering professionals has the potential to pave the way for effective and long-term human living on the red planet.

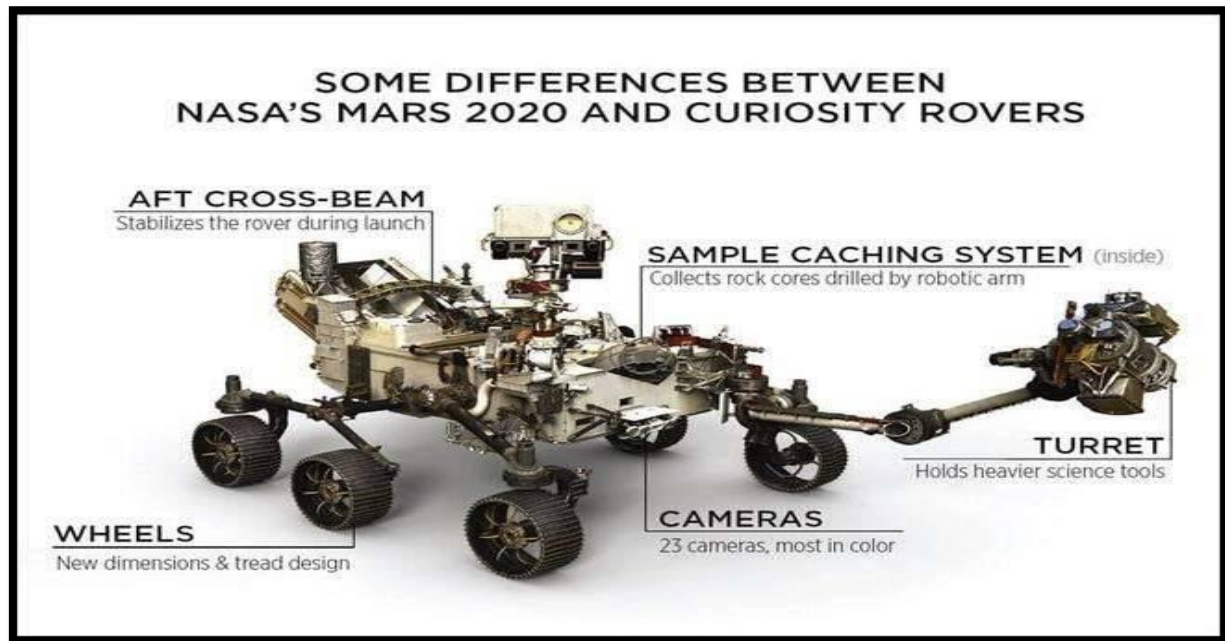


Figure 5.20: Rover Auxiliary Equipment (Raghunandan, 2021)

5.4.4. The Newest Explorer

This year, they launched a spacecraft from Cape Canaveral, Florida, to Mars. If everything goes as planned, this spacecraft will reach Mars in 9 months.

This spacecraft, named Phoenix, will search beneath the surface of Mars to find signs of possible life in the past or present on Mars. NASA plans to land the probe in May 2008 on a flat site similar to North Alaska on Earth. Unlike many other probes (including the Ghost and Opportunity rovers that are still operating on Mars), this probe does not have wheels and, therefore, cannot move on the surface of Mars. This small circular lander has three legs and is full of laboratory instruments, soil sampling, and analysis equipment.

Phoenix is the name of a legendary bird that rises from its ashes and rises again. The Phoenix probe was formed from the ashes of Mars Lander's failed space mission and another mission, Surveyor Lander, which was canceled in 2001.

It is believed to exist on Mars at a distance of tens of centimeters below the surface, in which case it will be accessible to the 2.4-meter robotic arms of this lander.

Scientists believe that about fifty to seventy percent of the upper parts of the Martian soil are made of water. This mission will not only shed light on the history of the ice in this part of Mars but also determine whether microbial life can exist there.

To find answers to these questions, this probe examines the complex molecules containing carbon (organic compounds) in the soil and examines the signs of periodic ice melting. Peter Smith, one of the researchers on this mission and a professor at the University of Arizona, says, "The main question is whether the ice has melted or not because liquid water along with soil provides a suitable habitable environment that is necessary for the formation of life." According to him, a habitable environment for microbes means that there is liquid water, complex organic molecules (the same type of substances that make up our body, such as proteins and amino acids), and an energy source on Mars.

Another researcher asks, "Why did the Viking probe (the Mars exploration mission carried out in the 1970s) not find organic molecules in the Martian soil?" Some scientists believe that there are mechanisms that can decompose organic molecules on the surface of Mars. Nevertheless, this mechanism may not be efficient in the polar regions because the water and ice in these regions destroy the oxidants that decompose organic substances.

Once the Phoenix reaches the surface of Mars, using energy provided by the solar panels, it will deploy its robotic arm and dig through the ground to get to the ice layer. After that, soil samples from this layer will be collected and brought to the lander deck to be examined by the Phoenix's powerful instruments. These tools examine the samples for the presence of water and organic matter, measure their physical properties, determine the abundance of various substances, and take microscopic pictures of the dust particles.

"This is the first time we have had an instrument on a probe that's gone to Mars that can look at a single speck of dust," says Dr. Tom Byck of Imperial College London and one of the project's scientists. These dust particles are fundamental because they cover the entire surface of the Red Planet, and their presence has many engineering and climate implications. For example, dust from Mars has

covered the surface of the solar panels of two rovers active on Mars, and as a result, it has become challenging to supply energy to these rovers.

This probe also examines the atmosphere and the climate of the Martian pole. According to current plans, Phoenix will operate on Mars for three months. Lockheed Martin is the manufacturer of this probe. Most of the equipment and tools used in the construction of Phoenix were previously designed and built for the 2001 Mars Surveyor lander. Since then, the tools have been stored in a clean room until the Phoenix program is again up and running. Of course, some of these parts have been reused similarly, and others have been upgraded. This lander is made of these parts.

- a computer system for commanding the probe and data management.
- An electrical system that also has solar panels and batteries.
- communication systems that communicate directly with Earth, the Mars Discovery Orbiter, and Mars Odyssey.
- a complex guidance system to land the probe successfully.
- A propulsion system with six hydrazine engines to safely land the probe.
- The main body of the probe ▪ has Several mechanical systems to move the various parts of the spacecraft.
- a complex temperature regulation system so the probe does not get too cold.
- A Treasure for Posterity Phoenix also has the Planetary Science Society collect a DVD mounted in its body and contents.

This compact disc is a multimedia collection called "Visions of Mars" and the literature and art related to Mars. There are ice tens of centimeters below the surface of Mars, in which case it will be accessible to the 2.4-meter robotic arms of this lander. Scientists believe that about fifty to seventy percent of the upper parts of the Martian soil are made of water. This mission clarified the history of ice in this part of Mars and determined whether microbial life could occur in this part (Tian et al., 2021).

Figure 5.21 depicts the landing site of the Mars rover, a vital location with the possibility for future settlement construction on Mars. The landing site selection is strategic since it gives essential information on the area's environmental conditions,

geological features, and available resources. The information acquired by the Mars rover stationed at this landing location is critical in assessing the area's feasibility for human habitation, identifying potential hazards and challenges, and determining resource availability. Scientists and engineers may use data from the Mars rover to make informed decisions on settlement design, infrastructure building, and resource usage techniques, setting the groundwork for long-term colonization efforts on the red planet.



Figure 5.21: The newest explorer (Nasa)

5.5. Mars Biologically

The temperature of Mars at the equator reaches 24 degrees Celsius during the day and drops to -73 degrees Celsius at night. These conditions make Mars a tolerable place for life. However, there are certain forms of life there. Several factors confirm this. For example, physical barriers easily prevent the penetration of ultraviolet radiation. Oxygen, nitrogen, and water are sufficient to sustain complex organisms such as bacteria, molds, and lichens.

It seems possible to have a layer of permafrost in the subsurface soil. This ice occasionally melts locally and so creates water for living organisms. There is a small amount of nitrogen in the atmosphere, but chemical salts also contain nitrogen in the soil. Bacteria, algae, mold, lichen, and some higher plants and insects were placed in artificial Martian environments, and it was observed that a surprising number of these organisms survived. Even some bacteria and molds tolerated these harsh conditions well as long as there was water.

Some experimenters have produced carbon compounds in pseudo-Mars conditions. They exposed mixtures of carbon monoxide, carbon dioxide, and water vapor in sterile or glass soil to ultraviolet radiation. They obtained some more complex carbonaceous compounds, which appear to be involved in forming even more complex biological compounds.

It is impossible to precisely reproduce Mars's conditions in the laboratory because we know little about them, and our techniques still need to be improved. Also, the test organisms were given enough water and oxygen to survive while we were still determining if there was enough oxygen and water to sustain terrestrial life on Mars.

If terrestrial life can survive on Mars, space probes can easily infect this planet. So, to avoid this, we have to disinfect every spacecraft we want to land on Mars (Russell et al., 2022).

5.6. The Existence Of Life On Mars

Today, there is no vegetation on Mars, not even simple forms like moss and lichen. If there is life in it, it is in the form of straightforward plants that have not been discovered yet. Most likely, there is no life on Mars now, but it is possible that in the distant past, a different situation prevailed. Once upon a time, there were streams full of water on this planet in the form of streams and rivers. Currently, scientists believe that the only water on Mars is in the regions of its polar ice caps, which never melt (Wormald et al., 2022).

5.7. Space Lasers

A new step in discovering life on Mars To investigate a specific issue, lasers can be used in a spectrometer device. One of the applications of the spectrometer is to detect chemical compounds using light. For example, when a light beam passes through a gas, the desired gas has specific effects on its wavelength. For instance, many gases absorb different wavelengths of light. Therefore, the light passing through the gas can be a unique fingerprint of that gas. (Therefore, with the help of a spectrometer, we can identify the type of gas).

For example, when a spectrometer absorbs sunlight from the top of a city, it can determine what gases the air in that city contains or the level of air pollution in that city. Now, a particular laser spectrometer can go in all directions and measure the amount of gas present. (In your opinion) For example, how can this device search for traces of life on Mars?

Yes, it is true. One way to search for life is through methane gas. Methane is a gas produced by living organisms, such as bacteria. Even a tiny amount of methane on Mars can mean some living organisms live there well and happily. Scientists are sending unique spectrometers to Mars as part of a rover.

Scientists believe that methane, and only methane, absorbs a specific wavelength of light; therefore, just like adjusting the sound in a radio station, scientists adjust their laser spectrometers to that wavelength. The spectrometer's laser aims at a stone at a distance from the rover and throws its beam at it. This beam passes through the Martian air with pressure, hits the stone, and then returns to the spectrometer. The meter returns. Suppose the return of the laser light emitted from the rock is weaker than before. In that case, it means that the methane in the Martian air has absorbed some of the energy of this laser beam with a unique wavelength, and the amount of energy absorbed by the methane indicates that the amount of methane is available.

5.8. Identification Of Martian Rocks And Sands

So far, various types of rocks and sediments have been discovered on Mars; most of these are similar to the rocks on Earth. Historically, the chemical composition of

Martian soil was understood by data from remote telescopic observations. These data indicate that a small fraction (2-4 wt%) of crystalline iron oxide, such as hematite, is present in a matrix of more poorly crystalline ferric oxides and other spectrally neutral aluminosilicates. These interpretations indicate the presence of homogeneous and fine-grained weathering products as the main component of soil everywhere on Mars.

Most of the remote sensing data from the Viking probe was obtained before the Mars rover landed. The Mars rover exploited the body of knowledge in the Mars soil by focusing on morphological, geochemical, and mineralogical characteristics. This mission carried a lander equipped with multi-spectral imaging capabilities compared to Viking. The highly mobile rover, capable of conducting soil mechanics experiments, was also equipped to measure soil and rock elemental chemistry (NASA, 1989).

Table 5.1 identifies the chemical structure of Mars's surface. This table and its explanations can help researchers use the surface of Mars itself to make concrete for 3D printers. Transferring equipment to Mars is more complex than transferring materials to Mars. So, now that the structure and atmosphere of Mars have been examined in , this table can be used as another knowledge option for construction on Mars.

Table 5.1: Mars Soil Mineralogy (Author)

	Na ₂ O	MgO	Al ₂ O ₃	SiO ₃	SO ₃	Cl	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃
Pathfinder soil	2.2	7.5	8.3	48.6	5.4	0.6	0.3	6.3	1.1	17.5
Viking soil	-	6.0	7.2	43.4	7.4	0.8	-	5.8	0.6	18.2

According to the investigation of the rover, which was equipped with soil mechanics testing facilities, the results of the rover test are shown in the first row, which is more accurate than the investigation of the Viking rover, which reached the results of the second row by examining the optical spectrum. Examining Table 2 shows that the surface of Mars has many sources of silicon and iron. Of course, the results obtained are similar to those of Viking, but they are more accurate.

Figure 5.22 shows a detailed picture of Mars' soil and rocks, emphasizing the importance of these resources for colony development and prospective agricultural activities. Understanding the chemical composition of Martian soil is critical for determining its viability for various building and farming applications. By examining the composition of soil and rocks, scientists can find essential minerals and elements used in building materials and nutrient-rich substrates for plant growth. This understanding permits smart resource utilization and agricultural methods, establishing the framework for long-term colony expansion and food production on the red planet.



Figure 5.22: Identification of Martian Rocks and Sands (NASA)

5.9. Concrete Used on Mars

Martian concrete was created by simulating Martian rock using basalt, which was tested for elemental and chemical composition using energy-dispersive X-ray spectroscopy (EDX). Basalt samples were very similar to Martian soil, which confirmed its use. Martian concrete was mixed at different sulfur-to-concrete ratios using a maximum nominal aggregate size of 1 mm and molten sulfur acting as a binding agent. Using the ASTM C39 compressive strength test and the ASTM C78 flexural strength test on the mixtures, it was determined that the mix with a 1:1 sulfur-to-aggregate mixture was the strongest, which yielded results of 22 and 4 MPa, respectively (NASA, 1989).

5.10. Mars Buildings

Caves were the first dwellings for humans, as the solution to shelter was as simple as finding a hole to live in. If present on Mars, natural caves would be a suitable early shelter for some aspects of Mars colonization. They will not be ideal for most required structures because they are limited in location, size, and ease of access. Nevertheless, living underground is a desirable option, so digging artificial caves is more likely to be used than natural caves.

Underground structures have many advantages, such as a more stable temperature, a safe environment, and protection from solar radiation and micrometeorites. On Earth, human underground construction involves large equipment for digging holes, explosives that break rock, and conveyor systems for removing waste. Since then, protecting the planet Mars has been the goal, but more than digging a hole is needed. Spaces should be created as tunnels that are extended to form caves. A logical choice for this is a mining device called a road header.



Figure 5.23: Road Header During Operation (Nasa)

Figure 5.23 depicts a drilling machine and emphasizes the importance of modern machinery for construction and maintenance in Martian communities. Such equipment and whether in the form of robots or remotely operated devices and are

critical for excavation and resource extraction and an' infrastructure building on Mars. These specialized machines are built to resist the harsh Martian climate and can execute a variety of activities required for settlement construction and management and including as drilling for water or minerals, constructing habitats, and constructing habitats and performing repairs. Their deployment demonstrates the importance of technical innovation and automation in enabling human presence and long term development on Mars.

Colonizing Mars, building subterranean cities and towns, developing advanced transportation methods to reach resources and other settlements, locating and using available resources safely and securely, and doing all the construction in an alien environment would be difficult at best. Martian surface cities will be very complex. They must be thoroughly heated and temperature controlled, protected from radiation, always supplied with the right mixture of gases, safely fed, and fed reliably. Domed cities may be the stuff of science fiction, but their ability to provide an outer layer of protection while giving the illusion of being outside may make them so popular.

It is necessary to provide intelligent alternatives to traditional energy sources on Mars, using new methods of capturing solar energy. Air, land, and eventually sea forms of transportation must each be able to move people safely and reliably at much greater speeds than here on Earth. A train should be able to travel from one city to another in a short period and so reduce the apparent distance between settlements. If the distances seem significant, the colonists feel confined and imprisoned (NASA, 1989).

Figure 5.24 portrays a colony snuggled into Mars' subsurface, demonstrating one potential strategy for reducing the risks associated with meteor impacts on the planet's surface. Underground towns protect against meteorite impacts, sheltering inhabitants and infrastructure from possible damage. Other novel solutions, such as reinforced surface structures or improved shielding technology, could be used to protect Martian communities against meteorite attacks. The choice of settlement architecture is determined by various criteria, including safety considerations, resource availability, and technological capability, with the ultimate goal of

ensuring the durability and lifespan of Martian colonists in the dynamic and harsh environment of the red planet.

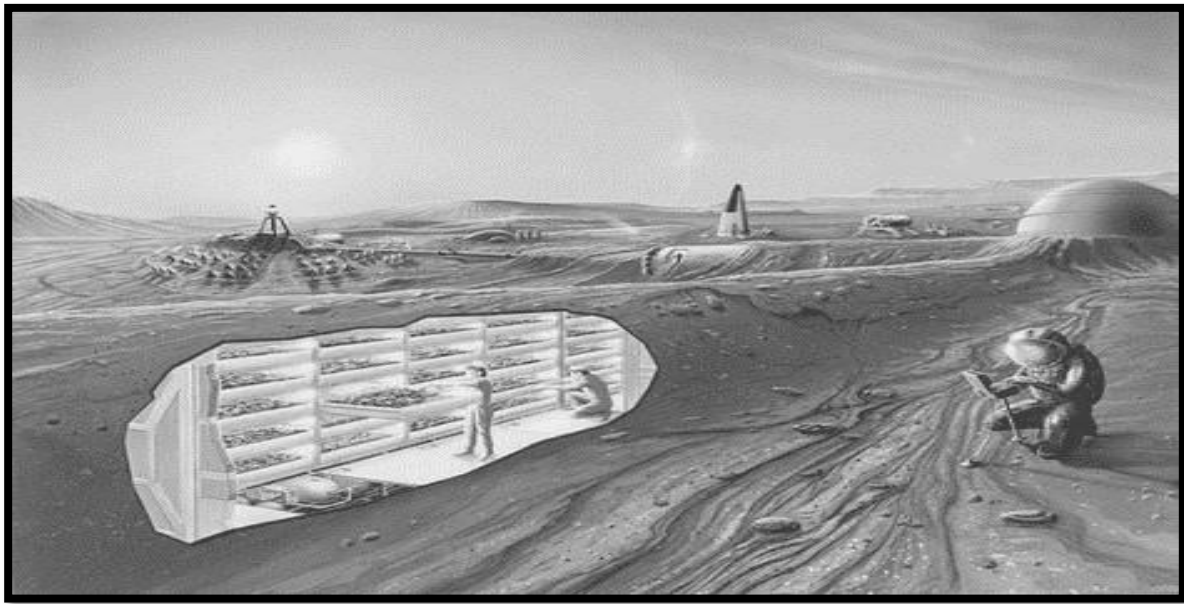


Figure 5.24: Underground Shelter In Cross-Section (Nasa)

5.11. The Requirement To Use BIM in Mars Buildings

BIM is a digital construction project management method standardized in many countries, such as the United Kingdom and the United States. With the help of BIM, project members can digitally represent Martian building models along with all relevant information throughout the planning process and development life cycle. As such, BIM supports not only the more efficient planning and execution of construction projects but also the realistic assessment of costs, schedules, and sustainable use of materials.

Figure 5.25 depicts a Martian house, demonstrating the potential application of Building Information Management (BIM) technology for design and management. BIM enables the generation and maintenance of digital representations of a structure's physical and functional properties, providing a comprehensive platform for collaborative design, construction, and facility management. Architects and engineers can use BIM technology to speed the design process, optimize building efficiency, and enable efficient maintenance operations for Martian homes. This

innovative technology improves construction projects' precision, efficiency, and sustainability, helping to create robust and functional colonies on Mars.

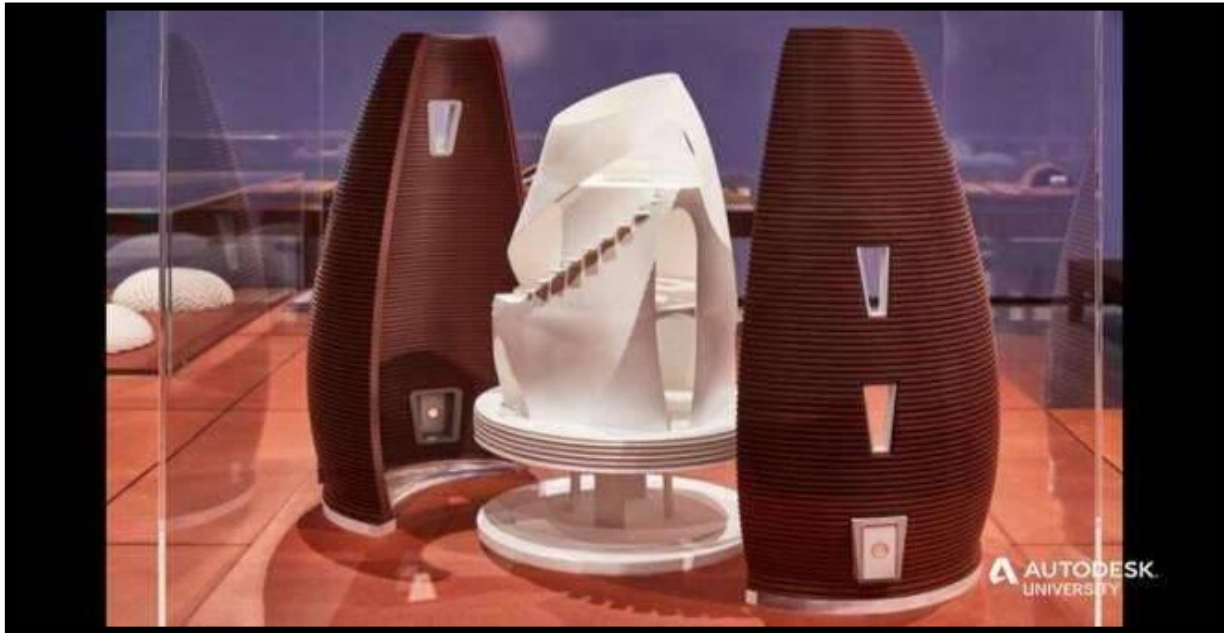


Figure 5.25: The Requirement To Use BIM in Mars Buildings (Nasa)

5.12. Mars Radiation

NASA's Pathfinder project has deployed various cutting-edge technological initiatives to address future human space travel demands. One of the missions that has been researched is installing outposts on the surface of Mars. Pathfinder's Surface Power initiative promises to provide ultra-compact solar array technology for these uses. To allow a more precise assessment of the size and mass of the photovoltaic power system in system analysis and trade-off evaluations of relevant technological alternatives, detailed information on solar radiation data on the surface of Mars is required.

The influence of dust storms on the output of solar arrays, which have been seen to occur locally and globally, is a significant source of worry. Since air turbidity may range from 3 to 9 depending on storm strength, it is generally considered that worldwide storms lower solar array production to almost nil. Furthermore, since such high turbidity levels may last a long time, the demand for energy storage rapidly becomes too enormous to be feasible. Even at extreme obscurities, there is

still a discernibly significant scatter component, allowing for the continued functioning of solar arrays.

Direct radiation and dispersed radiation are the two types of solar radiation present on the surface of Mars, much like on Earth. Scattering and absorption impact the direct beam along the route from the top of the Martian atmosphere to the surface. The optical depth of the Martian atmosphere may be used to calculate the radiation's absorption and scattering. The Viking lander's cameras captured specific diode pictures of the Sun and Phobos, which were used to calculate these calculations.

Data on Earth-terrestrial radiation are provided as long-term average values after being gathered over several years at many sites throughout the planet. Less than two Martian years' worth of optical depth data have been collected for Mars. Because of this, the predicted solar radiation in the current article agrees with the recent data. Additionally, the computed irradiance and observed opacities (optical depth) only apply to two places on Mars. Viking 1 (VLI) and Viking 2 (VL2) landers are situated at 22.3°N latitude and 47.9°N longitude and 47.7°N latitude and 225.7°N longitude, respectively.

Nevertheless, the similarities between the two landing sites' suspended dust features imply that dust exists elsewhere, at least at latitudes close to the landing locations. For latitudes 40°N to 40°S, VLI probe data may be utilized, and VL2 probe data for higher latitudes. The predominant component of Mars' atmosphere is suspended dust, which changes daily, seasonally, and yearly according to the length and strength of regional and global storms. The optical depth values listed in the section are believed to remain consistent throughout the day. Global storms, or days with low irradiance (dark days), correlate with large light depth values. The surface of Mars has an albedo that varies from 0.1 to 0.4. The calculated irradiances in the solar irradiance section are accurate to 0.1 albedo but may also approximate other albedo values (NASA, 1989).

Figure 5.26 illustrates the sun's potentially harmful rays directed toward Mars, a critical consideration for inhabiting the planet and managing structures. Understanding solar radiation patterns on Mars is essential for designing

protective measures against harmful UV rays and managing thermal conditions within habitats. Shielding materials, insulation, and architectural designs can be optimized to mitigate the adverse effects of solar radiation, ensuring the safety and well-being of inhabitants and the longevity of Martian structures. Additionally, harnessing solar energy for power generation while minimizing exposure to harmful rays is another aspect that requires careful consideration in Martian settlement planning and building management.

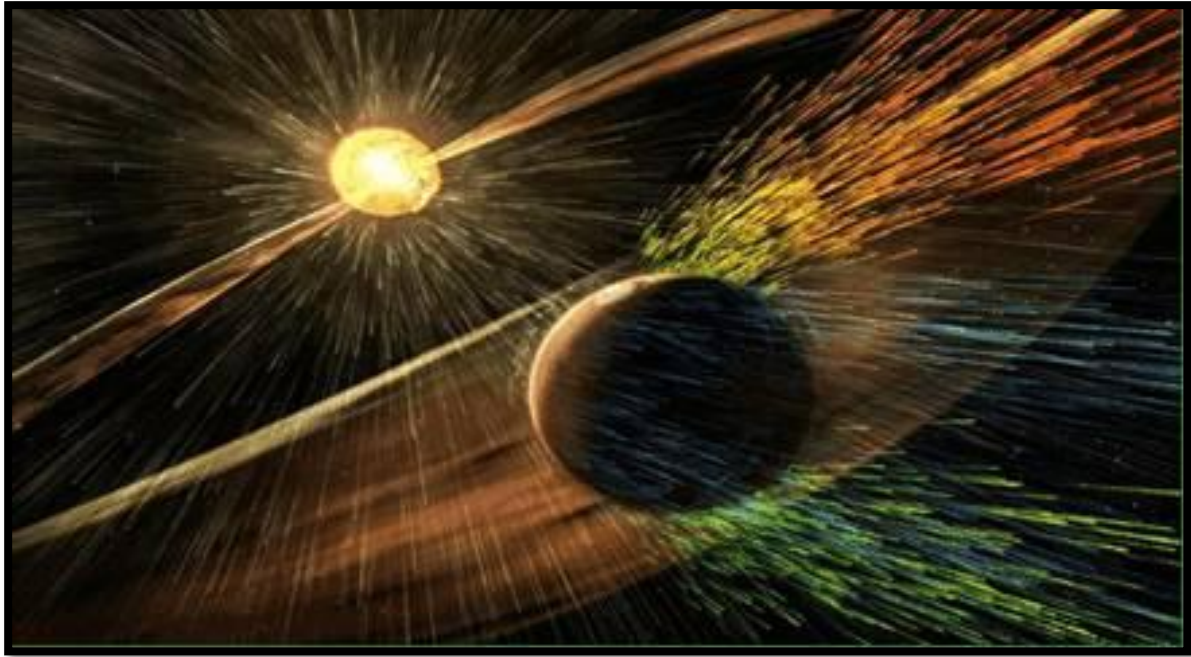


Figure 5.26: Mars Radiation (Nasa)

6. Methodology

6.1. Introduction

This Research has been implemented in two main parts, with the first part focusing on library studies and information collection from articles, thesis, etc. In this phase, the primary criteria for BIM in Mars buildings were derived from existing studies. These criteria were further refined through expert input using the fuzzy Delphi method. Based on the identified criteria, the necessary transactions were designed for the Blockchain in the second part. The proposed transactions formed the basis for presenting and implementing the proposed framework. The following section provides a detailed description of the intended research method.

The Delphi-fuzzy method was employed to screen the extracted criteria. This approach was chosen because researchers often encounter a multitude of criteria in their studies that cannot be adequately addressed in a single study or may not align with the research objectives. this relevant metrics were initially extracted from similar research, and these metrics underwent screening through the Delphi phase method to determine the most significant criteria related to the research topic.

The Delphi technique is a process based on group communication. typically used in situations where knowledge is incomplete or uncertain. Its primary goal is to achieve consensus among experts. In the traditional Delphi method, experts provide their opinions in specific numerical terms. However, due to the inherent uncertainty in many situations, experts often use qualitative language to express their views. This uncertainty aligns well with the concept of fuzzy sets, making it more appropriate to collect expert opinions in natural language and analyze them using fuzzy set theory.

A proposal was made to integrate the traditional Delphi method with the theory of fuzzy sets, resulting in the phase Delphi method. This approach incorporates membership functions to represent expert opinions. The advantage of the phase Delphi method lies in its attention to each expert's comments and its ability to integrate them to achieve group agreement. The implementation steps involve combining the traditional Delphi method with data analysis at each step using the definitions of phase sets. Fuzzy numbers, representing uncertainty about a phenomenon along with numerical data, were employed in this method.

The study utilized fuzzy numbers to extract the final framework and identify criteria influencing it based on the results obtained from the Delphi phase method.

6.2. Buildings on Mars

In its simplest sense, “concrete” combines a binder and an aggregate (filler). Most binders also require water as part of the concrete formulation (ES is a notable exception). Additionally, additives or admixtures may be used to modify the properties of the concrete, though they are not strictly required. On Earth, the use of OPC as a binder is so universal that OPC is colloquially referred to simply as “cement.” However, any substance that causes the components of a mixture to cohere is considered a binder, and alternative binders to OPC may be appropriate for Martian concrete.

An important point is that various methods have been presented for making concrete on Mars, all of which have been tested in laboratory conditions. All these methods have been implemented using a 3D printer in laboratory conditions. All buildings on Mars are designed and built using 3D printers, proving that the buildings on Mars and Earth differ. Therefore, different materials and tests must finally be done to reach a final model. However, the point that should be noted is that all the structures must be constantly checked (Reches, 2019).

In (Kading & Straub, 2015) research shows the human-crewed mission to Mars. In this mission, in the first phase, robots and devices will be deployed on Mars to build structures, and in the second phase, these devices and robots will be used as a practical base to advance the goals of human habitation. They are on Mars, and they start working. This Research presents suggestions for the concrete used in Mars buildings using a 3D printer. Also, other equipment to be used on Mars to continue human life, including the facilities required for structures, how to enter and exit, air conditioning, how to lay cables, how to use water, etc., have been stated. Finally, other methods The proposed methods have been compared. An essential point in these articles is using a 3D printer for designing structures. Also, the type of utility structure is of particular importance. Shows how performance-based design tools can be implemented as an architectural design method that proposes

an innovative approach to designing housing shells in extreme environmental conditions without human assistance.

This study attempts to use the environmental data disclosed by NASA and its habitat design requirements to develop a conceptual design for an innovative habitat form and then simulate it with Martian conditions to determine the structural behavior of the habitat shell according to finite element analysis. As a result, two established typologies of proposed habitation forms are presented in terms of their structural performance under the extreme loads of the Martian environment.

Internal radiation analysis is essential to assess the habitable crust's cross-sectional thickness and the thickness needed to provide maximum radiation protection. Wind is also a significant concern on Mars. The thickness of the housing shell section should be designed in such a way as to prevent the exchange of air inside and outside the housing, and this should be controlled ventilation. Also, this thickness should be such that it has the necessary resistance against the wind. Also, the windows' place and resistance in settlements should be considered.

Mars provides plenty of raw materials to establish a lasting, self-sufficient human colony on its surface. Due to the planet's vast distance from Earth, providing a permanent, interplanetary supply is neither possible nor economically reasonable. In-situ resource utilization (ISRU) will be necessary to keep the Earth launch burden and mission costs as low as possible and provide various construction materials apart from propellant and life support.

Including outposts on other planets in human spaceflight opens new psychological and sociological challenges. Crews will live in extreme environments under isolated and confined conditions for much longer than ever before. Therefore, designing a Mars habitat requires careful consideration of the physiological and psychosocial conditions of living in space (Dede, 2022).

According to Table 6.1, library studies show that these are the most important criteria that should be evaluated and screened for BIM in Mars buildings.

Table 6.1: Extracted Variables (Author)

Walls	Building components
The roofs	
Meteor protector	
Required building facilities	
window	
Air temperature	The interior of the building
Air pressure	
Ambient oxygen	
Ambient carbon dioxide	
Ambient humidity	
Amount of light	

6.3. Fuzzy Delphi

The Delphi method effectively gathers ideas and perspectives from expert opinions within a structured group communication framework. This strategy is beneficial when navigating settings characterized by ambiguity and limited knowledge, where fuzzy sets are essential in refining ambiguous concepts and laying the groundwork for making educated decisions. With its training in enabling nuanced debates and application in research and thesis creation, the Delphi method emerges as a valuable instrument for identifying original ideas and providing critical information to decision-makers.

Using the Delphi approach, researchers and decision-makers can tap into the collective wisdom of experts, allowing them to navigate challenging environments with greater clarity and certainty. This strategy creates an environment suitable for discussing creative solutions and making well-informed judgments using a consensus-driven approach. As a result, the Delphi approach helps bridge knowledge gaps and uncertainties and enables individuals and organizations to make strategic decisions informed by expert insights and collaborative conversation.

Figure 6.1 shows the entire process of fuzzy Delphi methodology, this process includes three phases, in this research, the main criteria were obtained in the first stage using fuzzy Delphi.

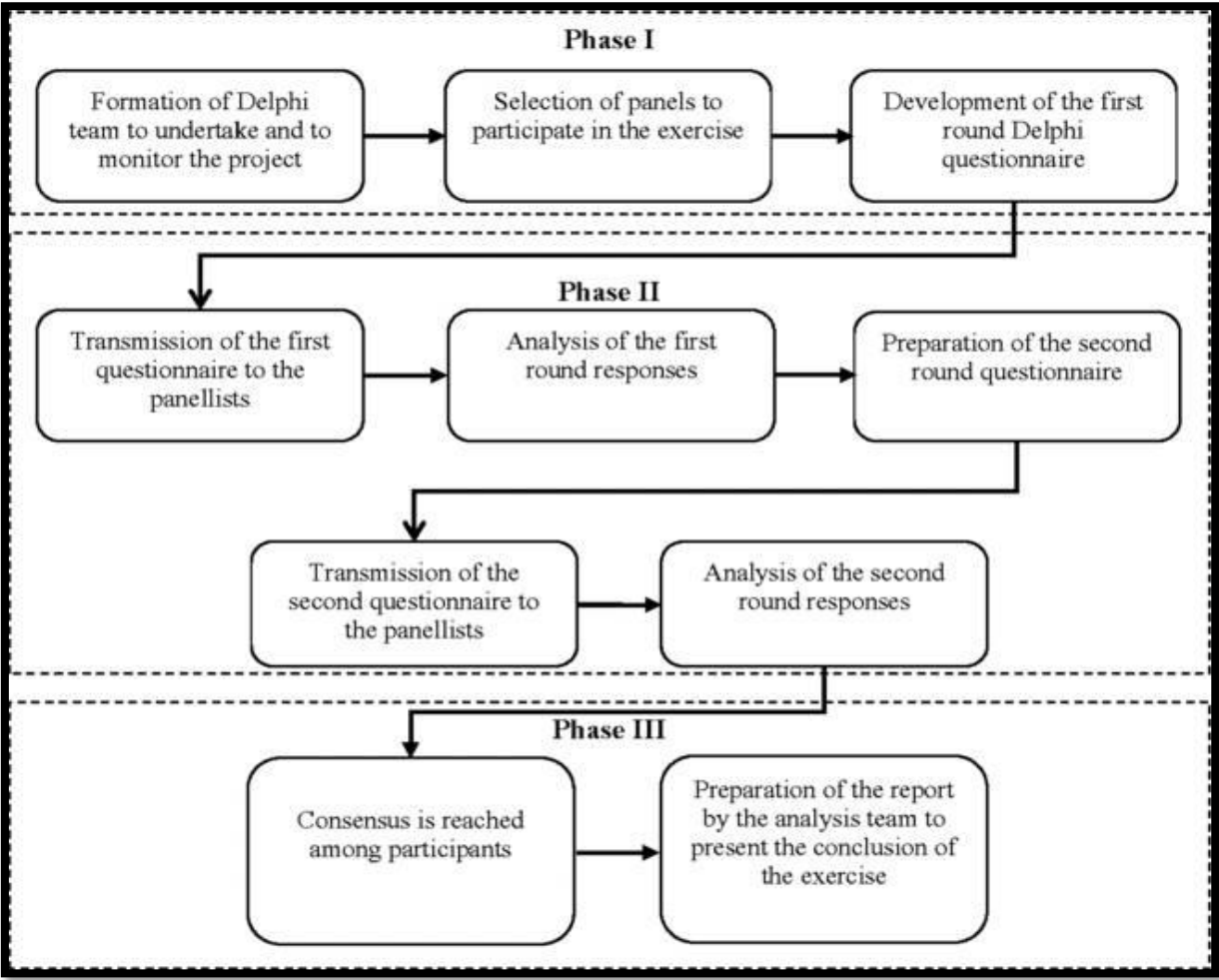


Figure 6.1: Fuzzy Delphi Process (Author)

Delphi is a powerful technique for extracting ideas and opinions from the collective agreement of experts' judgments, so it is based on a group communication structure. This technique plays a significant role in feeding and improving the implementation of the Dematel technique. It is used in cases where uncertain and incomplete knowledge is available to achieve group consensus. Since experts use their mental capabilities to present their opinions, uncertainty is possible. Therefore, it is better to integrate and analyze the data using fuzzy sets.

Fuzzy theory can mathematically transform many ambiguous concepts and provide a basis for decision-making in conditions of uncertainty. The Delphi method's training includes the required part of fuzzy discussions and the fuzzy Delphi

technique to gather opinions, which is mainly used in conducting research and writing theses.

The Delphi method is used in future research and pursues goals such as discovering innovative ideas and providing information for decision-making by identifying and screening the most essential decision-making indicators. The Delphi method is one of the best methodology for obtaining the opinions of experts in the research field, and combining it with Fuzzy logic makes it possible to use this method in qualitative cases as well.

There was a temple in the ancient city of Delphi attributed to Apollo, the god of the sun, music, and poetry; it was named the forerunner of Delphi. The Pythia was widely credited for his prophecies, inspired by Apollo, and was consulted before any important decision was made. The ancient city of Delphi has been transformed into a modern city and remains. Pythian oracles have also been replaced by a contemporary approach known as the Delphic technique.

For the first time in the late 1950s, in research by the US RAND Corporation, Delphi was introduced to scientifically study experts' opinions on the military defense project (Powell et al., 2004). The main goal of the Delphi method is to obtain the most reliable consensus from a group of experts with a set of intensive questionnaires with controlled feedback (Dulkey & Helmer, 1963).

Researchers can identify and prioritize problems and develop a framework for their diagnosis by obtaining the consensus of a group of experts using this process (Eckley & Pawlowski, 2004). Lynnstone and Turoff (1975) defined the Delphi technique as a method of structuring a group communication process so that this process is effective in allowing a group of people, as a whole, to deal with a complex problem. This definition has been adopted by several researchers (Wang et al., 2003).

Hasson et al. (2000) argued that different Delphi techniques exist. Modified Delphi, policy Delphi, and real-time Delphi have been used (Hasson et al., 2000). Generally, three types of Delphi are used: traditional Delphi, policy Delphi, and decision Delphi (Van Zöllingen & Klaasen, 2003). A series of questionnaires were used to collect

data from a panel of selected participants, and the Delphi technique was used to build consensus (Yang & Jamieson, 2001).

Several studies have been conducted using the fuzzy Delphi technique. Kaufman and Gupta (1988) developed the application of the fuzzy Delphi technique for forecasting. Ishikawa (1993) also developed the Delphi technique with triangular fuzzy numbers (Ishikawa, 1993). The Delphi technique is a structured process for collecting data through successive rounds and finally reaching a group consensus. Despite more than half a century of using the Delphi technique in scientific and academic research, there are still many uncertainties about this technique.

6.3.1. Fuzzy Delphi Technique Algorithm For Screening

The Delphi technique with a fuzzy approach can be used to determine the importance of criteria and screen key criteria. One significant advantage of the fuzzy Delphi technique compared to the traditional Delphi technique for screening criteria is that it can be used remotely to summarize and sort items.

The fuzzy Delphi technique algorithm includes the following steps:

- Identifying a suitable spectrum for fuzzification of linguistic expressions
- Fuzzy accumulation of fuzzified values
- De-fuzzification
- Choice of threshold and screening criteria

As shown in Table 6.2, the fuzzy Delphi technique algorithm for screening, first, a suitable fuzzy spectrum should be created to fuzzize the linguistic expressions of the respondents. For this purpose, it is possible to use the methods of developing fuzzy spectra or typical fuzzy spectra. For example, the triangular fuzzy spectrum for a five-point Likert scale on the importance of criteria is as follows:

Table 6.2: Triangular Fuzzy Numbers With A Five-Point Likert Scale (Author)

very important	important	medium	unimportant	very unimportant
(0.75,1,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)

In This Research, this method of criteria is used. Experts ' opinions are collected and fuzzy after choosing or developing a suitable fuzzy spectrum. In the second

stage, experts' opinions should be gathered. Several methods have been proposed for the fuzzy aggregation of experts' opinions. If an expert's opinion is represented as a triangular fuzzy number (l, m, u), the simplest way to calculate the fuzzy average of experts' opinions is:

$$F_{AVE} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n}$$

The values should be de-fuzzified after the fuzzy aggregation of experts' opinions. The researcher finally converts the final fuzzy values into a clear and understandable number using different methods, using the fuzzy approach. Typically, triangular and trapezoidal fuzzy numbers can be summarized by an explicit value, which is the best mean. This operation is known as fuzzification. There are many and complex methods for fuzzification. One of the simplest fuzzification methods is average triangular fuzzy numbers:

$$F_{ave} = (L, M, U)$$

$$x_m^1 = \frac{L + M + U}{3}$$

$$x_m^2 = \frac{L + 2M + U}{4}$$

$$x_m^3 = \frac{L + 4M + U}{6}$$

$$crisp \text{ number} = Z^* = \max(x_{\max}^1, x_{\max}^2, x_{\max}^3)$$

The values $x_{\max}^i$ They do not vary much and are constantly close to M. M is the average obtained by summing the possible values of m from different triangular fuzzy numbers. However, the explicit value is considered the maximum.

A threshold should be calculated after choosing the appropriate method and unfuzzifying the values for screening. This threshold is usually 0.7 but varies according to the researcher's opinion in different studies. The criterion is met if the apparent value of the unfuzzification of the collected expert opinions is greater than the threshold. If the criterion is less than the threshold, it is removed.

The factors affecting the information management of Martian buildings are shown in the below table. The researcher made this questionnaire because there was no valid and approved questionnaire in this field, and there was no research available to extract the required items with its help. Therefore, using the library studies, these criteria were extracted to control and manage those buildings using BIM in Martian buildings. So, elites and researchers in the field of Mars should screen these criteria so that the final criteria can be extracted. With the help of ranking these factors, the most essential criteria can be ranked, and based on the obtained rankings, the proposed framework can be explained.

Table 6.3: Questionnaire form (Author)

objects	Variables	very unimportant	unimportant	medium	important	very important
Building components	Roof					
	Walls					
	Meteor protector					
	Facilities required					
	Air exchange					
The interior of the building	Air temperature					
	Air pressure					
	Ambient oxygen					
	Ambient carbon dioxide					
	Ambient humidity					
	Amount of light					

6.4. Fuzzy AHP (Analytical Hierarchy Process)

The Analytical Hierarchy Process (AHP) is a highly effective technique in decision-making experiments and studies. It serves as the foundation for this strategy based on pairwise comparisons. This quality allows managers and decision-makers to

investigate alternative scenarios extensively. One of AHP's primary advantages is its capacity to formulate problems inside a multi-level hierarchical structure, allowing for a more systematic approach to decision-making.

Despite the widespread use of the AHP approach for selecting many possibilities, the fuzzy hierarchical analysis procedure becomes necessary. Traditional AHP involves pairwise comparisons at each level based on the purpose of decision-making. Nevertheless, the fuzzy hierarchical analysis method becomes critical when dealing with complicated decision situations involving uncertainty and ambiguity, necessitating a more flexible and nuanced approach to decision-making.

Figure 6.2 shows the entire Fuzzy AHP process, at this stage the criteria are ranked, using this methodology in the second stage of this research, the criteria were ranked.

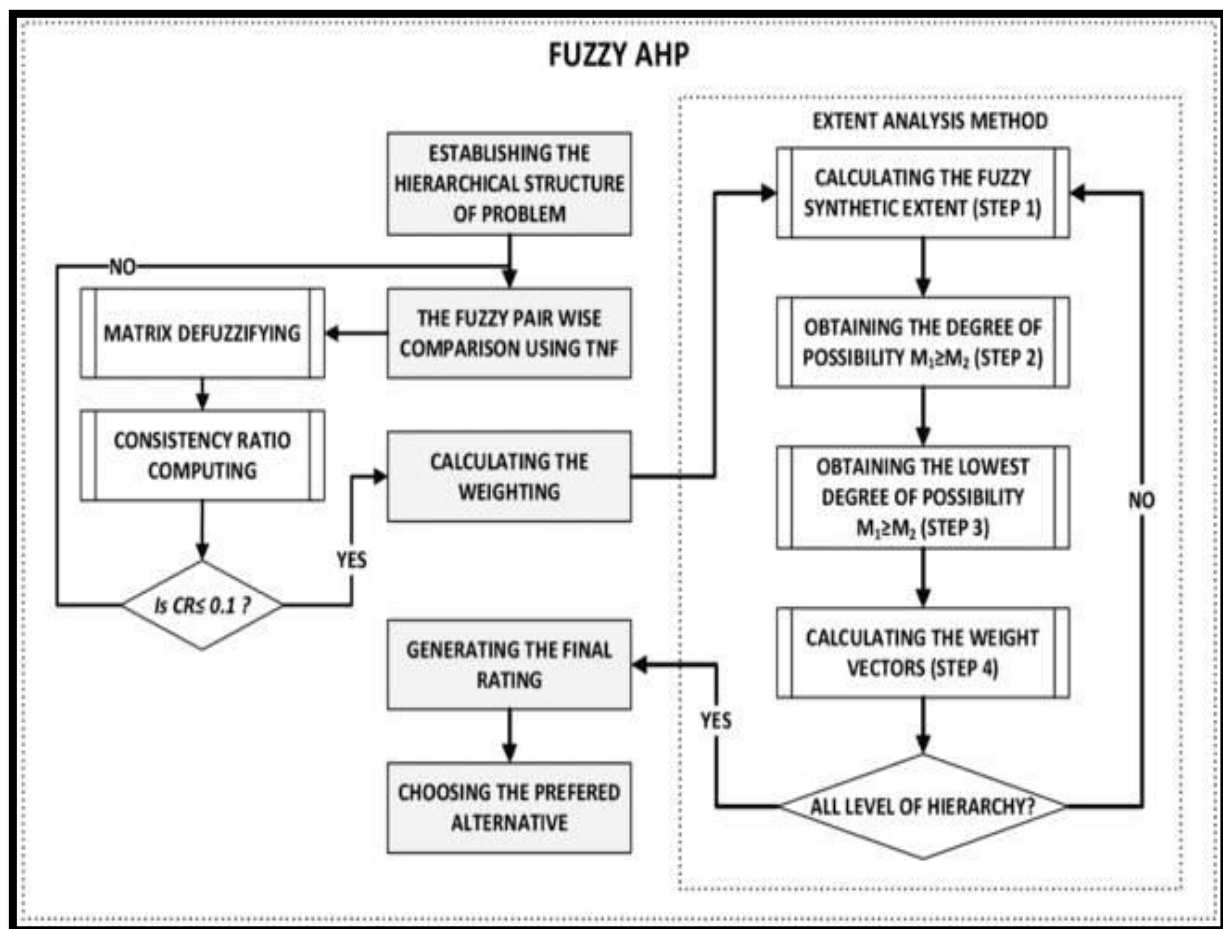


Figure 6.2: Fuzzy AHP Process (Leśniak, 2018)

AHP is one of the most effective techniques in decision-making experiments and analyses. AHP stands for Analytical Hierarchy Process and was first proposed by T. L. Saaty in 1980. This technique is based on pairwise comparisons, which allow managers and decision-makers to examine different scenarios. One of the advantages of this method is the possibility of formulating the problem in the form of a multi-level hierarchical structure.

The necessity of the fuzzy hierarchical analysis process: The AHP method has been widely used to choose one option among others. In this method, pairwise comparisons are made for each level to select the best option using a nine-point scale.

Therefore, the application of hourly AHP has some things that could be improved, such as the fact that the AHP method (1) is mainly used in crisp decisions. (2) It examines a very unbalanced scale of judgment, (3) the uncertainties in individual judgments need to be considered, and (4) the ranking of this method could be more precise. (5) Subjective judgments, choices, and performances of decision-makers have many effects on AHP results.

In addition, it is acceptable that people's evaluations of quality indicators are always subjective and, therefore, imprecise. So, the conventional and classical AHP must be more efficient in accurately achieving decision-maker needs. To model this uncertainty in human preferences, fuzzy set theory should be combined with pairwise comparisons to extend the AHP technique. This hybrid decision-making technique provides a more detailed understanding of the decision-making process.

AHP is a multi-criteria decision-making tool that can construct complex problems hierarchically, simplifying the evaluation of all criteria relevant to the decision (Saaty, 1980). All options are compared separately based on each criterion using a preference scale, and a priority list of options is obtained for each criterion. The most commonly used preference scale is the 1–9 scale. Fuzzy AHP enables the decision analyst to provide a more realistic score for alternatives in many uncertain cases. Chang's (1992) development analysis model is one of them, and it depends on the probability of each criterion.

Triangular fuzzy numbers (l, m, u) are used to create a pairwise comparison scale, and a pairwise comparison matrix is constructed for each level in the hierarchy. Then, the subsets of each row in the matrix are calculated to have a new set. The overall triangular fuzzy values (l_i, m_i, u_i) for the M_i criterion are obtained by calculating $l_i / \sum l_i, m_i / \sum m_i, u_i / \sum u_i, (i = 1, 2, \dots, n)$. Membership functions, which mean the average weight of the options in the corresponding matrix, are calculated using these values for each criterion. They are normalized, and each criterion's final weight of importance is obtained.

To apply the process depending on this hierarchy, according to Chang's (1992) development analysis method, each criterion is considered, and the g_i criterion is measured for each criterion.

The fuzzy hierarchical process method is used for weighting and ranking criteria or research options. There are three methods for calculating the weights in the fuzzy AHP method: 1—Chang's development analysis method, 2—improved fuzzy AHP method, and 3—Mykhailo fuzzy prioritization method. This section explains the fuzzy AHP method based on Chang's development analysis approach.

6.4.1. Step 1- Forming A Hierarchical Research Model

In this step, the hierarchical model of the research should be determined after identifying the criteria, sub-criteria, and research options.

6.4.2. Step 2- Forming Tables Of Paired Comparisons And Answering According To The Following Spectrum

As shown in Table 10.3 AHP method, pairwise comparisons should be created, and based on the following fuzzy spectrum, answer these paired comparisons. These nine spectra are a fuzzy AHP; of course, you can use 5 or 7 spectrums, but these nine spectra are standard.

Table 6.4: Fuzzy Number (Author)

Fuzzy number	Linguistic	The scale of fuzzy number
9	Perfect	(8,9,10)
8	Absolute	(7,8,9)
7	Very good	(6,7,8)
6	Fairly good	(5,6,7)
5	Good	(4,5,6)
4	Preferable	(3,4,5)
3	Not bad	(2,3,4)
2	Weak advantage	(1,2,3)
1	Equal	(1,1,1)

6.4.3. Step 3- Calculate the incompatibility rate of paired comparisons

In this step, the inconsistency rate of pairwise comparisons should be checked, and if this rate is less than 0.1, it means that the pairwise comparison has proper stability and compatibility. The inconsistency rate in fuzzy matrices can be calculated in two ways. First, the fuzzy pairwise comparison matrix is defuzzified, and then its inconsistency rate is calculated definitively or can be calculated using the Goss and Butcher inconsistency rate calculation method. Goose and Butcher's incompatibility rate is available on this site, which you can learn about for free by searching.

6.4.4. Step 4- Integration Of Paired Comparisons

When multiple respondents answered the pairwise comparisons, the geometric mean method was used to combine them. to obtain a merged pairwise comparison matrix. The integration of fuzzy matrices is such that the geometric mean of the first terms of all comparisons, the second terms, and the third terms are taken together.

6.4.5. Step 5- Calculation Of Weights By Chang's Development Analysis Method

First, we obtain S_i values for each row of the fuzzy pairwise comparison matrix based on the following relationship.

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1}$$

G_i is the target set, and M_{gi}^j are triangular fuzzy numbers. Then, based on the following relationship, we get the magnitude (degree of preference) of each S_i over S_k .

$$V(S_i > S_k) = \begin{cases} 1 & m_i \geq m_k \\ 0 & l_k \geq u_i \\ \frac{l_k - u_i}{(m_i - u_i) - (m_k - l_k)} & \text{otherwise} \end{cases}$$

In the last step, raw weights are calculated using the following relationship: each raw weight is divided by the total raw weights, and the average weight is obtained.

$$\begin{aligned} V(S \geq S_1, S_2, \dots, S_k) &= (V((S \geq S_1), (S \geq S_2), \dots, (S, S_k))) \\ &= \min(V((S \geq S_1), (S \geq S_2), \dots, (S, S_k))) \\ &= \min V(S \geq S_i) \quad i = 1, 2, \dots, k \end{aligned}$$

6.5. Suggested Method

After extracting the criteria shown in the table, these extracted factors should be validated by experts and specified with their opinions. First, an expert questionnaire is provided to these experts, which has five levels: important, unimportant, medium, low, and very low importance. Knowing the subject of the research and the extracted criteria, the experts give points to the criteria. Then, the final criteria of the study are extracted using the fuzzy-delphi-analysis-v2-01 software, the standard software for performing the fuzzy Delphi method. This

method shows which variables are most needed, which is achieved using the fuzzy Delphi technique. Then, these factors are ranked using fuzzy ranking or fuzzy AHP. This part is provided to the experts by presenting a pairwise comparison questionnaire, and now the experts give them points based on the degree of importance of each variable. Then, the fuzzy AHP method is implemented in MATLAB, and using its outputs, the rank of criteria is extracted to determine the level of warnings based on them. After this part is implemented, we will implement the proposed Blockchain -based method and express the results.

6.5.1. Framework BIM+Blockchain

Blockchain is a type of information recording and reporting system. Its difference from other systems is that the information stored in this system is shared among all members of the network, and by using encryption, it is impossible to delete and manipulate data.

Blockchain is a chain of blocks in which any information can be recorded. It consists of the two words block and chain, the general meaning of which is the chain of blocks. Each of these blocks has something called a hash. A hash is a string of characters that is made with unique functions.

Figure 10.1 illustrates an embodiment of the Blockchain. Our work shows that this chain is directly related to the research, and as mentioned, one of the outputs of This Research is that this Blockchain is displayed.

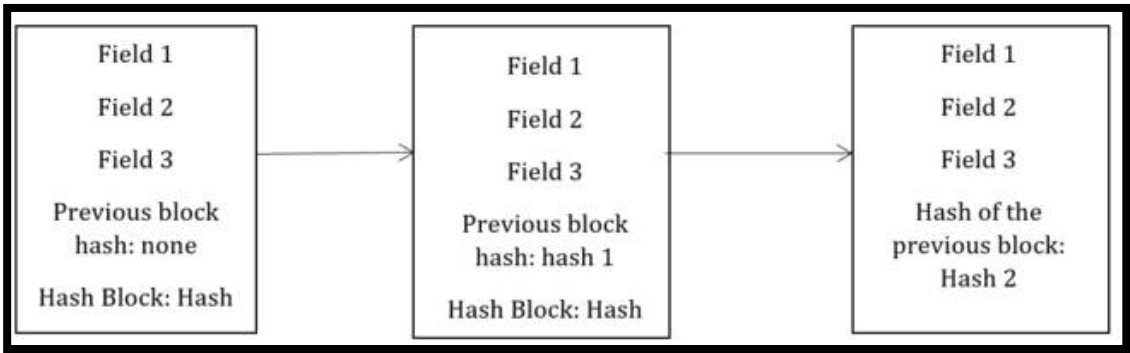


Figure 6.3: Blockchain Overview (Author)

In general, there are three types of Blockchain, which will be discussed further.

- Anti-monopolistic public Blockchain:

In this type of Blockchain, transactions are not monopolized. For example, to complete an event, it should be announced to all active people in the network, and this operation should be done. This type of Blockchain is used when the opinion of the entire community in that network is essential.

- Exclusive public Blockchain:

In this type of Blockchain, only certain people can confirm activities.

- Exclusive private Blockchain:

This type of Blockchain can be used for various private and public entities. In this Blockchain, specific people are selected to confirm the activities, and only specific people can view the recorded information.

The study used the first type of Blockchain. All the sensors used in buildings have to store their data on the Blockchain platform. The servers and service providers also store their information and processes on this platform. Regarding safety, the safest platform is used to store information because all network elements are involved.

6.5.2. Distributed Database

The information stored in the block is shared as a database and is constantly being reconciled. This method of using the network has apparent advantages. Blockchain databases are not stored in a specific location, meaning the records they maintain are public and easily verifiable. There is no centralized version of this information so that a hacker can destroy it. With data hosted by millions of computers simultaneously, its data is accessible to anyone on the Internet.

To implement this part, each block has an id that connects the blocks, which will be shown in This Research and the output. The distributed database system is essential because it can be used to maintain security. Not all clients in the network know which user's information is stored on the system, which leads to increased information security. Hackers cannot find information to access the information of

a unique client. This is also important for our research because we must be confident about data protection.

6.5.3. Durability and Strength of Blockchain

Blockchain technology is like the Internet, which has an internal strength. By storing blocks of information that are identical across its network, Blockchain cannot:

- Be controlled by a single entity
- It has no single point of failure.

Blockchain is truly a revolutionary mechanism that brings everyone to the highest level of accountability. There will be no false transactions, human and machine errors, or transactions without the parties' consent. Above all else, the most essential area that Blockchain helps in is guaranteeing the validity of a transaction by recording it not only in a central, centralized registry but also in a distributed system connected through a secure validation mechanism.

Relying on this feature of the Blockchain confirms the accuracy of information, which is one of the goals of this research. The accuracy of information received from sensors should be highly reliable.

6.5.4. The Idea of Decentralization

Blockchain is a decentralized technology. Everything that happens on it results from the network's overall performance, and this feature is used extensively.

Creating a new way to review transactions will make some aspects of traditional business unnecessary. For example, stock exchange transactions can be simultaneously placed on the Blockchain, or various audits, such as land registration, can be made entirely public.

Decentralization is now a reality. This way, we have a nonexclusive public Blockchain in which all buildings and residents can join, create Smart Contracts, and exchange information. One condition for membership in this Blockchain is to have sensors for all building members, which costs. Installing these sensors is the customer's responsibility, and the construction company must approve them.

These sensors are different depending on the type of contract with the company; for example, if the type of contract is only to adjust the oxygen in residence, the oxygen control sensors are installed in suitable places to send this information to the manufacturing company when the oxygen in the place decreases. Sensor information is stored in the cloud, which is then hashed, and its hash is placed in the non-exclusive public Blockchain.

Every contract created creates a ledger in the Blockchain. From now on, all transactions related to this contract are chained together in this ledger, and the hash of each block is stored in the next block. This means that if a minor change is made in the hash of one block, the hash of other blocks will also change, and all the blocks in the network will notice this change, which will make the information in. It is a Blockchain.

Each client has a private and public key and a digital signature to authenticate them. Customers can have a different public key to communicate with each company to increase the security of their anonymity.

6.5.5. Smart Contracts Methodology

Given the previous section and the necessity of a Smart Contract, this section examines the Smart Contract and how to contract between the customer and the service provider company. One type of information stored in BIM is how and where the sensors are placed in the contract. These issues are examined, and the need for a mechanism for signing a Smart Contract is one of the essential issues in this research.

The Smart Contract is essential because it mentions the sensors' placement, location, type, amount, and number used in a house. If a sensor sends an alarm through the Smart Contract, we will find out from where it sends the information and warning. It is also mentioned in the Smart Contract on which date these sensors were installed and when it is time to replace the battery or charge them. Also, according to the Smart Contract, we can find out how many sensors there are in the whole system, and if a sensor is out of service for any reason, with the help of the Smart Contract, we can find out the number and location of the out-of-service

sensors. Therefore, in the first step, there is a Smart Contract, the most essential part of the work. Also, the Smart Contract discusses the manner and amount of payments and financial management.

6.5.6. Negotiation Stage And User Contract Request

At first, the client becomes a member of the public non-exclusive Blockchain. Customers can get the company's public key through the company's website or Certification Authorities (CAs). The customer negotiates with the desired company about the terms, costs, and other matters of the contract, and then the customer requests the contract for the transaction. The company sends it. The structure of this transaction is as follows.

$$"T\_ID // Request\_Smart\_Contract // SP\_PK // User\_PK // Sing" \quad (1)$$

Equation (1) has been extracted according to the specifications of the customer and the company in question. Every customer must be able to communicate with a company; therefore, a public key is defined for every customer and every company active in this field so that the desired transaction can be saved in the Blockchain. Also, one token can be considered for each customer to sign electronic and digital contracts.

T_ID is the unique number and hash of the current transaction, Request_Smart_Contract is the customer's Smart Contract request to the construction company, SP_PK is the company's public key, User_PK is the customer's public key, and Sign is the customer's signature that specifies his identity. The customer submits this request to the Blockchain and sends it to the public non-exclusively.

The summary of the above transaction is shown in Table 6.5.

Table 6.5: Summary of Transactions (Author)

TRANSACTION	DETAILS
T_ID	The Unique Number And Hash Of The Current Transaction
Request_Smart_Contract	The Customer's Smart Contract Request To The Construction Company
SP_PK	Company's Public Key
User_PK	Customer's Public Key
Sign	Customer's Signature

6.5.7. Smart Contract Signing Stage

The construction company prepares the contract and sends it to the customer. After receiving the contract, the customer signs it and sends it to the desired company. The company also signs the contract and sends it to the Blockchain, and the construction company's signature is creating a new block. It is on the Blockchain. The structure of this transaction is as follows:

$$T\_ID || P\_T\_ID || User\_PK || User\_Sign || SP\_PK || SP\_Sign || Rfe.contract.ID \quad (2)$$

In the Blockchain, based on the standard defined in it, in order to create a Blockchain, it is necessary to store the hash of the previous block in the new block, in addition to the new hash, as a link between the two blocks; hence, according to the block Harshmand contract, which must be connected, the first two fields have also established this connection.

Also, the customer's public key, personal information, and signature are required to create a contract. After the customer signs, the company must have a public key as its profile and signature in the contract. The agreed items related to the project's sensors are included in this section.

T_ID is the hash of the current transaction, and P_T_ID is the hash of the previous transaction related to the same customer Smart Contract in the public Blockchain. User_PK and User_Sign are the customer's public key and customer's signature, and SP_PK and SP_Sign are the public key and signature of the construction company.

After the parties agree, the contract must be signed by the user and the company and placed in the Rfe. Contract. ID field of contracts related to sensors is mentioned in the contract. As mentioned, the conditions for concluding these contracts in the public Blockchain are that they must have sensors provided by the customer and installed by the construction company.

After installing the sensors, the customer adds his cloud, defines a new key, and sends the information from these sensors to the cloud. When the contract between the company and the customer is signed, the company needs to confirm the correctness of the customer's sensors by physical inspection. The construction company determines and informs the customer about the time to check the used sensors, such as the oxygen or temperature sensor.

Nevertheless, after signing the contract, creating a block in the public Blockchain for the intended user, and checking the sensors by the construction company, it is time to store the information and the information of the sensors used in the Blockchain platform. These include oxygen control sensors, temperature control sensors, and air exchange control from the structures and side walls of the building.

The summary of the above transaction is shown in Table 6.6.

Table 6.6: Summary of Transactions(Author)

TRANSACTION	DETAILS
T_ID	Unique Number And Hash Of The Current Transaction
P_T_ID	The Hash Of The Previous Transaction
User _ PK	Customer's Public Key
User _Sign	Customer's Signature
SP_ Sign	Public Key And Signature Of The Construction Company
Rfe. contract.ID	Field Of Contracts Related To Sensors

6.5.8. Sensors Methodology

Considering the harsh conditions on Mars and the necessity for real-time monitoring, using sensors is critical to ensure immediate alerts when vital factors are at risk. Any delay in responding to issues, especially those that affect essential systems, could lead to irreversible damage or jeopardize human safety. Therefore, sensors are a key component in the proposed framework, with specific types designated to monitor crucial elements. The framework includes four types of sensors: the first type monitors oxygen levels and air exchange; the second type regulates light, ultraviolet rays, and ambient temperature; the third type oversees the structural integrity of walls and roofs; and the fourth type controls building equipment.

Determining how many sensors a building needs and the specific structure of these sensors requires further research, particularly from electrical engineering experts. Factors such as the building's environment, size, and the areas that need to be monitored will influence the number and placement of sensors. This research could propose optimal sensor layouts and designs tailored to the Martian environment, ensuring precise, real-time control of critical systems and enhancing Martian habitats' overall safety and sustainability.

6.5.8.1. The Interior of the Building: Oxygen Sensor Control

At this stage, the sensors are programmed to measure the oxygen levels in the surrounding environment at predefined time intervals (using a time clock system). These measurements are taken automatically and periodically to ensure continuous monitoring of the habitat's air quality. After each set of data is collected, the oxygen levels are reviewed by an inspector, either human or through an automated validation system, to ensure the accuracy and validity of the data. Only after the inspector's approval is the data recorded and securely stored on the Blockchain platform.

This process ensures both real-time tracking of crucial life-support parameters and the transparency and immutability of the data, as the Blockchain platform makes it tamper-proof. The continuous validation and recording help maintain a reliable system for monitoring oxygen levels, ensuring the safety of the Martian habitat's occupants. The structure of this transaction is as follows.

$$"T\_ID || P\_T\_ID || S\_ID || \textit{Oxygen\_content}" \quad (3)$$

Since sensor information must be stored in the Blockchain, the received information and the way to store the oxygen sensor information in the Blockchain are as follows: T_ID is the hash of the current transaction, P_T_ID is the hash of the previous transaction, S_ID is related to the desired sensor number, and oxygen content is associated with the amount of oxygen in the environment.

The oxygen sensor is one of the most essential in Mars buildings. This sensor checks the amount of oxygen in the environment and warns if the oxygen level decreases. This sensor is necessary for Martian buildings because the atmospheric conditions of Mars and the oxygen in the environment are among the vital factors of humanity.

The summary of the above transaction is shown in Table 6.7.

Table 6.7: Summary of Transactions(Author)

TRANSACTION	DETAILS
T_ID	Unique Number And Hash Of The Current Transaction
P_T_ID	The Hash Of The Previous Transaction
S_ID	Desired Sensor Number
Oxygen_content	Amount Of Oxygen In The Environment



Figure 6.4: An Example Of An Oxygen Sensor (Baker, 2019)

Figure 6.4 shows an example of an oxygen sensor in terrestrial buildings that can also be used in Martian buildings. It depends on our work to use the oxygen sensor exactly, which can help our research. To have a view of oxygen sensors in Martian buildings.

6.5.8.2. The Interior of the Building: Temperature Control Sensor

This sensor is designed to monitor the environment's temperature, allowing for precise control of the building's climate in different areas, such as the commuting area, bedroom, living room, and other key spaces. By providing real-time temperature data, the sensor enables efficient regulation of heating and cooling systems, ensuring that each area maintains a comfortable and safe temperature suited to its specific function.

This sensor makes it possible to adjust temperatures based on occupancy, time of day, or environmental conditions. The data collected can also be stored in the Blockchain platform for transparent tracking, enabling automatic adjustments through Smart Contracts if necessary. This ensures that Martian habitats are energy-efficient while maintaining comfort and safety for the inhabitants. The structure of this transaction is as follows:

$$“T\_ID || P\_T\_ID || S\_ID || temperature” \quad (4)$$

According to the point that the sensor information must be stored in the Blockchain, the received information and the way to store the temperature sensor information in the Blockchain are as follows: T_ID is the hash of the current transaction, P_T_ID is the hash of the previous transaction, S_ID is related to the desired sensor number, and temperature is related to the ambient temperature.

When ultraviolet rays enter the residence, the ambient temperature increases. Therefore, a sudden increase or decrease in temperature can indicate the entry of ultraviolet rays into the residence, which can be very harmful and carcinogenic to humans. Therefore, a temperature control sensor should be installed in the Martian buildings to evaluate the ambient temperature and help manage building information.

The summary of the above transaction is shown in Table 6.8.

Table 6.8: Summary of transactions (Author)

TRANSACTION	DETAILS
T_ID	Unique Number And Hash Of The Current Transaction
P_T_ID	The Hash Of The Previous Transaction
S_ID	Desired Sensor Number
temperature	Temperature Is Related To The Ambient Temperature

Figure 6.5 shows an example of a temperature sensor, which is very important for our research because it gives us a view of the sensor used in buildings on Mars. Our research needs to know what the temperature sensor looks like and how it is placed and works. This is an example of sensors used in terrestrial buildings; a similar example can be used in Martian buildings, which is essential for our research.



Figure 6.5: Temperature Sensor (Schaefer, 2023)

6.5.9. Components Of Buildings

As outlined in the previous sections, the essential criteria for Building Information Modeling (BIM) in Martian structures were initially identified through library research. These criteria were refined through a Fuzzy Delphi questionnaire, followed by ranking with the Fuzzy Analytic Hierarchy Process (AHP) method. The ranked criteria are the foundation for the proposed framework presented in this research section. This framework has been developed based on insights gained from the earlier stages of the study, with the detailed results thoroughly evaluated in subsequent chapters. Each previous step has been crucial in leading up to the formation of this part of the research.

This section focuses on the critical building components whose information is continuously monitored and stored in the Blockchain through sensors. These components include walls, roofs, and facilities, integral to maintaining the habitat's safety and functionality. Each component is monitored in real-time to ensure structural integrity, environmental control, and operational efficiency. The

following sections provide a detailed discussion of each element, explaining how their data is managed within the Blockchain-based framework.

6.5.9.1. Components of Buildings: Air Change Sensor

This sensor indicates the air exchange between the building and the environment, which should be zero.

Considering Mars's atmosphere and the amount of air pressure that enters the walls, these sensors should measure the resistance of the external walls. Two different sensors and two different transactions can be considered for this.

The air exchange control sensor was used in places where the possibility of air entering and exiting in those areas is higher, and the wall resistance control sensor was used in places that have the most pressure against air currents, which are more. It is placed on the top of the walls to ensure their health.

A sensor should be added to control the facilities so that it can be used to determine their location and cause of failure. Therefore, a transaction is added to the previous transactions to maintain the facilities.

These transactions can generally be shown in one transaction, including the items of sensor type, control type, and sensor values, shown below.

$$\text{" } T\_ID // P\_T\_ID // S\_ID // \textit{Type\_Sensor} // \textit{Type\_Control} // \textit{Amount} \text{" } \quad (5)$$

Because all the sensors used are control types, but considering the sensitivity of oxygen and temperature, these two sensors are separated from the rest of the control sensors and evaluated separately.

Nevertheless, in this part, the sensors are divided into two types, and the information stored in the Blockchain is described below. T_ID is the hash of the current transaction, P_T_ID is the hash of the previous transaction, and S_ID is related to the desired sensor number.

Type_Sensor indicates the type of sensor that includes air exchange control, pressure control, and facility control. Type_Control indicates the type of control. Two sensitive and non-sensitive types are divided (the sensitive type for exchanging

air and pressure and the non-sensitive type for controlling facilities). Finally, the amount shows the values that the sensors show.

Considering the atmosphere of Mars, the structures should be designed to prevent the air from outside the building from entering inside. Therefore, these sensors are used to control this situation in real-time. If the outside air enters inside, toxic gases may enter the building, which may be dangerous for human life.

The summary of the above transaction is shown in Table 6.9.

Table 6.9: Summary Of Transactions (Author)

TRANSACTION	DETAILS
T_ID	Unique Number And Hash Of The Current Transaction
P_T_ID	The Hash Of The Previous Transaction
S_ID	Desired Sensor Number
Type_Sensor	Type Of Sensor
Type_Control	Type Of Control Sensor
Amount	Values Sensor

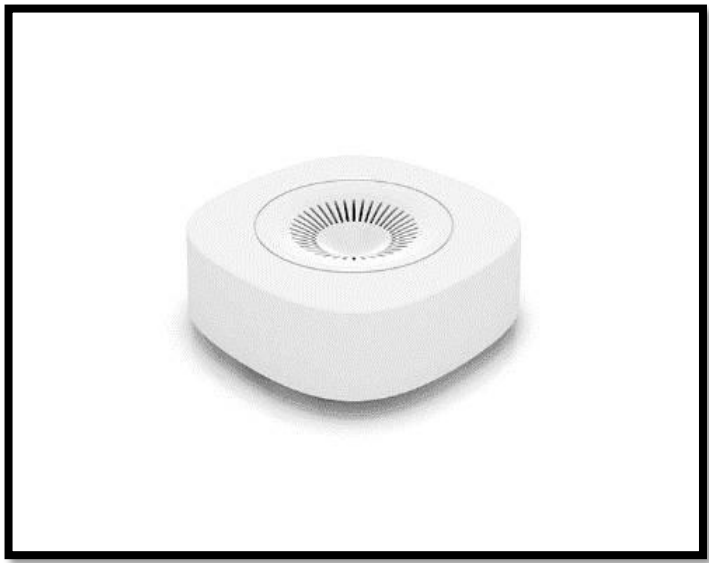


Figure 6.6: An example of a building air exchange sensor in a building (Dong, 2019)

Figure 6.6 shows the air vents on the ground, which should be prevented from entering human habitation because the Martian atmosphere is very different from the Earth's. Therefore, this sensor gives electrical engineers a vision for preparing a sensor for this issue. Given the nature of the Martian atmosphere, this sensor is critical to the mission.

6.5.9.2. Components of Buildings: Roof

The roof is one of the most essential building components, especially in Mars buildings. According to this point, in addition to determining the level of each floor of the building, the roofs in Mars buildings should include things such as air control and temperature control. The air exchange control sensor controls air control and prevents airflow between the floors, and the temperature sensor determines temperature control.

Also, the height of the roofs should be such that it leads to air circulation containing oxygen and temperature control. Therefore, the information that can be stored in the Blockchain as building management for roofs is the type of roof, the type of materials, the height of the roof, and the amount of load each roof bears.

Hence, this transaction is shown below.

***"T_ID // P_T_ID // R_ID // Roof_type ||Material ||Height ||Load amount// (6)
Description"***

Considering that the roof is one of the essential elements of a shelter for humans on Mars, its control must be evaluated separately; therefore, each roof must have a unique identifier, and its type must be known. The rest of the items in this transaction are the same as the other Blockchain mentioned below.

In the above transaction, T_ID is the current transaction identifier, P_T_ID is the previous transaction identifier, and R_ID is the roof identifier. Roof_Type is the type of roof that includes sloping, flat, and dome-shaped items (divided into two parts: the outer and inner roof). The summary of the above transaction is shown in Table 6.10.

Table 6.10: Summary Of Transactions (Author)

TRANSACTION	DETAILS
T_ID	Unique Number And Hash Of The Current Transaction
P_T_ID	The Hash Of The Previous Transaction
Roof_type	Type Of Roof
Material	Material Used In The Roof
Height	Height Of The Roof
Load amount	Amount Of Load Placed On The Roof
Description	Description Of The Roof Map

The type of materials used in the roof (depending on the type of soil on Mars), the height of the roof (depending on the type of its application), the amount of load placed on the roof, and the description of the roof map, which includes the size of the roof, the type of use of the roof, etc.

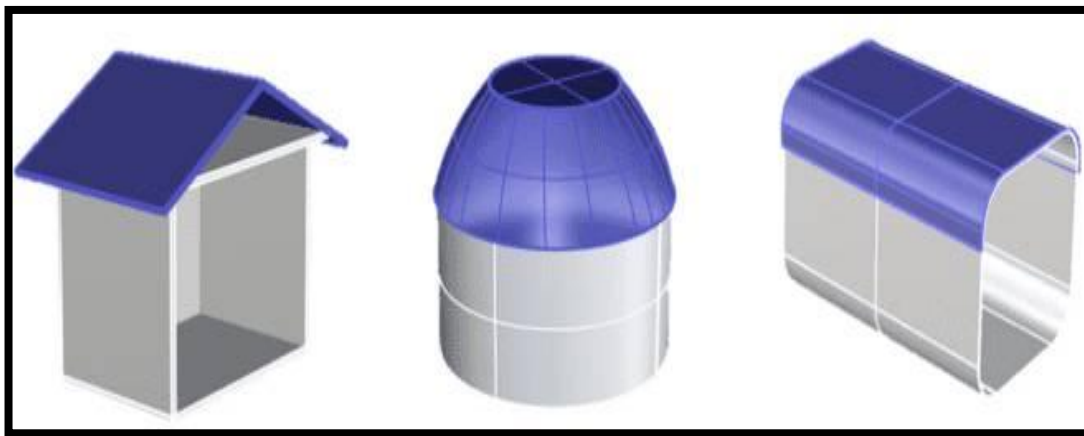


Figure 6.7: Type Of Roof (Author)

According to Figure 6.7, The proposed designed roofs for the roof of Martian buildings are inspired by old designs. These roofs include flat, sloping, and spherical.

6.5.9.3. Components of Buildings: Wall

The second most crucial factor in Mars buildings is the wall. The walls are divided into several types. He pointed out the side wall, internal wall, retaining wall, shear, and shear with the opening. Nevertheless, on the surface of Mars, there is also a kind of wall called the Guard Wall, which prevents meteorites from hitting the surface of Mars. Also, the thickness of the walls, the materials used in them, and the height of the wall can be added to the Blockchain as building management information.

This transaction is described below.

***“ T_ID // P_ T_ID // W_ID // Wall_type ||Material ||thickness||Load amount// (7)
Description”***

The wall is the same as the roof. In the above transaction, T_ID is the current transaction ID, P_T_ID is the previous transaction ID, and W_ID is the wall ID. Wall_Type is the type of wall that includes simple ones, parallel arrangements with grids, solid parallel arrangements, empty and unreinforced parallel arrangements (which are divided into two parts of the outer and inner walls), Material, the type of materials used in the wall (depending on the type of soil on Mars), the thickness of the wall (depending on its application), Laod amount, the amount of load placed on the wall, and The description is the description of the wall map, which includes the size of the wall and...

The summary of the above transaction is shown in Table 6.11.

Table 6.11: Summary Of Transactions (Author)

TRANSACTION	DETAILS
T_ID	Unique Number And Hash Of The Current Transaction
P_T_ID	The Hash Of The Previous Transaction
W_ID	Wall ID
Material	Type Of Materials Used In The Wall
thickness	Thickness Of The Wall
Load amount	The Amount Of Load Placed On The Wall
Description	Description Of The Wall Map

According to Figure 6.8, the designed walls are proposals for the roofs of Martian buildings inspired by ancient designs. The author suggested these walls so that they can be better controlled in the proposed framework.

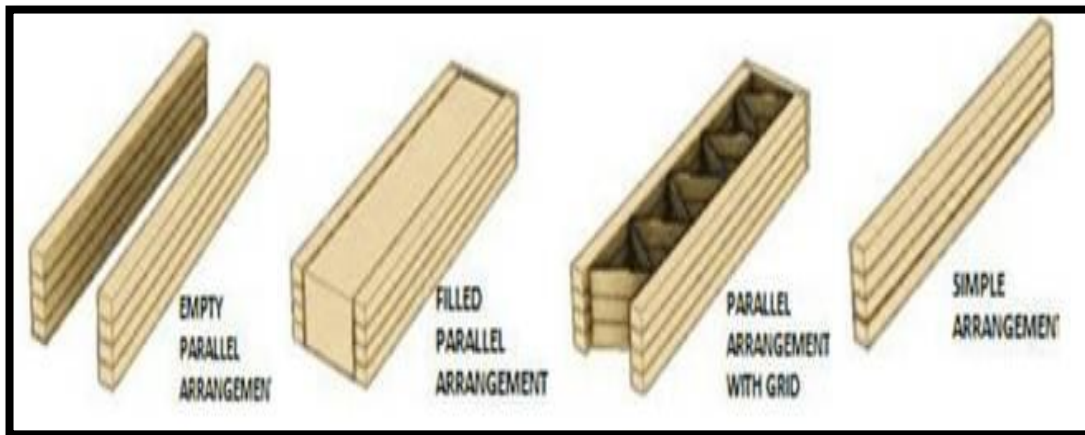


Figure 6.8: Type of wall (Author)

6.5.9.4. Components of Buildings: Facilities

The facilities of a building on Mars are critical to making the habitat livable and maintaining the conditions necessary for long-term human survival. These facilities provide essential services that give life to the building, ensuring it can support human activities. The key types of facilities in Martian buildings include systems

for distributing hot and cold water, sewage collection pipes, vent pipes for air circulation, fuel lines, fire extinguishing systems, and electrical piping. These systems are organized centrally in what is referred to as a central docket.

The management and maintenance of these facilities require precise documentation and tracking. The relevant transaction for these facilities is storing docket information in the Blockchain. This includes important details such as the location of each duct, its size, and a description of its function and materials. By storing this information in the Blockchain, it becomes immutable and easily accessible for inspections, repairs, or future upgrades, ensuring that the facilities continue to operate efficiently and safely in the demanding Martian environment. This system helps create a transparent and secure record of all the essential building facilities.

“ T_ID || P_ T_ID || D_ID || Location ||Size || Description”

(8)

In the above transaction, T_ID is the current transaction identifier, P_T_ID is the previous transaction identifier, and D_ID is the docket identifier. Location indicates the docket's location; Size indicates the docket's size; and Description is the description of the docket map, which includes items that have passed through the docket.

The summary of the above transaction is shown in Table 6.12.

Table 6.12: Summary Of Transactions (Author)

TRANSACTION	DETAILS
T_ID	Unique Number And Hash Of The Current Transaction
P_T_ID	The Hash Of The Previous Transaction
D_ID	Docket ID
Location	Location Of The Docket
Size	Size Of The Docket
Description	Description Of The Docket Map

Facilities can be necessary to some extent, but they may disturb the lives of the residents for some time. Nevertheless, they are not life-threatening to some extent. Humans need facilities to live in, and therefore, the health of the facilities should be evaluated. For this reason, a sensor must be installed to control the facility's health.



Figure 6.9: Operation Of The Facility Health Sensor (Palumbo, 2014)

Figure 6.9 shows an example of using health sensors in structures used in ground structures. Therefore, a similar example can be prepared for Mars buildings. So, this form can be important for our research, which the sensors of terrestrial structures can inspire, and a sensor can be prepared for Martian buildings and used in facilities.

6.6. Suggestion Framework

As mentioned in the previous sections, three categories of general information can be stored in the Blockchain: Smart Contracts, information collected by sensors, information used for building information management to control roofs, walls, and facilities, along with the description of each map.

Therefore, transactions have been considered for each part and stored in the Blockchain after completion. In the proposed method, an inspector is regarded as a controlling element. This inspector has four levels: normal, emergency 1, emergency 2, and emergency 3.

All the building's components work well in a normal state, and the building's condition is normal (Figure 6.10).

In the state of emergency 1, the transactions related to the facilities are evaluated, and if they were damaged and did not perform properly, they are included in this group. Also, the failure of sensors is included in this group; that is, if a sensor is damaged or its lifespan is over, a warning to announce the wear of that sensor should be sent to the manufacturing company. In this group, the technicians have the opportunity to solve the problem and take action to solve the problem, and no one's life is in danger (Figure 6.11).

Emergency mode two is related to the control of the temperature level, oxygen level, and air exchange level, which indicates that a part of the building has lost its proper function. This factor leads to a decrease in the oxygen level and an increase in temperature, which indicates the entry of ultraviolet rays into the building and the exchange of outside air. At this level of emergency, the robot rescue team does not have much time to enter and repair the defective part, but human life is not threatened. If it continues, the lives of people living in that building may be in danger (Figure 6.12).

Emergency level 3 is related to the damage to a part of the building, for which the robot rescue forces must quickly reach the accident scene and save people's lives. This level happens in earthquakes, meteorite collisions, or damage to a part of the building (Figure 6.13).



Figure 6.10: Normal Level (Author)



Figure 6.11: Emergency Level 1 (Author)



Figure 6.12: Emergency Level 2 (Author)

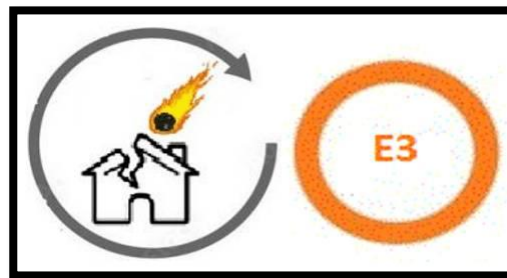


Figure 6.13: Emergency Level 3 (Author)

Based on figures 6.10 to 6.13, the level of warnings is shown. According to the set warning level, rescue robots come into action and perform rescue operations. Based on the results obtained from criteria screening and ranking based on Fuzzy AHP, the final criteria were ranked, and finally, based on the importance of these criteria, warning levels were shown, and these warning levels were prepared.

In short, this research focuses on building information modeling (BIM) in Martian buildings using library studies and expert input. The initial criteria for BIM were refined using the fuzzy Delphi method. Also, the fuzzy Delphi method was used to screen the extracted criteria, because researchers often face multiple criteria that

cannot be addressed in one study. The Delphi technique, which relies on group communication, is used to reach consensus among experts. Then, using fuzzy pairs and fuzzy numbers, the criteria were compared and the importance of each was determined, which was done to extract the final framework and identify the effective criteria. Then, based on these criteria, the necessary transactions for the blockchain were designed. Then the inspector-centered framework was presented, which according to the criteria and objectives has four normal levels, emergency level 1, emergency level 2 and emergency level 3.

6.7. Experts

In order to answer the questionnaires, the experts have been contacted by email, allowing for a streamlined and convenient method of communication. This approach ensured that the experts received all necessary information directly in their inboxes, enabling them to review and respond to the questionnaires at their convenience. Using email, the organizers could easily track responses and follow up if needed, ensuring the process remained efficient and organized. Furthermore, this method allowed for a formal record of communication, which could be referenced if any clarifications were required.

The characteristics of the experts who participated in this research are stated. These specifications are shown in Table 6.13.

Table 6.13: Specifications of experts

Row	Name	Affiliation	Title
1	Alejandro Serrano Borlaff	NASA	NASA Postdoctoral Fellow Astronomer
2	Díaz Michelena, Marina	National Institute of Aerospace Technology	Space magnetometers and planetary magnetism researcher
3	Ehsan Asna Ahsari	Assistant Professor at the Nottingham Trent University	Construction Management and Quantity Surveying
4	Hadi Sarvari	Birmingham City University	Construction Management Expert

At the end, effectively combined the Delphi-fuzzy method with Blockchain technology to address the complexities involved in designing Mars buildings using Building Information Modeling (BIM). The two-part methodology, starting with a comprehensive literature review and expert input, ensured that the most relevant and critical criteria were identified. By applying the fuzzy Delphi method, the study was able to screen and refine the extracted criteria, enhancing the precision of the research and ensuring that only the most significant metrics were considered for further analysis. This process underscored the importance of leveraging both qualitative and quantitative data, particularly in areas of uncertainty, to build a robust framework for future BIM applications in extraterrestrial environments.

7. RESULTS

7.1. Introduction

This chapter is divided into two parts:

- fuzzy analysis
- results obtained from blockchain.

In the first research stage, fuzzy analysis evaluates expert data, particularly addressing uncertainties and subjective judgments inherent in expert opinions. The relative importance of different criteria is assessed by applying the fuzzy Analytic Hierarchy Process (AHP) method, which incorporates fuzzy logic. Fuzzy figures compare each criterion's significance relative to others, offering a nuanced view of how experts prioritize them. This approach helps handle ambiguity and provides more accurate rankings. The fuzzy AHP method then calculates the final weights for each criterion, reflecting their importance in the overall decision-making process.

Once the criteria have been ranked, the focus shifts to integrating Blockchain technology with Building Information Modeling (BIM). This analysis section examines how Blockchain can enhance BIM by providing a decentralized, secure platform for storing and managing building information, such as sensor data and facility management. The Blockchain-BIM integration ensures data transparency, security, and real-time access to critical building information, fostering better decision-making and more efficient management of Martian habitats.

7.2. Selection Of Criteria

At this stage of the research, experts' opinions on the evaluated criteria were collected through a structured questionnaire. This questionnaire allowed the experts to provide their insights and assessments of the relative importance of each criterion under consideration.

The data obtained from these expert questionnaires were then processed and analyzed. This input formed the foundation for the next step, where the fuzzy AHP method was applied to weigh and rank the criteria. The expert responses ensured

that the analysis was grounded in real-world knowledge, contributing to a more accurate and reliable decision-making framework.

Table 7.1 thoroughly summarizes the experts' thoughts on the screening criteria used in This Research, explaining their considerations and points of view. The table methodically examines the many perspectives and factors influencing the selection process. This evaluation offers insight into the agreement or disagreement among subject-matter experts and is a valuable tool for comprehending the reasoning behind selecting the criteria.

Table 7.1: The opinions of experts in the first stage (Author)

Main criteria	Criteria	Expert1	Expert2	Expert3	Expert4
Building components	Walls	5	5	4	5
	The roofs	5	4	5	5
	Meteor protector	1	2	1	2
	Required building facilities	1	3	3	2
	Air exchange	4	5	3	4
Internal components of the building	Air temperature	4	3	1	4
	Air pressure	1	2	1	1
	Ambient oxygen	5	4	1	5
	Ambient carbon dioxide	1	1	1	1
	Ambient humidity	1	2	1	1
	Amount of light	1	1	1	1

Table 7.2 shows the second series of questionnaires answered by experts, providing key insights gathered during the follow-up phase of the research. This set of responses allows for a deeper analysis of the experts' perspectives, building upon the initial round of data collected.

Table 7.2: The opinions of experts in the second stage (Author)

Main criteria	Criteria	Expert1	Expert2	Expert3	Expert4
Building Components	Walls	5	5	4	5
	The roofs	5	4	5	5
	Required building facilities	3	4	4	3
	Air exchange	4	5	3	4
Internal Components of the building	Air temperature	5	3	4	4
	Ambient oxygen	5	4	3	5

After receiving the experts' opinions, these opinions were analyzed in fuzzy-delphi-analysis-v2-01 software, and the results are as follows: The obtained threshold was equal to 0.169, which included six criteria, and the rest of the criteria were excluded from the analysis. These criteria are shown in Table 13, along with their ranking and the points they obtained.

Table 7.3, the output of the fuzzy Delphi method, shows that six factors were included in the research, according to experts' opinions.

Table 7.3: Final Criteria (Author)

Criteria	Score	Rank
Wall	0/75	1
Roof	0/683	2
Building Facilities	0/267	6
Air Exchange	0/60	3
Environment Temperature	0/417	5
Ambient Oxygen	0/567	4

Of course, it should be mentioned that according to some experts, criteria such as dealing with meteorites can be seen in the walls or roof, or it has no function in BIM, and it cannot be addressed in the BIM of a building. All the extracted criteria can be evaluated and are essential in turn. However, due to the increase in the number of calculations, it is evident that some of these criteria will be left out of the research cycle. After extracting the criteria, they can be ranked, the results of which are given below.

7.3. Priority Criteria

The results and the results of the data collected from the questionnaires distributed to the experts will be discussed. In the first part, the data is reviewed, and then the other sections mentioned in the introduction are discussed. In this analysis, according to the method described in the previous part, four pairs of questionnaires were distributed among the experts, which in this part are given to express the opinion of the experts involved in the research. Six main criteria must be entered into BIM and stored in the Blockchain for Mars buildings. In the following, the even matrix is obtained.

Table 7.4 contains the expert scores for applying Fuzzy AHP to a decision-making problem. These scores represent the assessments made by experts regarding the relative importance or preference of various criteria or alternatives involved in the decision.

Table 7.4: Pairwise Comparison Matrix (Author)

	Wall	Roof	Facilities	Air exchange	Ambient temperature	Oxygen
Wall	1	1.2	4.5	1.2	3.7	2.4
Roof	*	1	3.7	0.5	2.9	2.4
Facilities	*	*	1	0.2	0.4	0.3
Air exchange	*	*	*	1	4.5	2.4
Environment temperature	*	*	*	*	1	0.5
Ambient oxygen	*	*	*	*	*	1

In this matrix, each number represents the share of superiority or non-superiority of the criterion according to experts compared to other criteria. For example, the coefficient (1,5), equal to 3.7, shows that, according to the experts involved in the design, the wall's criterion parameter is superior to the ambient temperature by a ratio of 3.7.

The obtained pair matrix should be examined from two perspectives:

- Inconsistency rate
- Being symmetrical

One of the features of this matrix is that the columns are symmetrical; for example, the columns (1,2) and (2,1) are inversely proportional to each other, and each is equal to the inverse of the other. This criterion has been met in this matrix in all regions, which will be approved from this point of view.

A program was developed in MATLAB to calculate the inconsistency rate, which is integrated into the main fuzzy analysis code. If the inconsistency rate condition is not met, the corresponding matrix will not be analyzed until the inconsistency is resolved. In this case, the algorithm used to calculate the inconsistency rate has produced a value of 0.225, which is significantly lower than the 10% threshold. Therefore, based on the two specified conditions, it can be confidently concluded that the results obtained from the paired matrix are accurate.

It is important to note that in the fuzzy method, there are two different algorithms for calculating the inconsistency rate. One is the standard algorithm that calculates the rate for a typical matrix, while the other is designed specifically for fuzzy matrices derived from paired comparison matrices. A critical point is that if there is an inconsistency in an even matrix, there is no need to use the fuzzy algorithm to check the inconsistency rate. However, if the inconsistency rate in some cases exceeds 10%, additional steps are taken to investigate and resolve the inconsistency before proceeding with the analysis.

The inclusion of these algorithms ensures that any inconsistencies in the matrices are handled effectively, preventing inaccurate or unreliable results. The process of evaluating and addressing inconsistency allows for a more robust analysis, as it

ensures that the paired comparison data used in the fuzzy method is reliable. In cases where the inconsistency rate is found to be above the acceptable threshold, the method will be re-examined, and appropriate actions will be taken to adjust and resolve any inconsistencies. This ensures that the final analysis remains valid and trustworthy.

7.3.1. Fuzzy Distribution Charts

This section discusses the results of the analysis and the fuzzy matrices. At the beginning, the image of each fuzzy number graph presented for the fuzzy matrix, which can be seen for each variable, has been presented.

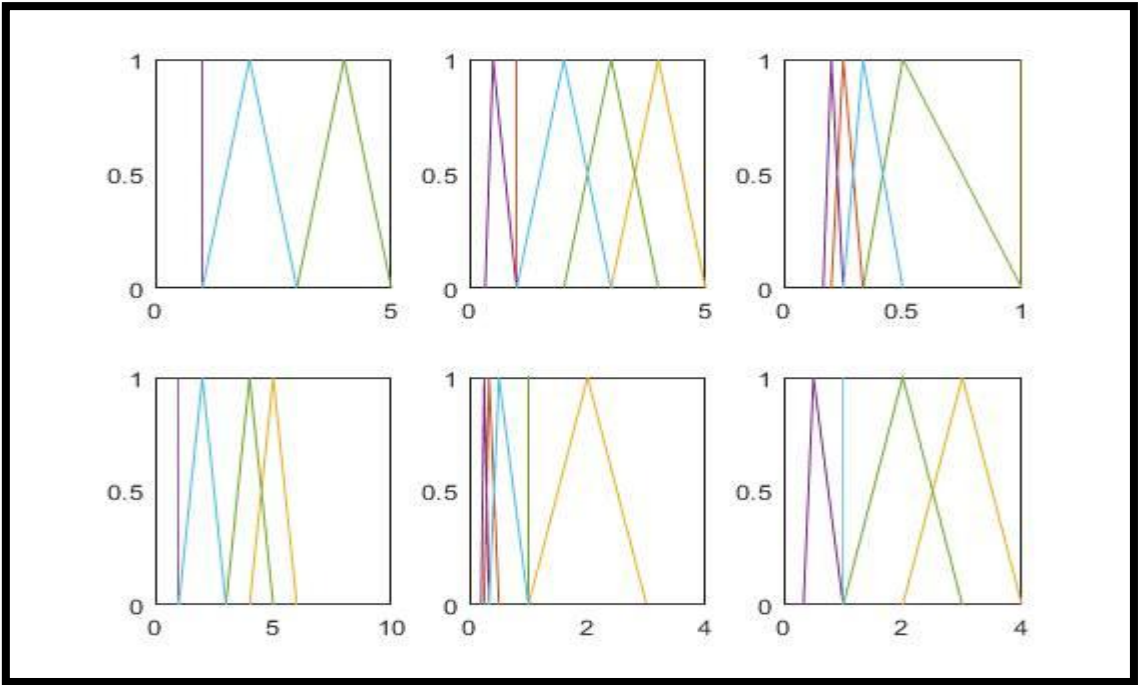


Figure 7.1: Fuzzy Distribution Charts (Author)

In the given figure 7.1, there are as many main variables as the fuzzy number diagram, each of which is related to the measurement of the variable compared to other variables in a fuzzy manner produced by the fuzzification function in the provided program. These charts are also like paired matrices, and the degree of superiority can be determined from them. Graphs with compact and low values correspond to inverse phase values, which indicate a low variable superiority ratio, and open graphs with more significant numbers indicate superiority over others. It

can be seen that the first variable, which has the advantage overall, has an entirely open and uncompressed graph.

7.3.2. Final Priority Of The Criteria

This part evaluates the final ranking of the research criteria, which are explained below.

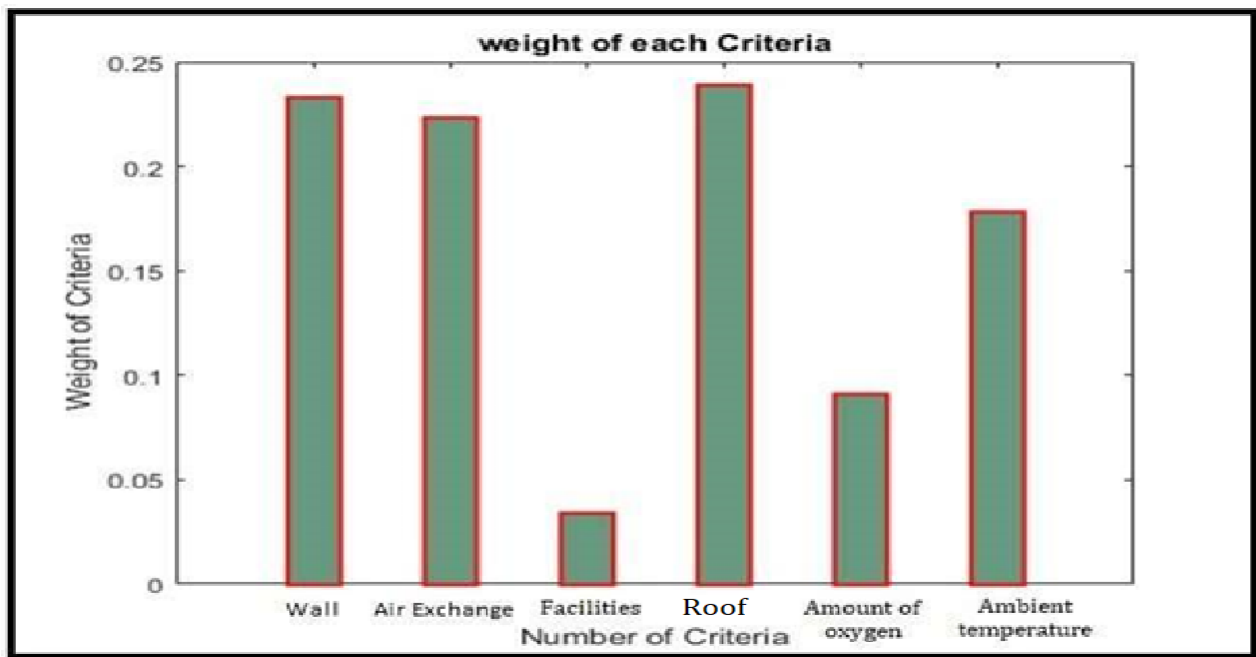


Figure 7.2: Fuzzy Final Ranking (Author)

As is apparent in Figure 7.2, the first, second, and fourth criteria, roof, wall, and air exchange, respectively, have the first rank and are of particular importance from the experts' point of view. The fifth and sixth criteria, the ambient temperature and the amount of oxygen in the environment are also in the next rank. Finally, the last rank is assigned to the facilities with a lower degree of importance. So, based on the experts' opinions, we can now implement it.

As mentioned in the previous sections, three categories of general information can be stored in the Blockchain: Smart Contracts, information collected by sensors, information used as building information management to control roofs, walls, and building facilities, along with the description of each map. Therefore, transactions have been considered for each part and stored in the Blockchain after completion.

In the proposed method, an inspector is regarded as a controlling element. This inspector has four levels: normal, emergency 1, emergency 2, and emergency 3.

In a normal state, all the components of the building work well, and the condition of the building is in a normal state.

In the state of emergency 1, the transactions related to the facilities are evaluated, and if they were damaged and did not perform properly, they are included in this group. Also, the failure of sensors is included in this group; that is, if a sensor is damaged or its lifespan is over, a warning to announce the wear of that sensor should be sent to the manufacturing company. In this group, the technicians have the opportunity to solve the problem and take action to solve the problem, and no one's life is in danger.

Emergency mode two is related to the control of the temperature level, oxygen level, and air exchange level, which indicates that a part of the building has lost its proper function. This factor leads to a decrease in the oxygen level and an increase in temperature, which indicates the entry of ultraviolet rays into the building and the exchange of outside air. At this level of emergency, the robot rescue team does not have much time to enter and repair the defective part, but human life is not threatened. If it continues, the lives of people living in that building may be in danger.

Emergency level 3 is related to the damage to a part of the building, for which the robot rescue forces must quickly reach the accident scene and save people's lives. This level happens in earthquakes, meteorite collisions, or damage to a part of the building.

7.4. Implementation Results

This section examines two critical factors in the performance of the Blockchain system: the amount of memory consumed and the duration of adding a new block to the Blockchain. These two factors are key to ensuring the efficiency and scalability of the Blockchain, particularly when managing complex transactions related to building management on Mars.

For the evaluation of the Blockchain system's performance, two key criteria are employed to analyze the transactions:

- **Memory Usage:** This criterion evaluates the memory consumption of the Blockchain system when new blocks are added. Efficient memory management is paramount, particularly in resource-limited environments like Mars, where data storage optimization is necessary.
- **Block Addition Time:** This criterion measures the time it takes to add a new block to the Blockchain. Faster block additions enhance real-time responsiveness, critical for managing life-support systems and infrastructure on Mars.

These evaluations were carried out using Python, with the implementation run on Google Colab, leveraging Google's servers to execute the Python programs. This setup allows for the analysis and simulation of Blockchain performance, providing a clear understanding of how the proposed system handles transactions. In the following sections, each type of transaction has been thoroughly evaluated, focusing on how they affect memory usage and block addition times.

7.4.1. Check The Contract Proposed Method

The first stage of the platform involves establishing a contract with customers through a Smart Contract. Smart Contracts are employed to automate the execution of agreements, ensuring that all participants can be immediately aware of the outcome without the need for intermediaries or delays. The process follows a series of steps to formalize the agreement between the customer and the construction company.

- **Customer Request:** The process begins when the customer initiates the contract by sending a contract request to the construction company. This request is the starting point for establishing the agreement and is logged as the first transaction in the Blockchain. Upon receiving the request, the construction company reviews the customer's profile, ensuring they meet the requirements for the contract. This step triggers a series of automated

checks, and once the customer is approved, the contract drafting process begins.

Each step in this process is tracked via transactions on the Blockchain, ensuring transparency and preventing tampering. Smart Contracts automate the next stages, ensuring that the contract flows smoothly without delays or intermediaries, providing real-time updates to the customer and the company throughout the process.

- **Company Review:** After receiving the contract request, the company reviews the profiles of the individuals or organizations applying for the contract. This review process is crucial for ensuring that the customer meets the eligibility criteria and compliance requirements set forth by the construction company. During this stage, the company may assess various factors, such as the customer's financial stability, past project experiences, and any relevant certifications or licenses. This evaluation helps mitigate risks and ensures that the company enters into a contract with a qualified and reliable client. The results of this profile review are logged as transactions in the Blockchain, a technology that creates a transparent and immutable record of the approval process, thereby enhancing the security and trust in the process. If the profiles meet the criteria, the process moves forward to drafting and signing the contract; otherwise, the company may communicate the reasons for denial to the customer.
- **Contract Signing:** Once the profiles are approved, the company drafts the contract based on the agreed-upon terms and conditions. This contract outlines the scope of work, timelines, payment terms, and any other relevant details necessary for the construction project after the contract is drafted and sent to the customer for review.

Both parties then begin the signing process, utilizing the Smart Contract functionality to sign the agreement digitally. This process is streamlined and efficient, ensuring that both parties can securely sign the contract without needing physical presence or paper documentation. The Smart Contract automatically records the signatures and finalizes the contract, making it an immutable part of the Blockchain. This digital signing not only enhances the

security of the contract but also provides immediate confirmation to both parties that the agreement has been executed, minimizing the potential for disputes and ensuring clarity in the contractual obligations.

Each of these steps, as depicted in the referenced figure, represents a critical transaction that must be meticulously recorded and completed on the Blockchain. Every phase of the contract process involves essential data exchanges, validations, and approvals, all securely stored within the Blockchain framework. This mechanism ensures transparency and immutability, providing a reliable record of the entire contracting process.

If any transaction is not completed successfully or encounters an error, the entire process is halted, preventing any incomplete or erroneous information from being stored. This feature is vital for maintaining the integrity of the contracting procedure. The Blockchain serves as a trustworthy intermediary, ensuring that all stages of the contract are fully executed and verified before being added to the decentralized ledger. By leveraging Blockchain technology, both parties can have confidence in the authenticity and accuracy of the contract, a key factor in minimizing the risk of disputes and enhancing trust in the agreement.

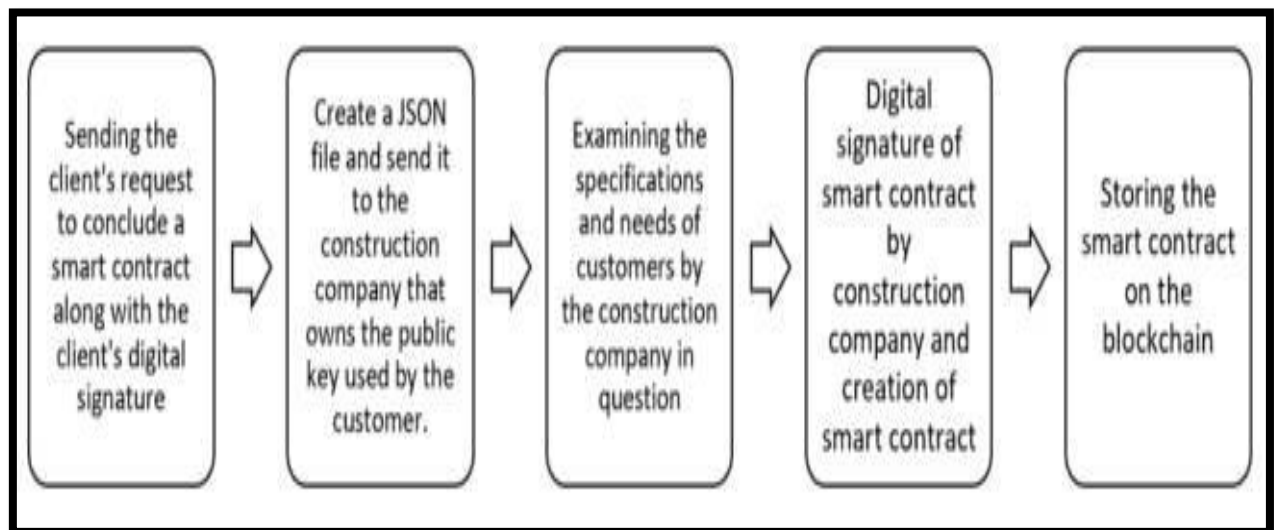


Figure 7.3: Contract Level (Author)

According to Figure 12.3, which shows the Smart Contract between the customer and the service provider, in the first stage, the customer submits his request to the

company, and the company signs the contract after reviewing the contract terms. After the parties sign the contract, it is stored in the Blockchain.

As it is clear from the figure above, all movements are forward, and if the desired transaction is stopped at any stage, that transaction will be lost and must be restarted from the beginning. In the first stage, each customer has a public token and a private token, where the private token of each person is the digital signature of that person. At this stage, the customer, having the public token of the desired company, sends his request and specifications to the company and signs the contract. After this step, the customer's request is sent to the chosen company as a JSON file. After checking the structure of the desired house and the customer's profile, the company signs the contract with the company's private token, sends the final contract to be stored in the Blockchain, and sends the final version of the Smart Contract to the customer. An example of a customer request for participation is shown in the figure below.

Figure 7.4 illustrates how the user submits information to the construction company to initiate a Smart Contract. The information typically includes essential details such as:

- **User Identification:** Name, contact information, and any relevant identification numbers.
- **Project Details:** Description of the construction project, including scope, location, and specifications.

Accompanying this submission, a JSON file is generated that contains structured data representing the information provided by the user. This JSON file is a standardized format for data exchange between the user and the company. It ensures that all the necessary information is captured in a machine-readable format, facilitating cracksless integration into the Smart Contract system.

Once the company receives this information, it processes the data to conclude the Smart Contract, confirming the agreement between both parties. The data within the JSON file becomes a part of the Smart Contract's conditions, ensuring that all agreed-upon terms are recorded and can be referenced in future transactions or

audits. This process enhances efficiency, reduces the likelihood of errors, and promotes transparency throughout the contract lifecycle.

```
{  
  "System": "'Linux'",  
  "Node Name": "'749a3b916e97'",  
  "Release": "'5.10.147+'",  
  "Version": "'#1 SMP Sat Dec 10 16:00:40 UTC 2022'",  
  "Nat_Code": "3258747698",  
  "name": "Amirhossein",  
  "family": "Javaheri",  
  "Address": "Madrid",  
  "user_sing": "30254780",  
  "timestamp": "2023-01-11 09:50:12.361892"  
}
```

Figure 7.4: Contract Information (Author)

Figure 7.5 illustrates the relationship between space utilization and the duration required to conclude a Smart Contract, specifically analyzing nodes ranging from one to 10,000. As the number of transactions on the Blockchain platform increases, there is a notable rise in the storage space required and the time needed to process these transactions. This trend highlights the scalability challenges faced by Blockchain systems, particularly as transaction volumes grow.

The data indicates a direct correlation between the number of transactions and resource consumption, underscoring the critical importance of efficient resource management strategies. As demand for transactions increases, it becomes even more critical to optimize Blockchain operations to handle higher volumes without compromising overall performance. This necessitates the development of innovative solutions, such as improved algorithms, better data storage techniques, and enhanced network protocols, to ensure that the Blockchain can scale effectively while maintaining its key features of security and transparency. Such optimizations are essential for sustaining performance in real-world applications,

especially in scenarios involving multiple users and complex Smart Contract interactions.

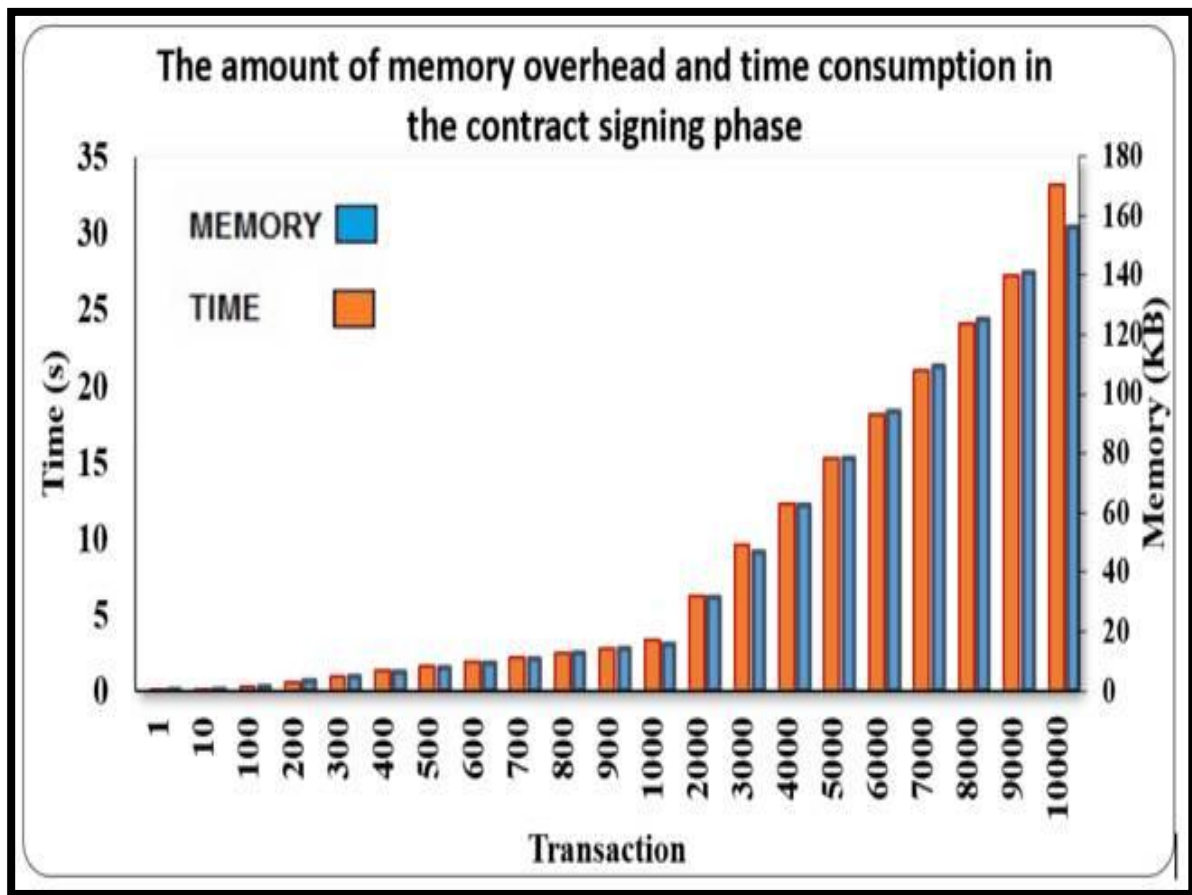


Figure 7.5: The Amount Of Memory Overhead And Time Consumption In The Contract Signing Phase (Author)

7.4.2. Check The Proposed Method

In this section, a platform is designed to facilitate data transmission to a central server, specifically to monitor and check the warning levels discussed in Part 4. The process begins with collecting data from various sensors installed in the environment. These sensors continuously monitor critical parameters such as oxygen levels, temperature, and structural integrity, providing real-time data essential for maintaining the safety of the Martian habitat.

Since the system operates on an intranet, the collected sensor data is formatted and sent to the central server as an XML file. This standardized data format ensures that the information is structured and easily interpretable by the server. Upon

receipt of the XML files, the inspector system can assess the warning level by cross-referencing the incoming data with the information stored in the Blockchain. This comparison allows the system to quickly identify any discrepancies or abnormalities, enabling prompt actions to address potential safety concerns. By integrating sensor data with Blockchain records, the platform enhances the reliability of monitoring processes. It facilitates timely responses to critical situations, ensuring the continued safety and habitability of the environment.



Figure 7.6: Flowchart Of Sending Data To The Central System (Author)

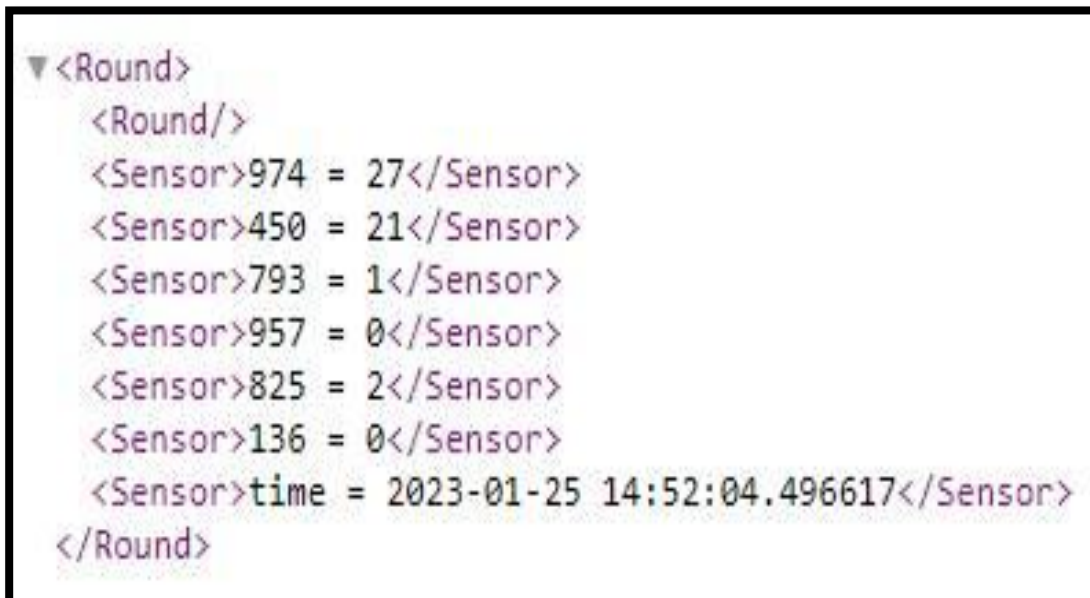
Figure 7.6 illustrates the operational flow of the developed system designed to ensure safety and responsiveness in the Martian habitat. The process begins with information collection by sensors that continuously monitor critical environmental parameters.

Once the sensors gather data, this information is directly stored in the Blockchain for secure and immutable record-keeping. Simultaneously, the data is transmitted to the controller server for further processing. Upon receiving the sensor data, the

server compares it with the corresponding information stored in the Blockchain to verify its accuracy and consistency.

If the data aligns correctly, the system determines the warning level based on predefined thresholds for safety parameters. If a critical warning level is identified, the system triggers the deployment of rescue robots to address the issue. This automated response mechanism highlights the system's capability to monitor environmental conditions and react swiftly to potential threats, ensuring the safety and well-being of inhabitants in the Martian habitat.

As it is clear from Figure 7.6 above, since the exchange of information is within the company's internal network, by using the XML file, the information can be sent to the primary source of the company, and the received information is compared with the information inside the Blockchain. After the correctness of the information is determined, the amount and level of warning should be issued. In this section, if the alarm level is at level 1, no message is sent to the technician and rescue robots. If it is at the 1st to third alarm level, depending on the alarm level, robots specific to each alarm level are activated, and according to the ID of the sensors, they refer to the location of the accident.

The image shows a screenshot of an XML document. It starts with a root element <Round>, followed by its closing tag </Round>. Inside, there are seven <Sensor> elements, each containing a sensor ID, an equals sign, and a numerical value. The sensors are: 974 with value 27, 450 with value 21, 793 with value 1, 957 with value 0, 825 with value 2, 136 with value 0, and a 'time' sensor with a timestamp '2023-01-25 14:52:04.496617'. The XML ends with </Sensor> and </Round> tags.

```
<Round>
  <Round/>
  <Sensor>974 = 27</Sensor>
  <Sensor>450 = 21</Sensor>
  <Sensor>793 = 1</Sensor>
  <Sensor>957 = 0</Sensor>
  <Sensor>825 = 2</Sensor>
  <Sensor>136 = 0</Sensor>
  <Sensor>time = 2023-01-25 14:52:04.496617</Sensor>
</Round>
```

Figure 7.7: Sensors XML File (Author)

Figure 7.7 illustrates the process by which sensors transmit collected information regarding the critical parameters of the Martian habitat. Each sensor measures specific environmental and structural conditions, providing vital data represented as numerical values:

- **Oxygen Sensor:** This sensor checks the amount of oxygen in the environment, currently reporting a level of 20.9%. This measurement is crucial for ensuring breathable air for inhabitants.



Figure 7.8: oxygen sensor (Author)

Figure 7.8 shows the oxygen sensor displaying a 20.9% oxygen level, indicating a safe environment for inhabitants. This reading aligns with normal atmospheric conditions, confirming adequate air quality and ensuring the health and safety of those present.

- **Temperature Sensor:** The second sensor monitors ambient temperature, which can range between 18 and 40 degrees Celsius, helping to maintain a comfortable living environment.

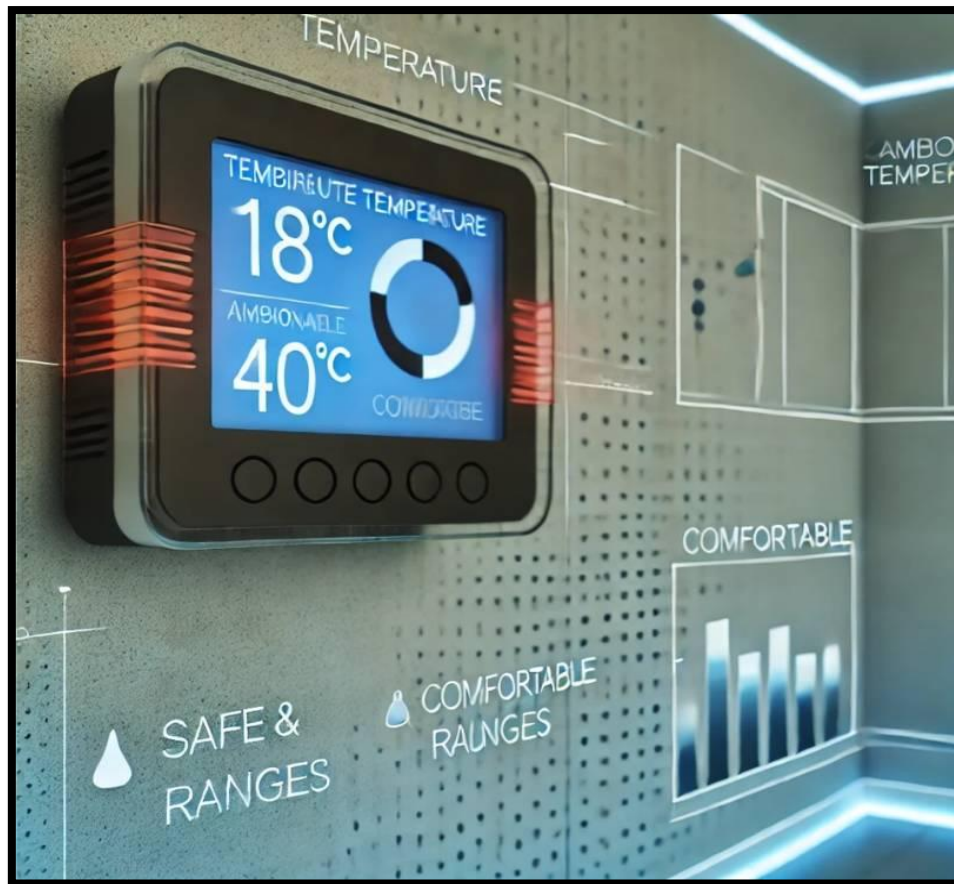


Figure 7.9: Temperature sensor (Author)

Figure 7.9 illustrates the temperature sensor monitoring ambient temperature, providing real-time readings ranging between 18 and 40 degrees Celsius. This range offers crucial data for maintaining optimal environmental conditions, ensuring comfort and safety within the monitored space.

- **Air Exchange Sensor:** This sensor assesses air exchange efficiency within the habitat, providing a value between 0 and 2. Effective air exchange is essential for maintaining a healthy atmosphere.

Figure 7.10 presents the air exchange sensor, displaying efficiency levels ranging from 0 to 2. These readings provide valuable insights into the ventilation system's performance, helping to ensure proper air circulation and maintaining a healthy environment within the monitored area.

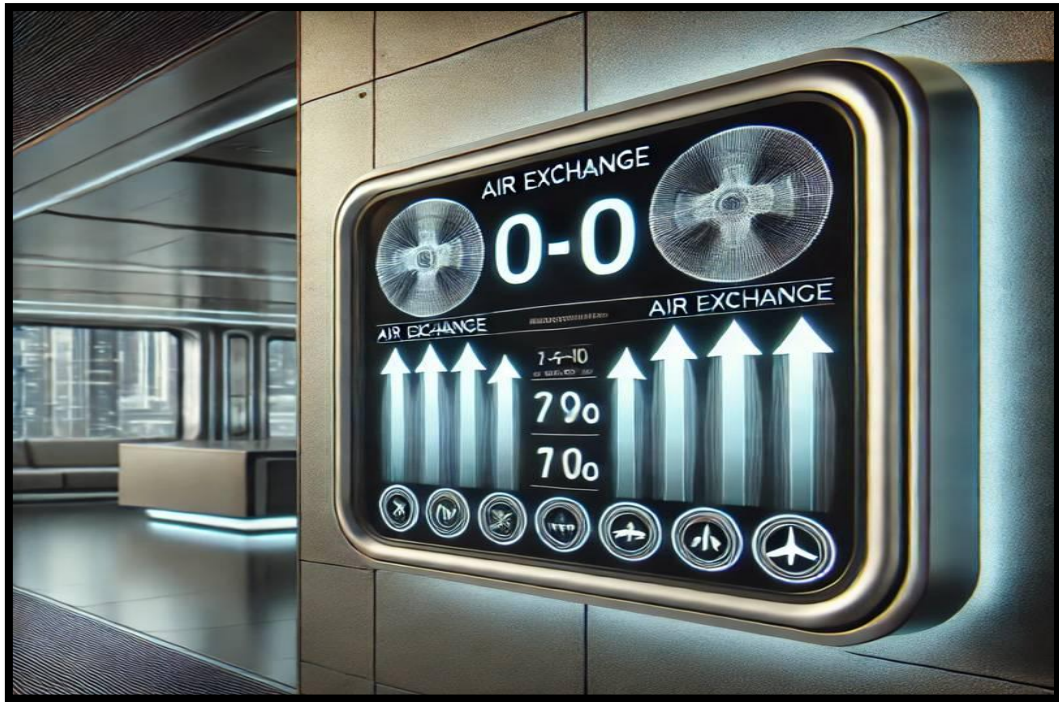


Figure 7.10: Air exchange sensor (Author)

- **Wall Sensor:** This sensor evaluates the condition of the walls, returning a score between 0 and 2. Here, 0 indicates a normal condition, 1 signifies a cracks, and 2 denotes wall destruction, indicating potential structural failure.



Figure 7.11: The wall sensor (Author)

Figure 7.11 shows the wall sensor, which evaluates the wall condition with scores indicating three possible states: normal, minor cracks, or wall destruction. These readings assist in assessing structural integrity, helping to identify potential maintenance needs or safety concerns.

- **Roof Sensor:** Similar to the wall sensor, this sensor checks the roof's integrity, scoring between 0 and 2. Again, 0 indicates normal, 1 indicates a cracks, and 2 indicates damage, ensuring the roof's safety.

Figure 7.12 depicts the roof sensor on a Mars building, displaying integrity scores, with the Martian landscape visible in the background. These scores provide critical information on the roof's condition, ensuring the structure's durability in the challenging Martian environment.

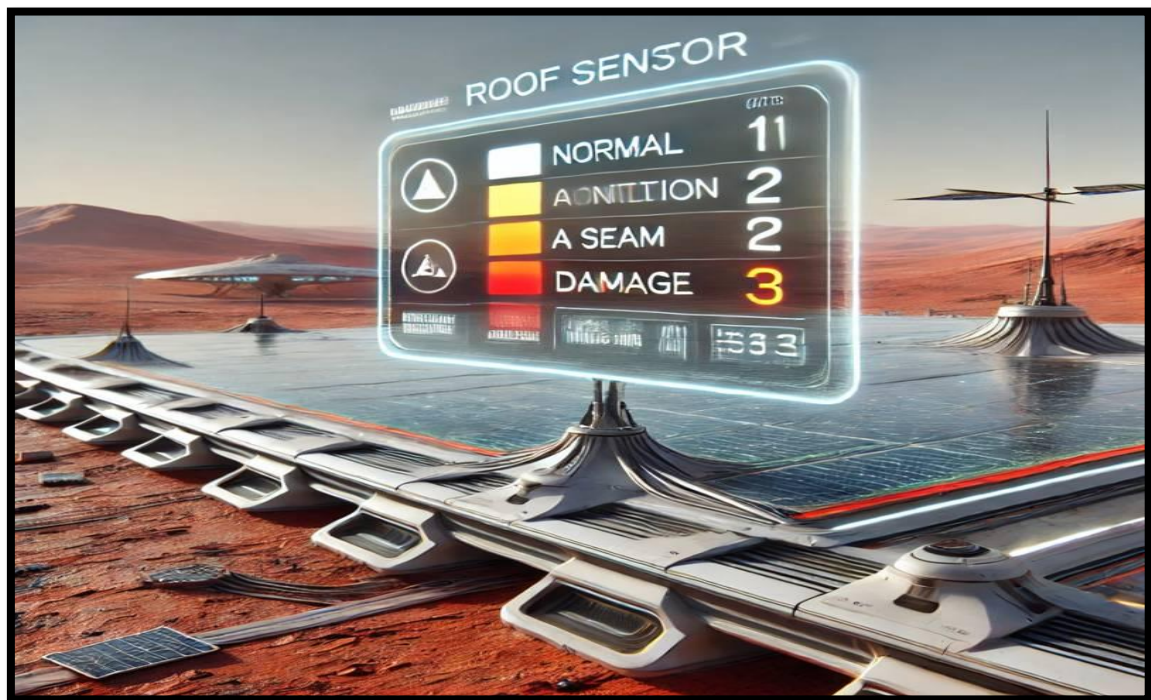


Figure 7.12: Roof sensor (Author)

- **Facility Inspection Sensor:** This sensor monitors the operational status of the building's facilities, providing a score between 0 and 2 to indicate varying levels of integrity.



Figure 7.13: Facility inspection sensor (Author)

Figure 7.13 illustrates the facility inspection sensor on a Mars building, monitoring the operational status of the facilities with scores ranging between 0 and 2. These scores help assess the functionality and maintenance needs, ensuring the facilities remain operational in the harsh Martian conditions.

This comprehensive data collection allows for continuous monitoring of environmental conditions and structural health, enabling prompt responses to any issues that may arise, thereby ensuring the safety and sustainability of human habitation on Mars.

As you know, in the buildings on Mars, due to the importance and sensitivity of the matter of life, the information and the accuracy of the information must be checked to make sure which sensor and which house need the attention of the rescue team and if the information undergoes transformation and changes. Moreover, the costs of maintaining and using robots will heavily penetrate the system.

Information processing plays a vital role in maintaining data integrity before information is transmitted to a central system through Blockchain technology. Prior to sharing any data, it is essential to evaluate its accuracy to prevent any potential leaks. The research employs XML files to leverage public Blockchain networks, as de-hashing information in these networks is not permissible under legal regulations.

A range of 1 to 12,000 data points was created within the Blockchain framework. The analysis focused on two critical variables: cost and time. By evaluating these factors, the research underscores the importance of efficient data management in Blockchain applications, highlighting how optimized processing can enhance overall performance while ensuring compliance with legal standards. This approach not only secures the data but also facilitates smoother operations in a decentralized environment, ultimately contributing to the effectiveness and reliability of Blockchain technology.

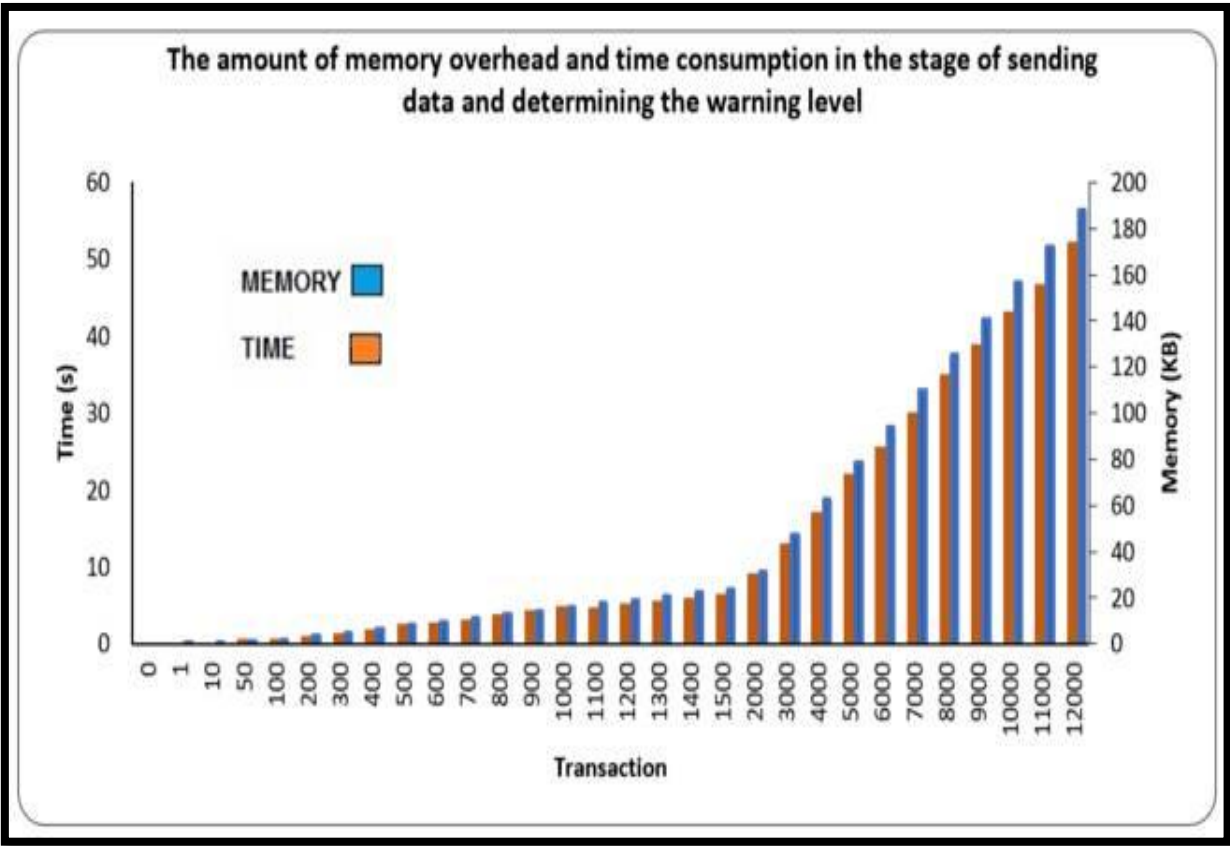


Figure 7.14: Amount Of Memory Consumed And The Duration Of Creating In Warning Level (Author)

As illustrated in Figure 7.14, the response time from the central system reaches its peak at approximately 60 seconds when processing 12,000 data points. While this average duration for sending data and awaiting a response may suffice in many scenarios, it poses significant risks in critical situations. For example, environments that require real-time monitoring of oxygen levels cannot afford delays, as a slow response could lead to dangerous conditions. To mitigate these risks, it is imperative to implement strategies that enhance the efficiency and speed of data transmission. Possible solutions include optimizing the data processing algorithms, utilizing faster communication protocols, or integrating real-time monitoring systems that can provide immediate alerts. By addressing these delays, we can ensure that critical environmental factors, such as oxygen levels, are monitored and managed effectively, thereby safeguarding against potential hazards. Timely responses are not only crucial for operational efficiency but also for ensuring the safety and well-being of individuals in environments sensitive to air quality.

For example, a separate framework can be created for the oxygen sensor so that the response speed can be increased and the response time can be reduced based on it, which, of course, with the increase in the number of oxygen sensors in the environment, is not much different from the designed framework. It will not have In general, the weakness of Blockchain work can be stated in this way: as the number of transactions increases, it will take more time to add a block to the previous Blockchain, and this is necessary to check the amount of oxygen in the environment, which is essential for the continuation of human life. It is dangerous.

Finally, in , the results of the methodology implementation are investigated. The critical point is that this proposed method is initially based on library studies and has a scientific basis. In the next step, based on experts' opinions, BIM and its elements were screened and ranked for Martian buildings, which can indicate the accuracy and scientific of the results of this section. However, the integration of BIM with Blockchain shows the importance of security in the information of Martian buildings. The reason for this was that the information about the Martian buildings is vital, and the smallest vandalism in it will lead to the loss of the lives of the inhabitants of Mars. Adopting this method can be the most effective security

method ever. However, the proposed framework is also based on the opinions of experts, which, from this point of view, is presented with a scientific and specialized basis, which can be very important.

The reason for using this proposed framework is the real-time control of Martian buildings, and with the help of this method, the safety of human lives living on Mars can be ensured to a great extent. As stated, This Research can begin with a new study on Martian buildings. So far, studies have yet to focus on this issue so seriously and more on other aspects of Martian buildings. Therefore, the proposed method is essential because it can give a vision to other researchers to provide a more robust framework by eliminating the shortcomings of this research.

Various researchers have explored the integration of Blockchain technology with Building Information Modeling (BIM), demonstrating that this combination can significantly enhance the security and accuracy of information. In the context of Martian buildings, the importance of these attributes becomes even more pronounced. Given the unique challenges of constructing and managing structures on Mars, even minor manipulation or sabotage of critical data can have dire consequences, potentially jeopardizing human lives.

The integration of Blockchain with BIM not only ensures the integrity of information but also establishes a reliable framework for monitoring and managing resources in such extreme environments. By providing an immutable record of all data related to Martian construction projects, this approach enhances accountability and transparency. Consequently, safeguarding against data tampering is essential, making the synergy between Blockchain and BIM particularly vital for the success and safety of future Martian endeavors.

Four levels were considered for this framework. According to experts, walls and roofs are the most essential elements in the BIM review of Martian buildings, and they are placed at the fourth level, or warning level 3. Also, temperature, oxygen, and air exchange in the environment are placed at warning level 2, and the facilities and equipment are placed at warning level 1.

According to the proposed framework, the sensor information is first stored on the Blockchain platform. This information is also classified based on the classifications made at three levels:

- Normal
- Damaged
- Warning

After receiving information from the sensors, this information is divided into three designated levels and then stored on the Blockchain platform.

The same information is also sent to the building control server simultaneously. The information the server receives matches the information stored in the Blockchain. If there is a match, the alarm level is activated for the sensors whose location is known in the contract. After the alert level is activated, rescue robots are instructed to perform rescue operations depending on the alert level.

The critical point highlighted in the discussion is that every record stored in the Blockchain must be verified. This requirement applies to managing Smart Contracts and storing data collected from sensors. Ensuring the integrity and accuracy of the information is essential for maintaining the system's reliability, especially in a challenging environment like Mars.

Table 7.6 presents relevant data concerning the time and memory required to store varying numbers of Blockchain records. This table serves as a crucial reference for understanding how scalability affects the performance of the Blockchain system, particularly as the number of transactions increases. The insights from this table can inform strategies for optimizing resource management and enhancing system efficiency to accommodate growing demands without compromising performance.

By analyzing the data in Table 7.6, researchers and engineers can assess the potential impact of record storage on system performance, guiding future improvements and developments in the infrastructure necessary for sustainable human presence on Mars. The emphasis on checking each record ensures that the system remains robust and responsive, which is crucial for the safety and well-being of its inhabitants.

Table 7.6: Amount of Memory And Time To Store The Smart Contract (Author)

Number of records	Duration	Amount of memory, bytes	Amount of memory, kilobytes
1	0.004	168	0.164063
10	0.03	312	0.304688
100	0.33	1752	1.710938
200	0.59	3352	3.273438
300	0.95	4952	4.835938
400	1.31	6552	6.398438
500	1.63	8152	7.960938
600	1.92	9752	9.523438
700	2.19	11352	11.08594
800	2.46	12952	12.64844
900	2.75	14552	14.21094
1000	3.35	16152	15.77344
2000	6.19	32152	31.39844
3000	9.54	48152	47.02344
4000	12.25	64152	62.64844
5000	15.25	80152	78.27344
6000	18.14	96152	93.89844
7000	21	112152	109.5234
8000	24.05	128152	125.1484
9000	27.2	144152	140.7734
10000	33.17	160152	156.3984

Table 7.7 illustrates the time required to store different transactions within the Blockchain, providing valuable insights into the efficiency and scalability of the system. A critical aspect to consider in Blockchain research is the impact of its decentralized architecture on the way information is processed. Unlike traditional computing systems, Blockchain relies on a distributed network to validate and record transactions, which can influence both the time required for processing and the memory space needed for storage.

In the next steps of the analysis, it is essential to determine the storage requirements and time consumption associated with adding new blocks to the Blockchain, as highlighted in the previous discussions within these tables. By quantifying these factors, researchers can better understand the limitations and capabilities of the Blockchain framework in managing the extensive data generated from Martian habitats.

The accompanying graphs from these tables visually represent the relationship between the number of transactions and the corresponding time and memory consumption. These visual aids can effectively communicate the scalability challenges faced by the Blockchain system and underscore the need for optimized solutions to enhance performance, particularly as the demand for data processing increases in the context of sustainable living on Mars.

By systematically evaluating these metrics, the research can provide critical insights into optimizing Blockchain operations and ensuring the integrity and efficiency of data management in extraterrestrial environments.

Table 7.7: Amount of Memory And Time To Store Sensor Information (Author)

Number of records	Duration	Amount of memory, bytes	Amount of memory, kilobytes
0	0	0	0
1	0.01	184	0.179688
10	0.06	328	0.320313
50	0.71	968	0.945313
100	0.65	1768	1.726563
200	0.97	3368	3.289063
300	1.36	4968	4.851563
400	1.9	6568	6.414063
500	2.54	8186	7.994141
600	2.86	9768	9.539063
700	3.17	11368	11.10156
800	3.91	12968	12.66406
900	4.46	14568	14.22656
1000	4.95	16168	15.78906
1100	4.81	17768	17.35156
1200	5.23	19368	18.91406
1300	5.66	20968	20.47656
1400	6.05	22568	22.03906
1500	6.54	24168	23.60156
2000	9.18	32168	31.41406
3000	13.13	48168	47.03906
4000	17.19	64168	62.66406
5000	22.14	80168	78.28906
6000	25.75	96168	93.91406
7000	30.04	112168	109.5391
8000	35.05	128168	125.1641
9000	39.01	144168	140.7891
10000	43.14	160168	156.4141
11000	46.77	176168	172.0391
12000	52.34	192168	187.6641

The results of the methodology implementation are investigated. The critical point is that this proposed method is initially based on library studies and has a scientific basis. In the next step, based on experts' opinions, BIM and its elements were screened and ranked for Martian buildings, which can indicate the accuracy and scientific of the results of this section. However, the integration of BIM with Blockchain shows the importance of security in the information of Martian buildings. The reason for this was that the information about the Martian buildings is vital, and the smallest vandalism in it will lead to the loss of the lives of the inhabitants of Mars. Adopting this method can be the most effective security method ever. However, the proposed framework is also based on the opinions of experts, which, from this point of view, is presented with a scientific and specialized basis, which can be very important. Also, part of the results is included in the Annex.

8. CONCLUSION

8.1. Introduction

The conclusion chapter provides a comprehensive analysis of the research findings. It begins with an overview of the problem statement and research objectives and then deals with the theoretical foundations underlying the research. The primary factors that are important for the research are thoroughly explored using previous research and theoretical frameworks. It identifies areas that need more attention or exploration in previous studies and provides the basis for new solution development.

Subsequently, a preliminary methodology is presented to address the identified research gaps. The results of this process are carefully evaluated. A systematic review of research findings provides valuable insights into the effectiveness of the proposed solution and its potential implications for the broader field of study. This comprehensive review increases the understanding and awareness of the research topic and provides the context for future studies and developments.

This research focuses on managing buildings on Mars, where extreme environmental conditions, such as intense radiation and low temperatures, present unique challenges. Blockchain technology securely stores all building-related data, ensuring transparency and preventing tampering. Inspectors conduct regular assessments, and based on their evaluations, each building is assigned a condition level, which helps maintain safety and prioritize maintenance efforts.

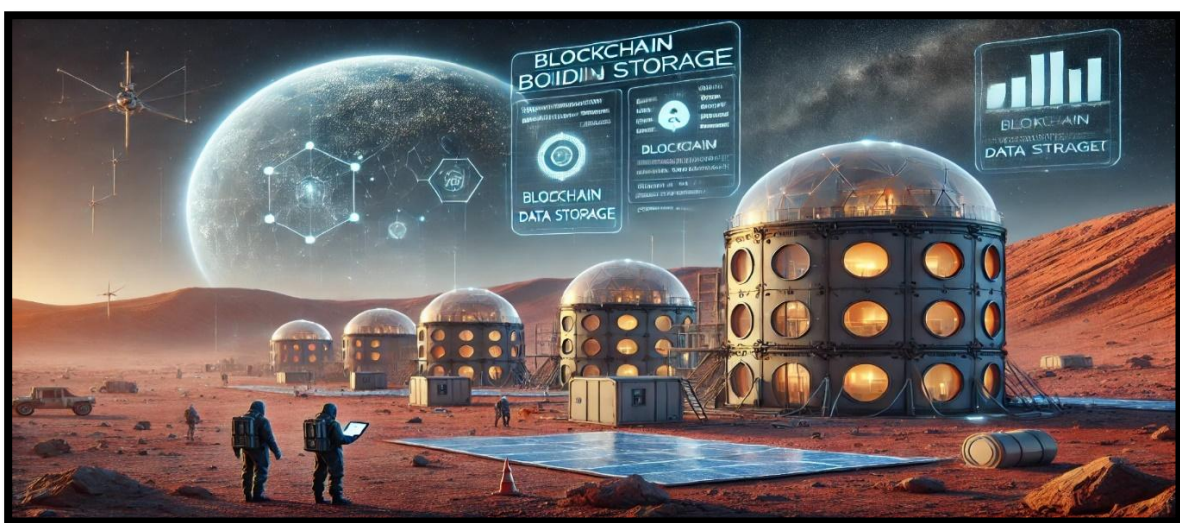


Figure 8.1: Mars colony (Author)

The Figure 8.1 shows a futuristic Mars colony with advanced, radiation-resistant buildings, where inspectors use blockchain-based systems to monitor and assess structural conditions.

8.2. Discussion

Integrating Building Information Modeling (BIM) with Blockchain technology provides a revolutionary method for managing the entire lifecycle of buildings on Mars, from construction to ongoing operation. BIM enables detailed, digital representations of building designs, while blockchain ensures secure, transparent, and tamper-proof storage of all project data, enhancing efficiency and accountability in Mars' challenging environment. Mars presents unique challenges, such as a harsh environment and limited resources, which demand innovative solutions beyond traditional construction methods used on Earth.

Using building information modeling, engineers can accurately model and analyze the mechanical, structural, and electrical components of Martian buildings, enabling optimized designs that anticipate and address potential challenges.

The inspector-centric framework introduced in this research is crucial for ensuring the effective management of inspections in extreme environments. It offers a structured approach that enables inspectors to efficiently handle specialized tasks, ensuring all aspects of a building's performance are systematically assessed. This method streamlines the inspection process, reducing the likelihood of oversight and enhancing the overall efficiency of operations.

By prioritizing critical issues, the framework plays a vital role in maintaining buildings' structural integrity and safety in harsh conditions. This approach ensures that potential risks are addressed promptly, safeguarding the long-term viability of the structures and providing a reliable system for ongoing maintenance and management.

Blockchain technology further enhances the management of Mars buildings by ensuring the security, transparency, and accuracy of data throughout the lifecycle of these structures. Given the critical need for reliable information in the harsh Martian environment, Blockchain's decentralized, tamper-resistant nature ensures

that the data related to construction, maintenance, and inspections is secure and easily traceable. By integrating Blockchain with BIM, this research presents a solution that improves the safety and management of Mars buildings and offers a model that could be applied in other resource-limited or extreme environments. This integration ensures that construction processes, resource management, and maintenance protocols are carried out efficiently and securely, critical for sustaining human life on Mars.

This research also highlights the broader implications of combining BIM and Blockchain technology, particularly in advancing construction practices in other extreme environments, including Earth. The proposed frameworks and methodologies, such as AI-driven predictive maintenance and IoT sensors for real-time monitoring, could revolutionize how we approach construction and maintenance in areas prone to extreme weather or Lack of resources. The interdisciplinary nature of this study, incorporating insights from space engineering, construction management, and information technology, sets a foundation for future developments in sustainable building practices. Ultimately, this research not only contributes to the advancement of space exploration but also has the potential to reshape how we build and manage structures in the face of increasingly unpredictable and challenging environments.



Figure 8.2: Buildings are managed using BIM and Blockchain technology (Author)

Figure 8.2 shows a futuristic Martian colony where advanced modular buildings are managed using BIM and Blockchain technology. Inspectors use high-tech tools for real-time monitoring, while blockchain ensures secure, transparent data management, highlighting innovative solutions for sustaining life in Mars' harsh environment.

8.3. General Conclusion

The Earth replacement search has become a serious problem due to the numerous challenges and situations our planet is experiencing. As researchers explore the possibility of human habitation on Mars, addressing the physical aspects of building structures on the Red Planet and the complex challenge of managing and securing information about these Martian structures becomes critical.

Building management is critical on Mars because buildings must adapt to countless challenges and conditions.

For example, the Martian environment, with its unique temperature changes and atmospheric conditions, requires buildings that can withstand these changes and maintain their security. These buildings must also be monitored in terms of security to prevent unauthorized access to information related to them and protect the residents of these structures from life risks.

With the advent of advanced technologies, there is a significant opportunity to enhance the management and storage of information pertaining to these structures. This is a crucial issue, as this information plays a pivotal role in making key decisions about the building and ensuring the safety of its occupants.

The hypothesis is that buildings on Mars are possible and can be made using advanced technologies, especially 3D printing. This provides the context for critically examining how information related to these Martian structures is stored and managed. One of the winners of NASA's Marsha competition, this egg-shaped building will serve as a living space for the potential inhabitants of the colony. The double-insulated hub can withstand the pressure of the Martian atmosphere, enabling complete construction on Mars and minimizing the need to transport finished buildings in one (space shuttle).

The materials needed for this construction are largely available on Mars, making the process sustainable and efficient. Researchers are creating a unique building material by combining basalt fibers, which can be extracted from Martian rock, with renewable bioplastics derived from plants that can be cultivated on Mars. This approach reduces dependency on Earth-based resources and supports the development of a self-sustaining colony.

These living hubs are designed as small, private spaces suitable for 1-2 people, providing a comfortable and functional environment for future Martian inhabitants. Although intended to be compact, they offer the essential space and privacy needed for daily life on Mars, making them ideal for early settlers moving to the Red Planet.

Our research uses Research resources (Book, Article, etc.) and criteria for effective Building Information Management (BIM) in the context of Martian structures. Our work is to create a framework that ensures protection and access to critical information, considering the extraterrestrial nature of buildings.

Realizing the importance of information security in Mars colonies, this research proposes an innovative approach by integrating Blockchain technology with BIM for Mars buildings. Due to its decentralized and secure nature, Blockchain presents itself as a promising solution to the challenges associated with managing information on Mars's unique context. As demonstrated in this research, the Mars Building Control Framework leverages the strengths of Blockchain and BIM. With its distributed ledger and cryptographic principles, Blockchain technology provides a tamper-resistant and transparent system for recording and managing information. This increases data security and ensures the integrity of information stored in the Blockchain.

This research aims to create a comprehensive and reliable building information management system on Mars by combining Blockchain with BIM. Integration allows for crackless and secure data flow, addressing concerns about data manipulation, unauthorized access, and data loss. Additionally, Blockchain's decentralized nature ensures no single point of failure, increasing the flexibility of the information management system in the challenging Martian environment.

Represents a forward-looking and innovative approach to information management challenges in Mars colonization. By integrating Blockchain technology with BIM, the proposed control framework attempts to protect the integrity and security of information about Martian structures, thereby contributing to the feasibility and safety of future human habitation on the Red Planet.

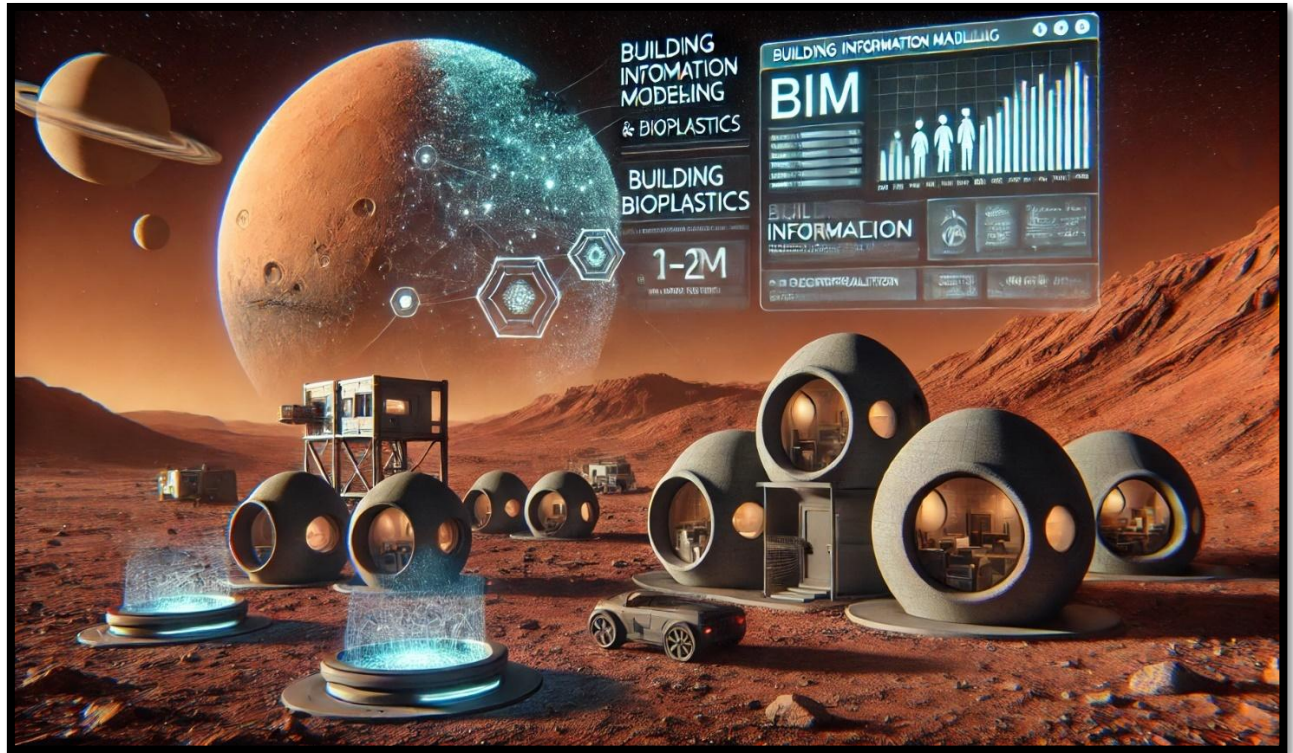


Figure 8.3: Mars colony with egg-shaped (Author)

The Figure 8.3 depicts a futuristic Mars colony with egg-shaped living hubs designed for 1-2 people, constructed from sustainable materials like Martian basalt fiber and bioplastics.

8.4. Practical Conclusions

Efforts to explore and possibly colonize Mars have captured the imagination of scientists and space enthusiasts. The main focus of this effort is the critical need for infrastructure to support human life in the harsh environment of Mars. For this challenge, an entire study focused on Martian buildings. This research not only looked at the components of these structures but also examined the internal

environment and extracted key criteria that determine the habitable parameters of the Red Planet.

The identified criteria were classified into two main categories that provided a structured framework for the analysis.

- The first category focused on building components.
- the second revolved around the interior environment.
- Three main criteria emerged in the first category: wall, roof, and building facilities. These components, critical to the structural integrity and performance of Martian buildings, constitute fundamental aspects of the study.
- The second category, focusing on the indoor environment, identified three main criteria: air exchange, ambient temperature, and ambient oxygen. These criteria, considered necessary to sustain human life in confined spaces, highlight the complex balance required to inhabit Mars.

In technology and data management, researchers realized the importance of balance. While a comprehensive set of metrics was critical, too much data could slow down the system. On the contrary, insufficient data can endanger human lives. This study involved experts in this delicate balance using the fuzzy Delphi method and the fuzzy Delphi questionnaire.

These methodologies, rooted in the consensus of experts (2 experts in Space filed and 2 experts in building management), aim to distill the criteria into their most essential components. The result is a revised set of criteria that incorporates Building Information Modeling (BIM) information designed specifically for buildings on Mars.

The next frontier in this discovery was protecting this information, which led researchers to consider integrating Blockchain technology.

Based on the explanations provided, one of the primary objectives of utilizing Building Information Modeling (BIM) for Mars buildings has been successfully achieved. BIM allows for the creation of highly detailed and accurate digital models of Martian structures, enabling efficient design, construction, and management processes tailored to the unique challenges of the Martian environment. In other

words, construction information management has been instrumental in identifying the critical factors necessary for the successful development of Mars buildings. To meet these objectives, advanced modeling and analysis techniques, such as the Delphi Fuzzy Method and AHP Fuzzy, are employed, providing a structured and systematic approach to decision-making and prioritization in the challenging Martian environment.

These methods allow for determining the priority and ranking of different factors, considering the ambiguities and roughness of the Martian environment. These tools allow engineers and experts to analyze and design buildings on Mars more accurately and, through them, achieve buildings compatible with Mars's harsh and unique environmental conditions.

For its secure and decentralized nature, Blockchain has provided a robust solution to store and protect the valuable data generated by this study. Eight transactions were carefully defined: two transactions were dedicated to Smart Contract registration, and six transactions were dedicated to storing information extracted from the experts' questionnaire. Once received, this information found a secure home on the Blockchain platform.

Although Blockchain composition is about storage and devising a dynamic and responsive system, a four-step framework was conceptualized to reach this goal, aligned with the extracted criteria, and introduced a hierarchy of urgency levels. The first normal level represents the baseline where all systems are operating optimally. Subsequent levels represented increasing degrees of urgency: first emergency level, second emergency level, and third emergency level.

The application of Blockchain in this framework includes the parallel transfer of information to the building control department's central server. As soon as the information is received, the server subjects it to the same hash function used in the Blockchain. This double-verification process ensured data integrity and consistency. All sensors were expected to report normality at a normal level, indicating a stable and efficient building.

Primary goals of this research in the field of BIM is to increase security and preserve information related to buildings. The security of important information stored in

BIM models is critical due to its sensitivity. One proposed solution to increasing the security of BIM is the use of Blockchain technology.

Using Blockchain, important information such as designs, technical specifications, materials used, etc., are stored as locked and immutable blocks in a data network. Each block contains a unique identifier and encrypted information that prevents any attempt to change or hack that information.

Blockchain ensures that any changes in information are traceable and that all participants in the construction process are informed of the changes. This security improvement protects BIM information against hacking attacks and unauthorized changes and increases trust in this information.

The integration of Blockchain technology into Building Information Modeling (BIM) offers substantial benefits, particularly in enhancing reliability and security. By leveraging Blockchain's decentralized and immutable nature, stakeholders in the construction and management of buildings can ensure that data remains secure and tamper-proof. This technological advancement can effectively streamline processes and facilitate better collaboration among various parties involved in a building's lifecycle.

Blockchain's capability to maintain accurate and accessible information about buildings can improve transparency and trust among stakeholders. It allows for the secure sharing of data, which is crucial for efficient project management and decision-making. By adopting Blockchain within BIM, the construction industry can not only safeguard sensitive information but also foster innovation, leading to more resilient and sustainable building practices.

However, the framework outlines specific actions based on urgency in emergencies, which are as follows:

Table 8.1: Framework level (Author)

Normal level	the building is that the condition of the whole building is suitable and all the sensors and sensors and criteria are working normally
First level	focused on assessing and addressing issues related to building facilities. Facility robots will be mobilized to resolve any identified issues quickly
Second level	a large response team included medical and rescue robots. These robots assessed environmental conditions such as temperature and oxygen levels, took corrective actions, and provided additional support to the facility's robots
Third level	considered very dangerous, involves firefighting robots. These specialized robots, as well as medical and rescue robots, were deployed to fix critical failures in wall and roof sensors and assist in human evacuation if necessary

The integration of BIM and Blockchain is considered useful research. The aim of this approach is to increase security and accuracy in building information management. In this approach, blockchain acts as an information inspector that categorizes and records building information. The Blockchain stores this information at each level by receiving factor information from sensors.

With this method, any damage or change in the condition of the building is quickly detected and recorded in the Blockchain. This allows managers and specialists to react immediately and take necessary measures for repairs or restoration. In this way, this integration increases security, accuracy, and efficiency in managing and monitoring buildings and helps ensure their condition.

Simulations were performed to confirm the effectiveness of this framework. The results showed that the framework shows acceptable memory consumption and speed values. It shows that the proposed system, integrating metrics, Blockchain, and a multi-layered emergency response framework, can be a suitable solution to ensure the safety and performance of Martian buildings.

This research identifies critical criteria for Martian buildings and proposes an innovative framework for their management and maintenance. By combining expert knowledge, advanced technology such as Blockchain, and a dynamic emergency response system, the study provided a comprehensive solution to the complex challenges of building infrastructure on Mars. As humanity approaches the possibility of interplanetary habitation, research efforts for sustainable and safe life on Mars.



Figure 8.4: Habitats designed to support human life (Author)

The Figure 8.4 illustrates a futuristic Mars colony with advanced modular habitats designed to support human life in the planet's harsh environment.

8.5. Final Conclusions

Building Information Modeling (BIM) and Blockchain technology are two distinct realms that have revolutionized how we approach construction and data management. Although, when combined, these technologies offer a promising avenue for addressing the unique challenges posed by constructing and managing buildings on Mars .

This Research focuses mainly on BIM management because Building Information Modeling is a powerful tool that can help improve the management and monitoring

of Mars buildings. This tool allows engineers and specialists to examine the various components of Mars buildings more precisely and in more detail.

Using BIM modeling, various parts of Mars buildings, including mechanical, electrical, structural systems, etc., are more accurately examined and evaluated. This allows engineers to make necessary improvements in the design and implementation of these parts and anticipate possible future problems.

BIM management allows managers and officials to plan, monitor, and improve the construction process more effectively. With accurate and comprehensive information about buildings, managers can make better decisions regarding maintenance, repairs, and productivity, as well as predict and fix problems that may occur during the building's life.

This is a relatively new and unknown field to apply to Mars construction. The challenges of building on Mars differ entirely from those on Earth, from the thin atmosphere to the need for more resources. Traditional approaches to ground construction and facility management must be more adaptable to Mars's harsh and alien conditions and require innovative solutions. Implementing BIM principles in this extraterrestrial context requires careful consideration of unique environmental factors and the complexities of maintaining structures in a challenging environment.

The Research introduces an inspector-centric framework, a concept that could be explored more extensively in BIM management. Unlike conventional methods where inspections are broadly conducted, this framework emphasizes assigning specific tasks to different inspectors based on their expertise and prioritizing inspections according to urgency. This approach ensures a meticulous and systematic examination of every aspect of the building, contributing to enhanced efficiency and safety. In the context of Mars, where resource limitations and environmental challenges amplify the importance of maintenance, an inspector-centric model becomes crucial for the longevity and functionality of structures.

Integrating Blockchain technology into BIM management introduces a paradigm shift in information security and transparency. While the application of Blockchain in terrestrial BIM processes is gaining traction, its adaptation for Martian buildings

is a unique proposition. Blockchain's decentralized and tamper-resistant nature can enhance the security and transparency of data, which is critical for managing information related to construction, maintenance, and inspections on Mars. The Research explores how Blockchain can be leveraged to create a secure and transparent platform for managing the intricate web of data associated with Martian structures.

Integrating BIM management with Blockchain in the context of Mars is an important advancement in engineering technology that continues to break new ground. When combined with Blockchain, the inspector-centric framework promises to provide a comprehensive and efficient solution to the challenges posed by off-site construction and facility management.

This integration enables the creation of a dynamic and reliable management structure that benefits from modern technologies such as Building Information Modeling (BIM) and Blockchain. This structure uses accurate and reliable information received through various sensors and devices and is stored and managed securely and reliably using Blockchain technology.

It will help improve performance and efficiency in the construction process on Mars and change the way we approach construction on other planets beyond Mars. By creating a reliable and stable infrastructure, this integration can lead our future efforts in space exploration and colonization to a new and more advanced stage.

There are several suggestions for further exploration of the research area.

- Specific protocols and standards for BIM management in Mars buildings must be developed to ensure interoperability and streamlined processes. Integrating different sensors and Internet of Things (IoT) devices for real-time monitoring and control of Martian facilities could significantly enhance building management efficiency.
- Algorithms for using artificial intelligence for predictive maintenance and anomaly detection are considered a critical frontier in the engineering space. Considering the resource limitations on Mars and the vital importance of preventive maintenance, these unique algorithms are used to find out.

- Artificial intelligence algorithms, including artificial neural networks, machine algorithms, and developmental algorithms, can be used to predict Martian buildings' maintenance and repair needs. Based on data collected from buildings and equipment, these algorithms can predict future patterns and trends and help managers and professionals take preventive measures to prevent breakdowns and failures. Also, these algorithms can monitor the condition of buildings and equipment in a continuous and improved manner, identify any anomaly or failure, and give it to the provider. This preventive maintenance can save Mars' limited resources and prevent outages from causing severe problems.

The Research is able to understand the subtleties of various Blockchain technologies, including public, private, and hybrid Blockchain. Assessing their capability for handling various areas of information development on Mars is critical, given the Martian environment's unique problems and requirements.

This research emphasizes the need for collaboration among experts in BIM, Blockchain, space engineering, and related disciplines. Each field brings unique insights and skills for addressing the complex challenges of managing building information on Mars. By working together, these experts can develop integrated systems that ensure efficient Martian structures' design, construction, and operation.

inspector-centric framework based on Blockchain for BIM management in Mars buildings is a pioneering exploration into uncharted territory. It addresses the unique challenges of constructing and maintaining buildings on Mars and introduces innovative concepts like the inspector-centric framework and Blockchain integration. This Method can shape the future of human exploration and habitation beyond Earth, contributing to developing sustainable and safe habitats on Mars and potentially on other celestial bodies in our vast universe.

However, the specified goals in our research are stated below, and the way to achieve them is also stated, that respectively:

- **Enhancing BIM security to maintain information security:** As mentioned, BIM manages the information of a building, but in the field of information

protection, a solution must be provided to increase the security of information. Currently, blockchain is presented as a solution with the highest reliability coefficient, and in this research, the security of BIM information has been increased by combining BIM with blockchain. On the other hand, since the discussion of this research was on the buildings of Mars, the accuracy of the information is of particular importance, because it improves the quality of human life on Mars. In our research, by combining these two together, it can be said that the level of security and accuracy of information in Mars buildings has been observed to a great extent. This integration was accompanied by the presentation of a proposed framework, which was discussed in detail.

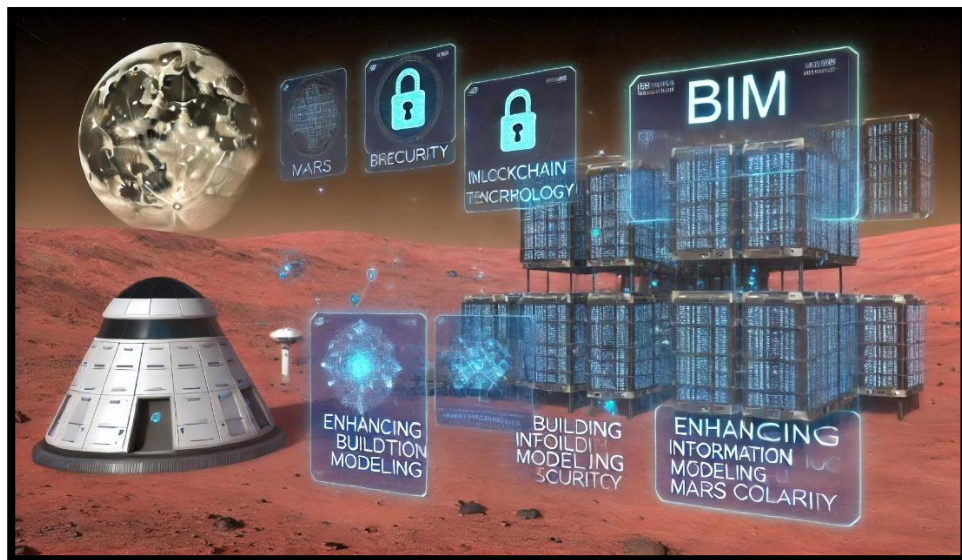


Figure 8.5: futuristic Martian habitat (Author)

The Figure 8.5 depict a futuristic Martian habitat where Building Information Modeling (BIM) is securely integrated with Blockchain technology to ensure the safety and accuracy of critical building information.

- **Using BIM for Mars buildings:** It can be said that BIM is different in buildings on Mars and buildings on Earth. On Mars, the goal of improving the quality of human life goals is to properly face the dangers for humans in life on Mars, while these dangers are less visible on Earth. For example, in Earth and terrestrial buildings, the amount of oxygen in the environment

can be adjusted by itself, and the inhabitants of Earth do not have much problem with this issue, but in Martian buildings, considering the atmosphere on Mars, it may be a serious challenge for quality. Human life on Mars. For example, the exchange of air in Earth's buildings mostly overshadows the discussion of energy consumption, but in the buildings of Mars, the exchange of air may put the quality of human life in serious danger. Therefore, by conducting library studies, a number of criteria that can be controlled as much as possible were extracted, and using the fuzzy Delphi method, these criteria were first screened, and then, using the fuzzy AHP method, these criteria were ranked. And the factors that should be given a lot of attention as BIM in Martian buildings and are part of the building information so that they can be managed were extracted. Based on this ranking, the proposed Framework has different levels and was presented.



Figure 8.6: Buildings designed using Building Information Modeling (Author)

The Figure 8.6 illustrates futuristic Martian buildings designed using Building Information Modeling (BIM), highlighting the unique challenges of sustaining human life on Mars compared to Earth.

- **Integration of BIM and Blockchain:** This action happened in such a way that by extracting BIM criteria in Mars buildings, a four-level framework was

presented that determined the level of warning. Based on this, the BIM information was initially stored in the blockchain instead of being stored in a centralized system, and then by comparing the received information with the blockchain and analyzing them, it is determined at which warning level the building is located.

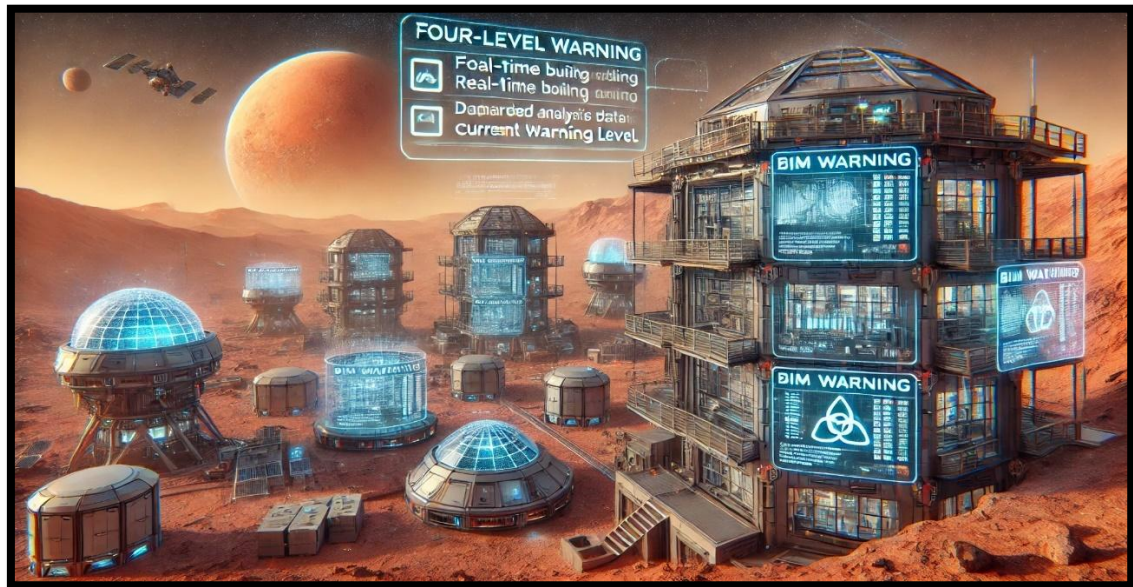


Figure 8.7: Four-level warning framework (Author)

The Figure 8.7 showcases a futuristic Martian colony where Building Information Modeling (BIM) is integrated with Blockchain technology. A four-level warning framework is depicted,

The objectives outlined in this thesis are critical to advancing the study of Building Information Modeling (BIM) and its applications in space architecture, particularly in Martian environments. Integrating BIM with blockchain technology to enhance information security is a significant contribution, ensuring the protection and accuracy of sensitive building data. Given that human life on Mars faces unique risks and challenges, improving the reliability of this information becomes crucial. By merging BIM and blockchain, this research proposes a framework that increases security and accuracy in managing data for Martian buildings, which is essential for safeguarding the quality of life in these new environments. This innovative approach addresses current challenges in

information management and sets the foundation for future advancements in the field.

Our research delves into the application of BIM in Martian buildings, highlighting the differences from its use on Earth. The Martian environment poses unique challenges, such as air quality and energy management, which directly impact the quality of life. By conducting a thorough analysis and using methodologies like the fuzzy Delphi and AHP, this research identifies and ranks the key criteria that need to be managed in Martian structures. The proposed framework provides a detailed system to address these challenges, ensuring that BIM can be adapted to meet the needs of extraterrestrial construction. These objectives collectively demonstrate the thesis's contribution to the theoretical understanding and practical implementation of BIM in future space habitation.

8.3. Sustainability on Mars

It signifies the role of technology in enhancing the quality of human life, a pivotal concept in the research present. The study aimed to create an innovative framework that protects human lives through four autonomous warning levels. This approach allows technology to function independently by eliminating human intervention, continuously monitoring potential threats, and responding swiftly. This capability is particularly important in environments where there are significant risks to human safety, as it ensures that preventive measures are in place to protect people effectively.

In an effort to save human lives, this study identified several critical factors for creating a safe living environment. Among these factors were the regulation of ambient oxygen level, temperature and exchange rate measurement and prevention of toxic gas penetration into living spaces. These elements play a critical role in ensuring that individuals can conduct their daily activities in a safe and healthy atmosphere. The research underscores the necessity of a multi-faceted approach to environmental safety by systematically addressing these variables.

Our research also thoroughly evaluated the facilities designed for human habitation and work. A significant focus was placed on the roof, which serves as a protective shelter from external hazards. In extreme environments like Mars, the roof becomes a critical barrier against harsh conditions, including radiation and extreme temperatures. The design and construction of roofs must account for these factors, ensuring that they provide safety and contribute to the overall stability and habitability of the living environment.

The wall is equally important to the roof, which serves as a vital barrier separating the human living space from the external environment. In the context of Mars, where atmospheric conditions can be unforgiving, the walls must be engineered to withstand severe external threats. These walls must protect inhabitants from environmental hazards such as dust storms and radiation while maintaining internal environmental stability. Thus, the design of both roofs and walls is critical for ensuring a secure and habitable space for humans in extreme conditions.

Our research highlights the crucial interplay between optimizing protective structures and managing essential resources in sustaining human life. Specifically, in extreme environments like Mars, integrating resilient design features, such as robust roofs and walls, along with effective management of vital resources like oxygen and light, is paramount. The findings suggest that without these optimizations, the potential for long-term human habitation in such challenging environments diminishes significantly.

Advocates for a comprehensive approach that combines protective measures with advanced automated technologies to foster sustainable living conditions in harsh environments. By utilizing autonomous systems to monitor and manage essential resources, alongside constructing durable physical barriers, the research presents a forward-thinking strategy for ensuring human safety and enhancing the quality of life in extreme conditions. Ultimately, this approach prepares humanity for the potential colonization of extraterrestrial environments and contributes valuable insights into improving safety and sustainability on Earth.

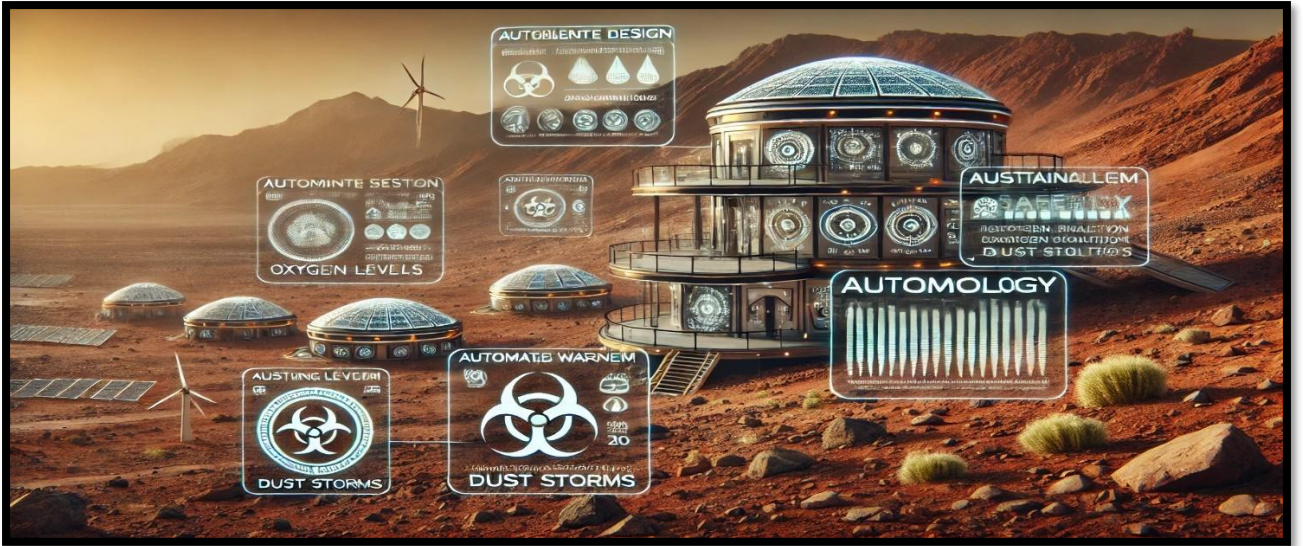


Figure 8.8: Advanced habitats (Author)

The Figure 8.8 showcases a futuristic Martian colony focused on sustainability and human safety, featuring advanced habitats with resilient roofs and walls designed to withstand Mars' harsh conditions, including radiation and dust storms.

8.3.1. The impact of the sustainability of Mars on Earth

The lessons learned from designing protective structures for extreme environments, such as Mars, have significant implications for improving living conditions on Earth. The challenges faced in creating habitats that can withstand the harsh conditions of another planet offer valuable insights into enhancing the safety and durability of our buildings. By applying the principles derived from these designs, we can develop structures better equipped to handle the increasing frequency and intensity of extreme weather events we encounter here on Earth.

The principles of robust roof and wall designs utilized in Martian habitats can directly influence construction methods in areas prone to severe weather, such as hurricanes and floods. Implementing these designs can help buildings withstand high winds, heavy rainfall, and other environmental stresses. This adaptation protects the structures' physical integrity and also safeguards the lives of those residing in them.

Focusing on sustainable construction practices is crucial in this context. By optimizing resource management and using eco-friendly materials, we can create buildings that are not only resilient but also minimize their environmental footprint. Sustainable construction techniques, such as utilizing renewable resources and implementing energy-efficient systems, reduce waste and conserve energy, making our living spaces healthier and more efficient.

This holistic approach to sustainability fosters the development of secure and thriving communities. When we design with both resilience and sustainability in mind, we address the immediate challenges posed by extreme weather and enhance the overall quality of life for all inhabitants. Healthy living environments lead to better physical and mental well-being, promoting community and connection among residents.

Ultimately, the insights gained from designing protective structures for extreme environments can significantly improve our living conditions on Earth. By integrating robust design principles, sustainable practices, and a focus on community well-being, we can create living spaces that are safe, resilient, and conducive to a thriving life.



Figure 8.9: Sustainability of Mars on Earth (Author)

Figure 8.9 showing a futuristic vision where both planets thrive in harmony.

8.6. Future Lines of Investigation

Every research that is done, in addition to the goals that are considered for the research, has a higher goal: to bring the research results into the real world. This research is no exception to this rule. Therefore, the results of this research should be checked to see who the beneficiaries are. The most important factor of this research, distinguishing it from other research, is Mars and life on Mars. Therefore, the leaders of organizations and organizations that work on and live on Mars are the primary beneficiaries of this research and can use the results of this research.

8.6.1. Research Directions

Researchers are intensively investigating the possibility of creating homes on Mars, motivated by growing worries about resource depletion on Earth and the need to expand human habitation beyond our planet. Mars is an attractive choice due to its potential as a habitable environment, which is supported by existing research and its distinctive traits. However, more research on building management in Martian environments must be done, emphasizing the vital need for establishing comprehensive techniques adapted to interplanetary dwellings' constraints.

The proposed methodology for building habitats on Mars promotes building performance and data integrity using an inspector-oriented approach. This technique is intended to speed up the discovery and remediation of possible difficulties, thereby improving Martian habitats' overall efficiency and reliability. While early implementation may require specific skills from network engineers, the collaborative nature of this research promotes multidisciplinary participation, enabling cross-sectoral improvements in alien architecture and engineering.

The findings of this research are a crucial step in developing solid frameworks for managing buildings in Martian conditions. Beyond its immediate use, the established methodology has enormous promise for informing the design and operation of safe infrastructure on Earth and other alien habitats. Engineers can use the knowledge acquired from Mars habitat research to adapt and develop comparable frameworks to solve the particular challenges of varied environments,

substantially contributing to the more considerable evolution of sustainable habitation beyond Earth.

Furthermore, the research findings help to advance technological innovation in architecture and engineering, opening the path for more efficient and sustainable building methods in space and on Earth. This research emphasizes the necessity of environmental preservation and resource efficiency in space exploration and colonization efforts by creating and applying appropriate building management approaches in Martian habitats. Finally, this research contributes to the establishment of a sustainable human presence beyond Earth, as well as to the development of terrestrial infrastructure and sustainability efforts.

8.6.2. Future Research Opportunities

Due to the novelty aspect of the topic discussed in this research, many research projects can be proposed based on this topic, which can be extended to the rest of the fields, considering the interdisciplinary nature of this topic. Here are some suggestions that can be made for future lines of research:

- **Integrating Artificial Intelligence (AI)** within the BIM and Blockchain framework for Mars construction offers exciting avenues for enhancing the efficiency, safety, and sustainability of extraterrestrial habitats. One key area for further research is the development of AI-driven predictive maintenance algorithms tailored to the unique challenges of Mars. These algorithms can analyze data from real-time monitoring systems, such as IoT sensors embedded within the structures, to predict potential failures or maintenance needs before they become critical. AI's ability to process large datasets and detect patterns will be essential for resource optimization, as Mars offers limited access to materials and human intervention for repairs.

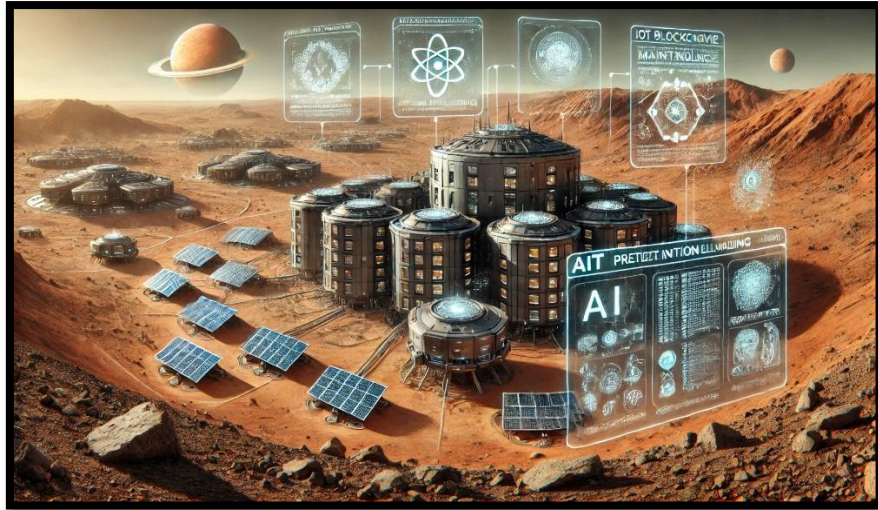


Figure 8.10 Martian colony integrating AI (Author)

The image depicts a futuristic Martian colony integrating AI with BIM and Blockchain, showcasing IoT-equipped habitats using real-time data for predictive maintenance and resource optimization in Mars' harsh environment.

- The role of **electrical engineers** on Mars (Figure 8.11) is very critical and challenging. They are responsible for the design and development of sensors that perform well in the harsh and special environmental conditions of Mars. These sensors should be optimal in terms of ruggedness, reliability and performance in low atmospheric pressure and temperature conditions. Electrical engineers should pay special attention to factors such as energy efficiency and evaluation in the design of sensors. Natural energy sources, such as the use of solar cells, and the use of low-energy energy sources are very important. Also, electrical engineers must send and process the collected information accurately and efficiently using advanced processing methods. In addition, electrical engineers need to integrate wiring, power sources, and communication links into the sensor structure. This integration will help them to crackslessly and optimally introduce sensors into the Martian work structure and achieve better performance. electrical engineers, with their precision and technical knowledge, play a very

important role in creating and upgrading sensors that are designed to ensure performance in the challenging Martian environment.

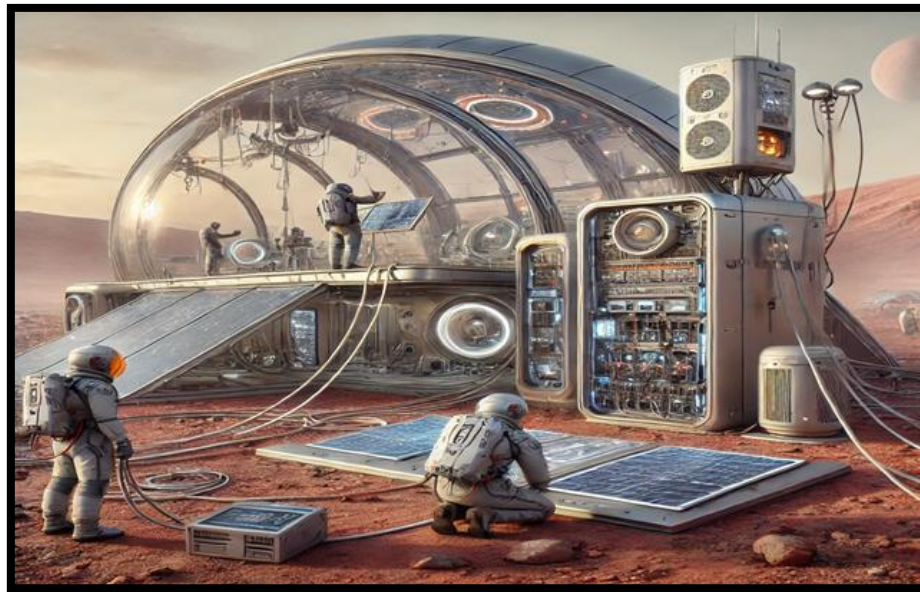


Figure 8.11: Electrical engineers on Mars (Author)

- **Network engineers** (Figure 8.12) are responsible for designing the communication infrastructure involved in connecting sensors, a central server, and other systems on Mars. They should be familiar with challenges such as latency, bandwidth limitations and possible interference in the Martian environment and propose solutions for them. One of the main challenges of Martian communication is the delay in data transmission. This delay is caused by the large distance between Earth and Mars, which increases the time for data transmission. Network engineers should look for solutions to minimize this delay, including the use of protocols and technologies that enable efficient and reliable data transmission over long distances. Engineers must be aware of bandwidth limitations that may arise due to limited resources on Mars. Choosing the right network protocols and technologies to accommodate these constraints is critical. Possible interference with other networks or systems is another challenge that needs to be managed. Engineers must implement protocols and settings that reduce potential interference and establish reliable and stable

communications. Selecting and using the correct network protocols and technologies, including wireless communications and TCP/IP, is fundamental to establishing reliable and efficient communications in the Martian space. By considering all these challenges and applying appropriate solutions, network engineers can provide an effective communication infrastructure for data transmission in the Martian environment.

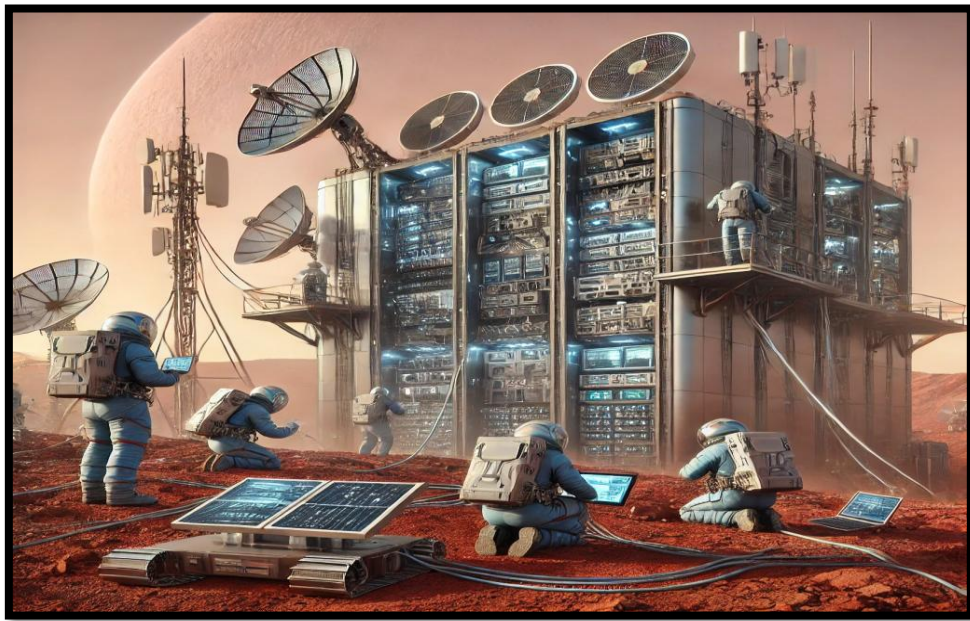


Figure 8.12: Network Engineers (Author)

- **Power engineers** (Figure 8.13) on Mars will focus on developing the energy infrastructure to support the sensor network and other systems in this environment. These infrastructures can include a combination of renewable energy sources such as solar power, energy storage solutions such as batteries, and even innovative technologies such as wireless power transmission. The use of renewable energy sources, especially solar energy, due to the abundance of sunlight on Mars, provides the possibility of providing energy for various systems. Power engineers must optimize solar energy extraction and conversion technologies and systems to meet the energy needs associated with sensor networks and other systems. In addition, energy storage solutions, such as batteries, are of great

importance in this environment because energy sources may not be available at certain times. Batteries with high capacity and long life can meet this need and ensure the stability of the energy grid. wireless energy transfer can also be used as an innovative technology. This technology enables the transfer of energy between devices without the need for a wired connection and can be very useful when a wired connection is difficult. By optimizing the production, storage and distribution of electricity, power engineers can ensure the stability and efficiency of the energy grid in the Martian environment and so provide support for other systems including the sensor network.



Figure 8.13: Power engineers on Mars (Author)

- **Building engineers** (Figure 8.14) are faced with the responsibility of designing and building the Mars habitat and must pay attention to structural integrity, environmental sustainability and resource efficiency in choosing building materials and construction methods. They must use methods and materials that make buildings resistant to the harsh environmental conditions of Mars and consider the possibility of using local materials such as rocks and Martian soil. The use of 3D printing can be a suitable solution for building a habitat using local materials on Mars. This method helps to minimize the need to transfer building materials from

Earth and to use the resources available in the Martian environment. civil engineers play an important role in ensuring the structural stability of the habitat and incorporating the placement of sensors into building design to monitor factors such as structural health, environmental conditions, and occupancy. These sensors can provide engineers with the necessary information about the condition of the structure, the living conditions and the needs of the inhabitants so that they can take appropriate measures to preserve and improve the habitat. by combining science and technology, civil engineers can design infrastructure to build habitats on Mars and use local materials to achieve the best performance and sustainability in the harsh environmental conditions of Mars.



Figure 8.14: Building engineers on Mars (Author)

- **Architects** (Figure 8.15) face the unique challenge of designing habitats for Mars that not only ensure structural integrity but also prioritize environmental sustainability and resource efficiency. In this context, they must focus on creating architectural designs that are not only resilient to the extreme environmental conditions of Mars but also make use of local materials, such as Martian rocks and soil, to minimize reliance on Earth-based resources. The use of advanced techniques like 3D printing offers a promising solution, allowing architects to craft habitats using indigenous

Martian materials. This approach reduces the need for transporting construction materials from Earth and aligns with the goal of creating self-sustaining structures within the Martian environment. In addition to material selection, architects play a critical role in integrating technology and design to enhance the livability and functionality of Mars habitats. By incorporating sensors into their designs, architects can monitor essential factors like structural health, environmental conditions, and even occupancy levels. These sensors provide vital information that helps maintain the habitat's safety and improve the quality of life for its inhabitants. Through the fusion of innovative design principles and cutting-edge technology, architects contribute to the creation of sustainable and efficient living spaces that can endure the harsh Martian conditions while ensuring human comfort and well-being.

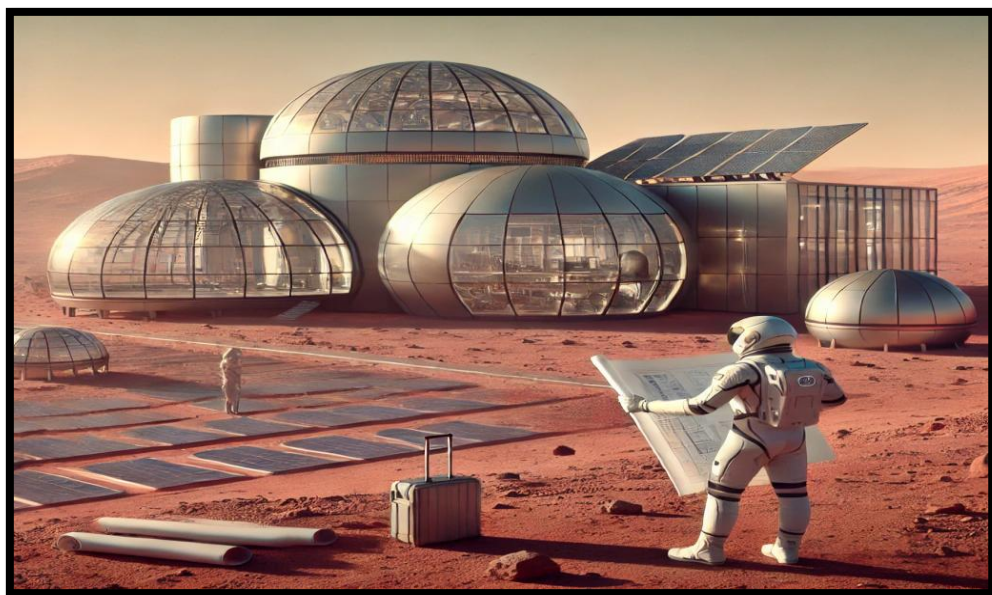


Figure 8.15: Architects on Mars (Author)

- **Monitoring** (Figure 8.16) the establishment of the Mars habitat is of great importance to civil engineers, who use monitoring techniques for this purpose. These techniques include the use of motion sensors, barometers, and remote sensing technologies. Using these techniques, engineers can track the location or condition of the habitat over time and ensure its

health. Motion sensors can use a receiver to detect and track a change in motion or a change in location. These senses give engineers the necessary information to ensure the condition of the habitat. They are used to measure the pressures and forces that affect the structure of the habitat. This information can help engineers to ensure the structural stability of the habitat and identify what changes are undesirable. And remote sensing technologies, such as satellite imagery, can provide engineers with information about habitat condition and changes. This information can help analyze environmental conditions and factors such as Martian soil conditions, temperature fluctuations, and seismic activity. By carefully analyzing and analyzing this data, engineers can assess the health of the habitat and, if possible, identify what might be caused by Martian environmental factors and make predictions.

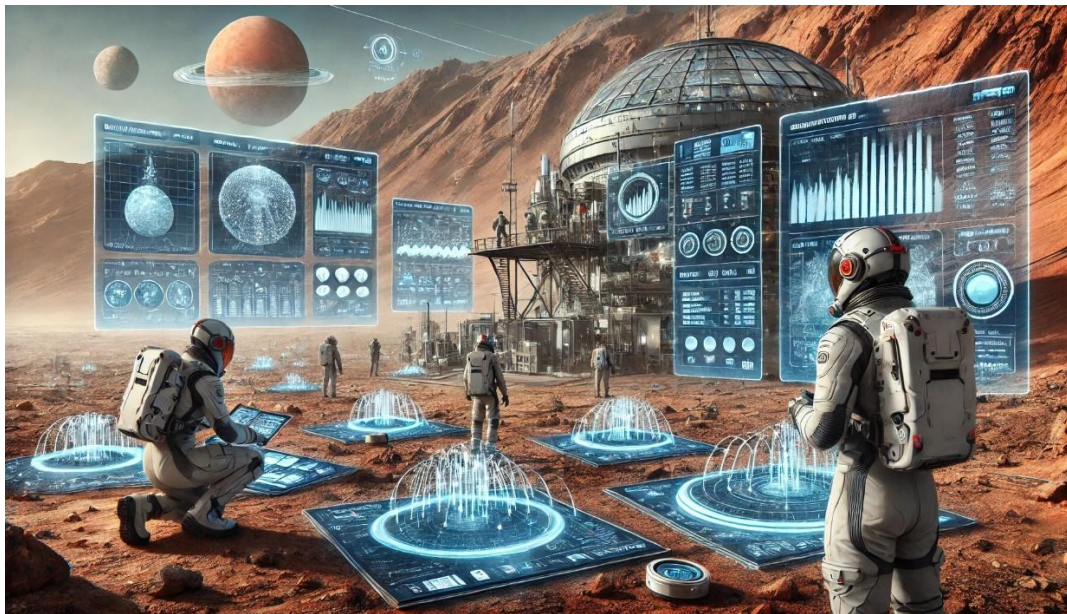


Figure 8.16: Monitoring Mars building (Author)

The successful implementation of sensor networks in Martian habitats requires close collaboration between electrical, network, power, and civil engineers. Each discipline brings unique expertise, allowing for developing robust and reliable systems that can support human life and scientific exploration on Mars.

At the end We will not stop exploring, but at the end of the search we will reach the starting point, and we will know a new method.

Amirhossein Javaherikhah

References

- Afsari, K., Eastman, C. M., & Shelden, D. R. (2016). Cloud-based BIM data transmission: current status and challenges. Paper presented at the ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction.
- Ali, K. N., Alhajlah, H. H., & Kassem, M. A. (2022). Collaboration and Risk in Building Information Modeling (BIM): A Systematic Literature Review. *Buildings*, 12(5), 571.
- Albalá, I. C., Montes, M. V., Rodríguez, R. Q., & Viñas, R. M. (2018, December 13). Design an innovative learning experience for the final project of the building engineering degree. Presented at INTED2012 Conference, Valencia, Spain.
- Alshahrani, H., Islam, N., Syed, D., Sulaiman, A., Reshan, M., Rajab, K., Shaikh, A., Shuja-Uddin, J., & Soomro, A. (2023). Sustainability in Blockchain: A Systematic Literature Review on Scalability and Power Consumption Issues. *Energies*. <https://doi.org/10.3390/en16031510>.
- Ameen, A., Mohammed, M., & Rashid, A. (2024). Enhancing Security in IoMT: A Blockchain-Based Cybersecurity Framework for Machine Learning-Driven ECG Signal Classification. *Fusion: Practice and Applications*. <https://doi.org/10.54216/fpa.140117>.
- Antcliff, D., Keeley, P., Campbell, M., Oldham, J., & Woby, S. (2013). Developing an activity-pacing questionnaire for chronic pain and fatigue: a Delphi technique. *Physiotherapy*.
- Appelbaum, D., & Nehmer, R. (2020). Auditing Cloud-Based Blockchain Accounting Systems. *J. Inf. Syst.*, 34, 5-21. <https://doi.org/10.2308/isis-52660>.
- Appelbaum, J., & Flood, D. J. (1990). Solar radiation on Mars. *Solar Energy*, 45(6), 353-363.
- Ardani, J. A., Utomo, C., & Rahmawati, Y. (2021). Model Ownership and Intellectual Property Rights for Collaborative Sustainability on Building Information Modeling. *Buildings*, 11(8), 346.
- Azaria, A., Ekblaw, A., Vieira, T., & Lippman, A. (2016). Medrec: Using blockchain for medical data access and permission management. Paper presented at the 2016 2nd international conference on open and big data (OBD).
- Barrera-Vera, J. A. (2008, June 1). Aplicación del modelado sólido a la resolución de cubiertas de edificios. Paper presented at Congreso Internacional Conjunto, XVII INGEGRAF y XV ADMA, Seville.
- Babbie, E. (2002). *The basics of social research* (2nd ed.). Wadsworth/Thomson Learning.
- Bastos Porsani, G., Del Valle de Lersundi, K., Sánchez-Ostiz Gutiérrez, A., & Fernández Bandera, C. (2021). Interoperability between building

- information modeling (BIM) and building energy model (BEM). *Applied Sciences*, 11(5), 2167.
- Becerik-Gerber, B., & Rice, S. (2010). The perceived value of building information modeling in the US building industry. *Journal of Information Technology in Construction (ITcon)*, 15(15), 185-201.
- Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2012). Application areas and data requirements for BIM-enabled facilities management. *Journal of Construction Engineering and Management*, 138(3), 431-442.
- Bedrick, J., & Davis, D. (2012). Aligning LOD, LoD, and OEM into a project collaboration framework. *Journal of Building Information Modeling*, 2012, 25-26.
- Begić, H., & Galić, M. (2021). A systematic review of Construction 4.0 in the context of the BIM 4.0 premise. *Buildings*, 11(8), 337.
- Benaroya, H. (2016). *Turning dust to gold: Building a future on the Moon and Mars*. Springer Science & Business Media.
- Bergsrud, C., & Straub, J. (2013). Space solar power as an enabler for a human mission to Mars. <https://doi.org/10.2514/6.2013-5415>
- B,I,T,G. (Producer). (2020, November 9). [Title of document or webpage]. Retrieved from https://static1.squarespace.com/static/57390d2c8259b53089bcf066/t/57ec74e4b3db2bc3c7a0d5da/1475114316630/bim101++an_insight.pdf, 2016
- Bojadziev, G., & Bojadziev, M. (2007). *Fuzzy logic for business, finance, and management* (2nd ed.). Advances in British Columbia Institute of Technology, Canada.
- Bosch, A., Volker, L., & Koutamanis, A. (2015). BIM in the operations stage: Bottlenecks and implications for owners. *Built Environment Project and Asset Management*, 5(3), 331-343.
- Brasser, R. (2013). The formation of Mars: Building blocks and accretion time scale. *Space Science Reviews*, 174, 11-25.
- Browne, N., Robinson, L., & Richardson, A. A. (2002). Delphi study on the research priorities of European oncology nurses. *European Journal of Oncology Nursing*, 6(3), 133-144.
- C&EN. (2023). To build settlements on Mars, we'll need materials chemistry. *Chemical & Engineering News*. Retrieved from <https://cen.acs.org/articles/96/i1/build-settlements-Mars-ll-need.html>
- Carr, M. H. (1976). The volcanoes of Mars. *Scientific American*, 234(1), 32-43.
- Cathcart, R. B. (2021). Mars, a stepping-stone world, macro-engineered. *Terraforming Mars*, 37-49.
- Cavagna, G. A., Willems, P. A., & Heglund, N. C. (1998). Walking on Mars. *Nature*, 393(6686), 636-636.

- Cervsek, T. (2011). A review and outlook for a 'Building Information Model' (BIM): A multi-standpoint framework for technological development. *Advanced Engineering Informatics*, 25(2), 224-244.
- Chand, M., Ahmad, V., Kathuria, S., Negi, P., Singh, T., & Chhabra, G. (2023). Digital currency security with the intervention of blockchain. 2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS), 1356-1362. <https://doi.org/10.1109/ICSCSD58221.2023.1020047>
- Chen, C., Yao, H., Chen, Y., Zhang, L., Guo, S., Wu, S., Li, S., Lao, Z., & Zhang, C. (2023). Ultradurable omni-liquid-repellent smart window as a high-performance wettability/transparency manipulator enabled via laser-writing magnetism-actuated microshutters. *Advanced Functional Materials*, 33. <https://doi.org/10.1002/adfm.202308314>
- Chias, P., Abad, T., de Miguel, M., García-Rosales, G., & Echeverria, E. (2019). 3D modeling and virtual reality applied to complex architectures: An application to hospitals' design. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W9, 255-260. <https://doi.org/10.5194/isprs-archives-xlii-2-w9-255-201>
- Cheng, J. C. P., & Ma, L. Y. (2012). A BIM-based system for demolition and renovation waste quantification and planning. In *Proceedings of the 14th International Conference on Computing in Civil and Building Engineering (ICCCBE 2012)*.
- Chobey, A. K., & Dwivedi, A. (2022). Digital currency security with the intervention of blockchain. 2023 International Conference on Sustainable Computing and Data Communication Systems (ICSCDS), 1356-1362.
- Cirillo, C., Xu, X., Tanaka, A., Fricker, J., Robles-Ortega, M., Ortega, L., Huang, Q., Li, M., Liu, Y., Hu, W., Liu, M., Chen, Z., Li, F., Zhao, J., Wang, R., Cai, Y., Bastida, F., Guillamón, M., Zhang, L., Chang, G., Zhu, S., Xiong, C., Du, L., Mollanejad, M., Hopper, N., Wang, Y., Deng, X., Marcucci, D., Coppola, P., Ibeas, A., dell'Olio, L., Cordera, R., Yin, L., Wang, Y., Li, L., & Wang, Z. (2024). Journal of Urban Planning and Development Reviewer List 2023. *Journal of Urban Planning and Development*. <https://doi.org/10.1061/jupddm.upeng-4888>
- Coupry, C., Noblecourt, S., Richard, P., Baudry, D., & Bigaud, D. (2021). BIM-based digital twin and XR devices to improve maintenance procedures in smart buildings: A literature review. *Applied Sciences*, 11(15), 6810.
- Cowan, D., et al. (2013). Direct care activities for assistants in nursing in inpatient mental health settings in Australia: A modified Delphi study. *Collegian*. <http://dx.doi.org/10.1016/j.colegn.2013.11.00>
- Di Giuda, G. M., Pattini, G., Seghezzi, E., & Paleari, F. (2020). The Construction Contract Execution Through the Integration of Blockchain Technology. In E. Seghezzi, G. M. Di Giuda, G. Pattini, & F. Paleari (Eds.), *Digital*

Transformation of the Design, Construction and Management Processes of the Built Environment (pp. 1-15). DOI: 10.1007/978-3-030-33570-0_3

- Dalkey, N., & Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management Science*, 9(3), 458–467.
- Dalkey, N. C. (1969). An experimental study of group opinion. *Futures*, 1(5), 408-426.
- Das, M., Luo, H., & Cheng, J. C. (2020). Securing interim payments in construction projects through a blockchain-based framework. *Automation in construction*, 118, 103284.
- Das, M., Tao, X., & Cheng, J. C. (2021). BIM security: A critical review and recommendations using encryption strategy and blockchain. *Automation in construction*, 126, 103682.
- Dede, G. (2022). Performance-driven design methodology for habitation shell design in extreme conditions on Mars. *Frontiers of Architectural Research*, 11(2), 224-238.
- design, a. (2023). Building for Mars: Four designs to support a colony on the red planet. Retrieved from <https://www.architectureanddesign.com.au/news/four-creations-for-life-on-mars>
- Dickinson, J., Pardasani, A., Ahamed, S., & Kruithof, S. (2009). A survey of automation technology for realising as-built models of services. Paper presented at the Proc. 1st Int. Conf. Improving Construct. Use Through Integr. Design Solutions.
- Donath, D. (2009). *Bauaufnahme und Planung im Bestand*: Springer.
- Dounas, T., Lombardi, D., & Jabi, W. (2020). Framework for decentralised architectural design BIM and Blockchain integration. *International Journal of Architectural Computing (IJAC)*.
- Ehlmann, B. L., Mustard, J. F., Murchie, S. L., Poulet, F., Bishop, J. L., Brown, A. J., . . . Milliken, R. E. (2008). Orbital identification of carbonate-bearing rocks on Mars. *Science*, 322(5909), 1828-1832.
- Eldeep, A. M., Farag, M. A., & Abd El-hafez, L. (2022). Using BIM as a lean management tool in construction processes—A case study. *Ain Shams Engineering Journal*, 13(2), 101556.
- Ellen, B. L. A. v. (2018). *Building on Mars*. (Master (MSc) Thesis), Delft University of Technology, Netherlands.
- Erri Pradeep, A. S., Yiu, T. W., Amor, R., DeJong, M., Schooling, J., & Viggiani, G. (2019). Leveraging Blockchain Technology in a BIM Workflow: A Literature Review. Paper presented at the International Conference on Smart Infrastructure and Construction 2019 (ICSIC).
- Erri Pradeep, A., Yiu, T., & Amor, R. (2019). Leveraging blockchain technology in a BIM workflow: A literature review. Paper presented at the International

Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving data-informed decision-making.

- Erri Pradeep, A., Yiu, T., Amor, R., DeJong, M., Schooling, J., & Viggiani, G. (2019). Leveraging Blockchain Technology in a BIM Workflow: A Literature Review. International Conference on Smart Infrastructure and Construction 2019 (ICSIC). ICE.
- Ezell, E. C., & Ezell, L. N. (1984). On Mars: Exploration of the Red Planet, 1958-1978 (Vol. 4212): Scientific and Technical Information Branch, National Aeronautics and Space.
- Fenton, L. K., & Michaels, T. I. (2010). MARS MARS. Mars, 5, 159-171.
- Förster, Bernadette., von der Gracht, Heiko. (2014). Assessing Delphi panel composition for strategic foresight — A comparison of panels based on company- internal and external participants, Technological Forecasting and Social Change, Volume 84, Pages 215-229 .
- Frahm, J.-M., Pollefeys, M., Lazebnik, S., Gallup, D., Clipp, B., Raguram, R., . . . Johnson, T. (2010). Fast robust large-scale mapping from video and internet photo collections. ISPRS Journal of Photogrammetry and Remote Sensing, 65(6), 538-549.
- Garzia, F., & Lombardi, M. (2018). The role of BIM for Safety and Security management. Building Information Systems in the Construction Industry, 51.
- Gaur, S., & Tawalare, A. (2022). Investigating the role of BIM in stakeholder management: Evidence from a metro-rail project. Journal of Management in Engineering, 38(1), 05021013.
- Gan, V. J. (2022). BIM-based graph data model for automatic generative design of modular buildings. Automation in construction, 134, 104062.
- Ganah, A., & Lea, G. (2021). A global analysis of BIM standards across the globe: A critical review. Journal Of Project Management Practice (JPMP), 1(1), 52-60.
- Ghazouani, M., Ikidid, A., Zaouiat, C., Layla, A., Lachgar, M., & Er-Rajy, L. (2023). A Blockchain-based Method Ensuring Integrity of Shared Data in a Distributed-Control Intersection Network. International Journal of Advanced Computer Science and Applications. <https://doi.org/10.14569/ijacsa.2023.0141052>.
- Golait, P., Tomar, D., Pateriya, R., & Sharma, Y. (2023). Blockchain Security and Challenges: A Review. 2023 IEEE 2nd International Conference on Industrial Electronics: Developments & Applications (ICIDeA), 140-145. DOI: 10.1109/ICIDeA59866.2023.10295211.
- Golait, P., Tomar, D., Pateriya, R., & Sharma, Y. (2023). Blockchain Security and Challenges: A Review. 2023 IEEE 2nd International Conference on

- Industrial Electronics: Developments & Applications (ICIDeA), 140-145. <https://doi.org/10.1109/ICIDeA59866.2023.10295211>.
- Golovinskiy, A., Kim, V. G., & Funkhouser, T. (2009). Shape-based recognition of 3D point clouds in urban environments. Paper presented at the 2009 IEEE 12th International Conference on Computer Vision.
- Gray, M., Gray, J., Teo, M., Chi, S., & Lamari, F. (2013). Building information modeling: an international survey. Paper presented at the Proceedings of the 19th International CIB World Building Congress, Brisbane 2013: Construction and Society.
- Greathouse J and T Dexter (2000) An accessible analytical approach for investigating what happens between the rounds of a Delphi study. *Journal of Advanced Nursing*, 32(4), 1016–1024.
- Group, M. C. W. (1983). Channels and valleys on Mars. *Geological Society of America Bulletin*, 94(9), 1035-1054.
- Gupta, U.G. and Clarke, R.E. (1996) Theory and Applications of the Delphi Technique: A Bibliography (1975-1994) *Technological Forecasting and Social Change*, 53, 185-211.
- Gursel, I., Saryildiz, S., Akin, Ö., & Stouffs, R. (2009). Modeling and visualization of lifecycle building performance assessment. *Advanced Engineering Informatics*, 23(4), 396-417
- Habibi, A., Sarafrazi, A., & Izadyar, S. (2014). Delphi Technique Theoretical Framework in Qualitative Research. *The International Journal of Engineering and Science (IJES)*, 3(4), 8-13.
- Haro-Olmo, F., Varela-Vaca, Á., & Álvarez-Bermejo, J. (2020). Blockchain from the perspective of privacy and anonymisation: A systematic literature review. *Sensors (Basel, Switzerland)*, 20. <https://doi.org/10.3390/s20247171>
- Hasson, F., Keeney, S., & McKenna, H. (2000). Research guidelines for the Delphi survey technique. *Journal of Advanced Nursing*, 32(4), 1008-1015.
- Hazra, A., Alkhayyat, A., & Adhikari, M. (2024). Blockchain for cybersecurity in edge networks. *IEEE Consumer Electronics Magazine*, 13, 97-102. <https://doi.org/10.1109/MCE.2022.3141068>
- Hossain, M. (2017). Application of advanced technology to build a vibrant environment on planet Mars. *International Journal of Environmental Science and Technology*, 14, 2709-2720. <https://doi.org/10.1007/s13762-017-1354-7>
- Hsu, P.-F., & Chen, B.-Y. (2007). Developing and implementing a selection model for bedding chain retail store franchisee using Delphi and fuzzy AHP. *Quality & Quantity*, 41, 275-290.
- Hsu, Y.-L., Lee, C.-H., & Kreng, V. B. (2010). The application of fuzzy Delphi method and fuzzy AHP in lubricant regenerative technology selection. *Expert Systems with Applications*, 37, 419-425.

- Huber, D., Akinci, B., Oliver, A. A., Anil, E., Okorn, B. E., & Xiong, X. (2011). Methods for automatically modeling and representing as-built building information models. In Proceedings of the NSF CMMI Research Innovation Conference.
- Ignatova, E., Zotkin, S., & Zotkina, I. (2018). The extraction and processing of BIM data. Paper presented at the IOP Conference Series: Materials Science and Engineering.
- Ishikawa, A., Amagasa, M., Shiga, T., Tomizawa, G., Tatsuta, R., & Mieno, H. (1993). The max-min Delphi method and fuzzy Delphi method via fuzzy integration. *Fuzzy Sets and Systems*, 55, 241–253.
- Ismail, Z.-A. B. (2022). A BIM-based model checking in the green building maintenance: a review. *Construction Innovation*.
- Jakosky, B., & Edwards, C. (2018). Inventory of CO₂ available for terraforming Mars. *Nature Astronomy*, 2, 634-639. <https://doi.org/10.1038/S41550-018-0529-6>
- James, P. (1978). The clouds of Mars as seen by Viking. *The Mars Reference Atmosphere*, 91-98.
- Jeon, K., Lee, G., Kang, S., Roh, H., Jung, J., Lee, K., & Baldwin, M. (2021). A relational framework for smart information delivery manual (IDM) specifications. *Advanced Engineering Informatics*, 49, 101319.
- Jiang, L., Ying, L., Wei, W., & Tao, Z. (2024). Identifying the most influential nodes in spreading process on high-order network. *Acta Physica Sinica*. <https://doi.org/10.7498/aps.73.20231416>
- Jhunjhunwalla, D., Mishra, D., Hembram, D., & Salkuti, S. (2024). Revolutionizing domestic solar power systems with IoT-enabled Blockchain technology. *International Journal of Applied Power Engineering (IJAPE)*. <https://doi.org/10.11591/ijape.v13.i1.pp255-262>
- Jolliff, B., & Team, A. S. (2005). Composition of Meridiani hematite-rich spherules: A mass-balance mixing-model approach. Paper presented at the 36th Annual Lunar and Planetary Science Conference.
- Jönsson, E. (2015). Consequences of implementing the buildingSMART Data Dictionary. In Proceedings.
- Jünger, S., Brearley, S., Payne, S., Mantel-Teeuwisse, A. K., Lynch, T., Scholten, W., & Radbruch, L. (2013). Consensus building on access to controlled building medicines: A four-stage Delphi consensus procedure. *Journal of Pain and Symptom Management*, 46(6), 897-910..
- Kamleshg Singh. (2022). The New Tech Paradigm of Blockchain. Learn-Share-Change-Grow. <https://kamleshg Singh.com/2022/09/27/the-new-tech-paradigm-of-blockchain/>
- Kading, B., & Straub, J. (2015). Utilizing in-situ resources and 3D printing structures for a manned Mars mission. *Acta Astronautica*, 107, 317-326.

- Kassem, M., Iqbal, N., Kelly, G., Lockley, S., & Dawood, N. (2014). Building information modeling: Protocols for collaborative design processes. *Journal of Information Technology in Construction (ITcon)*, 19, 126-149.
- Kass, D., Schofield, J., Kleinböhl, A., McCleese, D., Heavens, N., Shirley, J., & Steele, L. (2020). Mars Climate Sounder observation of Mars' 2018 global dust storm. *Geophysical Research Letters*, 47(23), e2019GL083931.
- Kaufmann, A., & Gupta, M. M. (1988). *Fuzzy mathematical models in engineering and management science*. Elsevier Science Inc.
- Keil, M., Lee, H. K., & Deng, T. (2013). Understanding the most critical skills for managing IT projects: A Delphi study of IT project managers. *Information & Management*, 50(7), 398-414.
- Kelly, K. P., & Porock, D. (2005). A survey of pediatric oncology nurses' perceptions of parent educational needs. *Journal of Pediatric Oncology Nursing*, 22(1), 58-66.
- Klein, L., Li, N., & Becerik-Gerber, B. (2012). Image-based verification of as-built documentation of operational buildings. *Automation in Construction*, 21, 161-171.
- Koo, H. J., & O'Connor, J. T. (2022). A strategy for building design quality improvement through BIM capability analysis. *Journal of Construction Engineering and Management*, 148(8), 04022066.
- Kozicki, J., & Kozicka, J. (2011). Human friendly architectural design for a small Martian base. *Advances in Space Research*, 48, 1997-2004. <https://doi.org/10.1016/J.ASR.2011.08.032>
- Kurokawa, H., Kurosawa, K., & Usui, T. (2017). A lower limit of atmospheric pressure on early Mars inferred from nitrogen and argon isotopic compositions. *Icarus*, 299, 443-459. <https://doi.org/10.1016/j.icarus.2017.08.020>
- Landeta, J. (2006). Current validity of the Delphi method in social sciences. *Technological Forecasting and Social Change*, 73(5), 467-482.
- Landis, G. A. (2009). Meteoritic steel as a construction resource on Mars. *Acta Astronautica*, 64(2-3), 183-187.
- Lawrence, D. J., Peplowski, P. N., Beck, A. W., Burks, M. T., Chabot, N. L., Cully, M. J., . . . Goldsten, J. O. (2019). Measuring the elemental composition of Phobos: The Mars-moon exploration with GAMMA rays and NEUTRONS (MEGANE) investigation for the Martian Moons eXploration (MMX) mission. *Earth and Space Science*, 6(12), 2605-2623.

- Lee, C.-Y., & Chong, H.-Y. (2021). Influence of prior ties on trust and contract functions for BIM-enabled EPC megaproject performance. *Journal of Construction Engineering and Management*, 147(7), 04021057.
- Lee, S., & Kim, J. (2024). Opportunistic block validation for IoT blockchain networks. *IEEE Internet of Things Journal*, 11, 666-676. <https://doi.org/10.1109/JIOT.2023.3287166>
- Leovy, C., Zurek, R., & Pollack, J. (1973). Mechanisms for Mars dust storms. *Journal of Atmospheric Sciences*, 30(5), 749-762.
- Leśniak, A., Kubek, D., Plebankiewicz, E., Zima, K., & Belniak, S. (2018, November 16). Fuzzy AHP application for supporting contractors' bidding decision. *Symmetry*. <https://doi.org/10.3390/sym10110642>
- Li, J., Greenwood, D., & Kassem, M. (2019). Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Automation in Construction*, 102, 288-307.
- Li, X., Mei, Y., Gong, J., Xiang, F., & Sun, Z. (2020). A blockchain privacy protection scheme based on ring signature. *IEEE Access*, 8, 76765-76772. <https://doi.org/10.1109/ACCESS.2020.2987831>
- Li, X. T., Zhang, H. W., Liu, Z. Z., Qu, W. Y., Wu, Z. H., & Wang, L. (2021). Application of BIM coding and example modeling for typical asphalt pavement diseases based on Omni Class. Paper presented at the *Journal of Physics: Conference Series*.
- Liebske, C., & Khan, A. (2019). On the principal building blocks of Mars and Earth. *Icarus*, 322, 121-134.
- Lindeman, C. A. (1981). Priorities within the health care system: A Delphi survey. *American Nurses' Association*.
- Linstone, H. A., & Turoff, M. (Eds.). (1975). *The Delphi method: Techniques and applications*. Addison-Wesley.
- Liu, X., Eybpoosh, M., & Akinci, B. (2012). Developing as-built building information model using construction process history captured by a laser scanner and a camera. In *Construction Research Congress 2012: Construction Challenges in a Flat World*.
- Liu, Z., Chi, Z., Osmani, M., & Demian, P. (2021). Blockchain and Building Information Management (BIM) for sustainable building development within the context of smart cities. *Sustainability*. <https://doi.org/10.3390/SU13042090>
- Liu, Z., Jiang, L., Osmani, M., & Demian, P. (2019). Building Information Management (BIM) and Blockchain (BC) for sustainable building design information management framework. *Electronics*.

- Losch, A. (2019). Interplanetary sustainability: Mars as a means of a long-term sustainable development of humankind in the solar system? The Human Factor in a Mission to Mars. https://doi.org/10.1007/978-3-030-02059-0_9
- Lu, K., Jiang, X., Yu, J., Tam, V. W., & Skitmore, M. (2021). Integration of life cycle assessment and life cycle cost using building information modeling: A critical review. *Journal of Cleaner Production*, 285, 125438.
- M, M., Gómez-Fernández, D., Das, N., & Annavarapu, R. (2021). Conceptual design of Mars sub-surface habitat for sustaining thermal stability. *OSF Preprints*. <https://doi.org/10.31219/osf.io/vc79r>
- Macnee, C. L., & McCabe, S. R. N. (2008). *Understanding nursing research: Using research in evidence-based practice* (2nd ed.). Wolters Kluwer Health/Lippincott Williams & Wilkins.
- Malone, D., Abarca, J., Hansten, P., Grizzle, A., Armstrong, E., Bergen, R. V., Duncan-Edgar, B., Solomon, S., & Lipton, R. (2005). Identification of serious drug-drug interactions: Results of the partnership to prevent drug-drug interactions. *American Journal of Geriatric Pharmacotherapy*, 3(2), 65-76.
- Martino, J. P. (1983). *Technological forecasting for decision making*. North-Holland
- McKenna, H., Hasson, F., & Smith, M. (2002). A Delphi survey of midwives and midwifery students to identify non-midwifery duties. *Midwifery*, 18(4), 314-322.
- Meadows, A., Maine, L., Keyes, E., Pearson, K., & Finstuen, K. (2005). Pharmacy executive leadership issues and associated skills, knowledge, and abilities. *Journal of the American Pharmacists Association*, 45(1), 55-62.
- Meijering, J. V., Kampen, J. K., & Tobi, H. (2013). Quantifying the development of agreement among experts in Delphi studies. *Technological Forecasting and Social Change*, 80(8), 1607-1614.
- Mell, P., & Grance, T. (2011). *The NIST definition of cloud computing*. National Institute of Standards and Technology (NIST).
- Mill, T., Alt, A., & Lias, R. (2013). Combined 3D building surveying techniques—terrestrial laser scanning (TLS) and total station surveying for BIM data management purposes. *Journal of Civil Engineering and Management*, 19(sup1), S23-S32.
- Mitroff, I. I., & Turoff, M. (1975). Philosophical and methodological foundations of Delphi. In H. A. Linstone & M. Turoff (Eds.), *The Delphi method: Techniques and applications* (pp. 17-34). Addison-Wesley.
- Motamedi, A., & Hammad, A. (2009). Lifecycle management of facilities components using radio frequency identification and building information model. *Journal of Information Technology in Construction (ITcon)*, 14(18), 238-262.

- Mrabet, K., Bouanani, F., & Ben-Azza, H. (2023). Dynamic decentralized reputation system from blockchain and secure multiparty computation. *J. Sens. Actuator Networks*, 12, 14. <https://doi.org/10.3390/jsan12010014>
- Mullegowda, R., Hiremani, N., Birje, M., & Ramaswamy, N. (2024). A novel smart contract based blockchain with sidechain for electronic voting. *International Journal of Electrical and Computer Engineering (IJECE)*. <https://doi.org/10.11591/ijece.v14i1.pp617-630>
- Muñoz, S. (2019, November 13). Impact of BIM ISO standards in Spain. Digital Built Environment Institute. <https://www.dbei.org/news/impact-of-bim-iso-standards-in-spain/>
- Musk, E. (2018). Making life multi-planetary. *New Space*, 6(1), 2-11.
- Muthumanickam, N. K., Duarte, J. P., Nazarian, S., Memari, A., & Bilén, S. G. (2021). Combining AI and BIM in the design and construction of a Mars habitat. In *The Routledge companion to artificial intelligence in architecture* (pp. 251-279). Routledge.
- NASA. (2023). In-depth of Mars. NASA Solar System Exploration. Retrieved from <https://solarsystem.nasa.gov/planets/mars/in-depth/>
- Naser, M. (2019). Space-native construction materials for earth-independent and sustainable infrastructure. *Acta Astronautica*. <https://doi.org/10.1016/J.ACTAASTRO.2018.12.014>.
- Nathan, S., Govindarajan, C., Saraf, A., Sethi, M., & Jayachandran, P. (2019). Blockchain meets database: Design and implementation of a blockchain relational database. arXiv preprint arXiv:1903.01919.
- Nawari, N. O., & Ravindran, S. (2019). Blockchain technology and BIM process: Review and potential applications. *Journal of Information Technology in Construction*, 24, 209-217.
- Niu, B., Zhou, S., & Zhang, H. (2023). Influential node identification of network based on agglomeration operation. *International Journal of Foundations of Computer Science*. <https://doi.org/10.1142/s0129054123500028>
- Nuta, S., Schuldt, J., & Nishide, T. (2023). PoS blockchain-based forward-secure public key encryption with immutable keys and post-compromise security guarantees. *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*, 106, 212-227. <https://doi.org/10.1587/transfun.2022cip0016>
- Northwestern. (2023). Building concrete shelters on Mars. McCormick School of Engineering, Northwestern University. Retrieved from <https://www.mccormick.northwestern.edu/news/articles/2016/01/building-concrete-shelters-on-mars.html>

- Okoli C and SD Pawlowski (2004) The Delphi method as a research tool: An example, design considerations, and applications. *Information & Management* 42(1), 15–29 .
- Olatunji, O. (2011). A preliminary review on the legal implications of BIM and model ownership. *Journal of Information Technology in Construction*, 16, 687-696.
- OmniClass, A. (2006). Strategy for classifying the built environment. In: Edition.
- Pan, J., Song, Z., & Hao, W. (2021). Development in consensus protocols: From PoW to PoS to DPoS. 2021 2nd International Conference on Computer Communication and Network Security (CCNS), 59-64. <https://doi.org/10.1109/CCNS53852.2021.00020>
- Panuntun, L., Susanti, B., & Rosdiana, S. (2023). Performance test of hash functions in proof of work schemes in blockchain. 2023 IEEE International Conference on Cryptography, Informatics, and Cybersecurity (ICoCICs), 47-52. <https://doi.org/10.1109/ICoCICs58778.2023.10277647>
- Parab, L., Nitnaware, P., & Patil, S. (2023). Cryptocurrency with blockchain technology — A literature review. 2023 Somaiya International Conference on Technology and Information Management (SICTIM), 17-22. <https://doi.org/10.1109/SICTIM56495.2023.10104971>
- Park, A., & Li, H. (2021). The effect of blockchain technology on supply chain sustainability performances. *Sustainability*. <https://doi.org/10.3390/SU13041726>
- Parn, E. A., & Edwards, D. (2019a). Cyber threats confronting the digital built environment: Common data environment vulnerabilities and blockchain deterrence. *Engineering, Construction and Architectural Management*, 26(2), 245-266.
- Parn, E. A., & Edwards, D. (2019b). Cyber threats confronting the digital built environment: Common data environment vulnerabilities and blockchain deterrence. *Engineering, Construction and Architectural Management*.
- Peng, Y., Liu, X., Li, M., Li, Z., Hu, T., Xiao, Y., et al. (2020). Sensing network security prevention measures of BIM smart operation and maintenance system. *Computer Communications*, 161, 360-367.
- Perminov, V. (1999). The difficult road to Mars: A brief history of Mars exploration in the Soviet Union.
- Petrescu, R. (2019). Mars could have enough molecular oxygen to support life. *Journal of Aerospace Technology and Space Science*, 3, 11-23. <https://doi.org/10.3844/JASTSP.2019.11.23>
- Petrov, G., & Ochsendorf, J. (2005). Building on Mars. *Civil Engineering*, 75, 46-53. <https://doi.org/10.1061/CIEGAG.0000039>

- Pinheiro, S., Wimmer, R., O'Donnell, J., Muhic, S., Bazjanac, V., Maile, T., et al. (2018). MVD-based information exchange between BIM and building energy performance simulation. *Automation in Construction*, 90, 91-103.
- Powell, C. (2003). The Delphi technique: Myths and realities. *Journal of Advanced Nursing*, 41(4), 376-382.
- Rai, A., Singh, M., Sudheendramouli, H., Panwar, V., Balaji, N., & Kukreti, R. (2023). Digital signature for content authentication. 2023 International Conference on Advances in Computing, Communication and Applied Informatics (ACCAI), 1-6. <https://doi.org/10.1109/ACCAI58221.2023.10200472>
- Rahman, A., Nasir, M., Rahman, Z., Mosavi, A., S., S., & Minaei-Bidgoli, B. (2020). DistBlockBuilding: A distributed blockchain-based SDN-IoT network for smart building management. *IEEE Access*, 8, 140008-140018. <https://doi.org/10.1109/access.2020.3012435>
- Raman, R., & Varshney, L. (2021). Coding for scalable blockchains via dynamic distributed storage. *IEEE/ACM Transactions on Networking*, 29, 2588-2601. <https://doi.org/10.1109/tnet.2021.309861>
- Raposo Grau, J. F. (2008). "Dibujar", "Procesar", "Comunicar". El dibujo en la formación de los arquitectos. In *Proceedings of the XII Congreso Internacional de Expresión Gráfica Arquitectónica (EGA)*, May 29-31, 2008, Madrid, Spain. ISBN 978-84-9728-270-3.
- Rashid, K. M., Louis, J., & Fiawoyife, K. K. (2019). Wireless electric appliance control for smart buildings using indoor location tracking and BIM-based virtual environments. *Automation in Construction*, 101, 48-58.
- Reches, Y. (2019). Concrete on Mars: Options, challenges, and solutions for binder-based construction on the Red Planet. *Cement and Concrete Composites*, 104, 103349. <https://doi.org/10.1016/J.CEMCONCOMP.2019.103349>
- Reches, Y. (2019). Concrete on Mars: Options, challenges, and solutions for binder-based construction on the Red Planet. *Cement and Concrete Composites*. <https://doi.org/10.1016/J.CEMCONCOMP.2019.103349>
- Riahi, K., Brahmia, M., Abouaissa, A., & Idoumghar, L. (2022). FPBFT: A fast PBFT protocol for private blockchains. 2022 9th International Conference on Internet of Things: Systems, Management and Security (IOTSMS), 1-8. <https://doi.org/10.1109/IOTSMS58070.2022.10062170>
- Rivera-Valentin, E., & Chevrier, V. (2015). Revisiting the Phoenix TECP data: Implications for regolith control of near-surface humidity on Mars. *Icarus*, 253, 156-158. <https://doi.org/10.1016/J.ICARUS.2015.03.003>
- Robertson, H. A., & MacKinnon, N. J. (2002). Development of a list of consensus-approved clinical indicators of preventable drug-related morbidity in older adults. *Clinical Therapeutics*, 24(10), 1595-1613.

- Rogers, A. D., & Nekvasil, H. (2015). Feldspathic rocks on Mars: Compositional constraints from infrared spectroscopy and possible formation mechanisms. *Geophysical Research Letters*, 42(8), 2619-2626.
- Roe, G., & Wright, G. (2001). Expert opinions in forecasting: The role of the Delphi technique. In J. S. Armstrong (Ed.), *Principles of forecasting: A handbook for researchers and practitioners*. Kluwer Academic Publishers, 125-144.
- Russell, J., Stutte, G. W., & De Leon, P. (2022, July). Evaluation of candidate crop plant *Lactuca sativa* in biologically enhanced Martian regolith. 51st International Conference on Environmental Systems. Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). *BIM handbook: A guide to building information modeling for owners, designers, engineers, contractors, and facility managers*. John Wiley & Sons.
- Sagar, K., Awasthi, A., Dwivedi, S., Shrivastava, M., Pahwa, S., Swathi, B., & Hlail, S. (2023). Smart resource management: An innovative way of balancing materials, energy, and waste for a green future. *E3S Web of Conferences*. <https://doi.org/10.1051/e3sconf/202345301037>
- Sai, A., Buckley, J., Fitzgerald, B., & Gear, A. (2020). Taxonomy of centralization in public blockchain systems: A systematic literature review. *ArXiv*, abs/2009.12542. <https://doi.org/10.1016/J.IPM.2021.102584>
- Sai Erri Pradeep, A., Amor, R., & Wing Yiu, T. (2020). Blockchain improving trust in BIM data exchange: A case study on BIMCHAIN. *Construction Research Congress*.
- Sarao, P., Kaur, N., & Sharma, M. (2023). Blockchain: A review study of protocols and enterprise frameworks. 2023 International Conference on Computational Intelligence, Communication Technology and Networking (CICTN), 474-479. <https://doi.org/10.1109/CICTN57981.2023.10141434>
- Saude, B., LaSart, N., Blair, J., & Beik, O. (2023). Microgrid-based wind and solar power generation on Moon and Mars. *IEEE Transactions on Smart Grid*, 14, 1329-1332. <https://doi.org/10.1109/TSG.2022.3210774>
- Schmidt, K. G. (2007). *The water cycle on Mars* (PhD Thesis, University of Copenhagen, Denmark).
- Schmidt, R. C. (1997). Delphi surveys using nonparametric statistical techniques. *Decision Sciences*, 28.(3)
- Semaan, J., Underwood, J., & Hyde, J. (2021). An investigation of work-based education and training needs for effective BIM adoption and implementation: An organisational upskilling model. *Applied Sciences*, 11(18), 8646.
- Shakila, M., & Rama, A. (2023). Design and analysis of digital certificate verification and validation using blockchain-based technology. 2023 Eighth International Conference on Science Technology Engineering and Mathematics (ICONSTEM), 1-9. <https://doi.org/10.1109/ICONSTEM56934.2023.10142400>

- Sharma, D., & Saxena, M. (2023). Different cryptographic hash functions for security in the blockchain. 2023 International Conference on Data Science and Network Security (ICDSNS), 1-6. <https://doi.org/10.1109/ICDSNS58469.2023.10245326>
- Shen, X., Xu, C., Zhu, L., Lu, R., Guan, Y., & Zhang, X. (2023). Blockchain-based lightweight and privacy-preserving quality assurance framework in crowdsensing systems. *IEEE Internet of Things Journal*, 11, 974-986. <https://doi.org/10.1109/JIOT.2023.3288349>
- Tanaka, K. L., Skinner, J. A., & Hare, T. M. (2005). Geologic map of the northern plains of Mars (2329-132X). Retrieved from
- Tao, X., Das, M., Liu, Y., Wong, K. Y., Chen, K., & Cheng, C. P. (2021). A Conceptual Framework for Secure BIM-based Design: Using Blockchain and Asymmetric Encryption. Paper presented at the Proceedings of the International Symposium on Automation and Robotics in Construction.
- Tao, X., Das, M., Zheng, C., Liu, Y., Wong, P. K.-Y., Xu, Y., . . . Cheng, J. C. (2023). Enhancing BIM security in emergency construction projects using lightweight blockchain-as-a-service. *Automation in construction*, 150, 104846.
- Tao, Y., Muller, J. P., & Poole, W. (2016). Automated localisation of Mars rovers using co-registered HiRISE-CTX-HRSC orthorectified images and wide baseline Navcam orthorectified mosaics. *Icarus*, 280, 139-157.
- Thomas, P., Squyres, S., Herkenhoff, K., Howard, A., & Murray, B. (1992). Polar deposits of Mars. *Mars*, 767-795.
- Tian, H., Zhang, T., Jia, Y., Peng, S., & Yan, C. (2021). Zhurong: Features and mission of China's first Mars rover. *The Innovation*, 2(3).
- Trebi-Ollennu, A., Baumgartner, E. T., Leger, P. C., & Bonitz, R. G. (2005, October). Robotic arm in-situ operations for the mars exploration rovers surface mission. In 2005 IEEE International Conference on Systems, Man and Cybernetics (Vol. 2, pp. 1799-1806). IEEE.
- Turoff, M; Linstone, HA. (2008). The Delphi method: techniques and applications. [Cited 2008 Oct 19]. Available from: <http://is.njit.edu/pubs/delphibook/>
- Tzedaki, V., & Kamara, J. M. (2013). Capturing as-built information for a BIM environment using 3D laser scanner: A process model. *AEI 2013: Building Solutions for Architectural Engineering*, 486-495.
- Tzeng, G.-H., Teng, J.-Y.(1993) Transportation investment project selection with fuzzy multiobjectives. *Transp.Plann. Technol.* 17(2), 91–112.
- Urien, P. (2021). Innovative Countermeasures to Defeat Cyber Attacks Against Blockchain Wallets. 2021 5th Cyber Security in Networking Conference (CSNet), 49-54. DOI: 10.1109/csnet52717.2021.9614649.

- Vago, J., Witasse, O., Baglioni, P., Haldemann, A., Gianfiglio, G., Blancquaert, T., . . . de Groot, R. E. (2013). ESA's next step in Mars exploration. *ESA Bulletin Magazine*, 155, 12-23.
- Van Zolingen, S.J. and Klaassen, C.A. (2003) Selection Processes in a Delphi Study about Key Qualifications in Senior Secondary Vocational Education. *Technological Forecasting and Social Change*, 70: 317-340.
- Vieira, R., Carreira, P., Domingues, P., & Costa, A. A. (2020). Supporting building automation systems in BIM/IFC: reviewing the existing information gap. *Engineering, Construction and Architectural Management*.
- Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in construction*, 38, 109-127.
- von der Gracht, Heiko. (2012), Consensus measurement in Delphi studies Re-opinion and implications for future quality assurance, *Technological Forecasting & Social Change*, Vol. 79, PP. 1525–1536
- Wang, C.C., Wang, Y., Zhang, K., Fang, J., Liu, W., Luo, S., Tang, S., Wang, S. and Lu, V.C. (2003). Reproductive Health Indicators for China's Rural Areas. *Social Science and Medicine*, Vol. 57, 217-225.
- Wang, H., Hao, X., Yin, L., Gong, P., Xiong, F., & Ren, W. (2022). A blockchain-based and privacy-protected method for sharing of BIM big data. Paper presented at the 2022 7th International Conference on Cloud Computing and Big Data Analytics (ICCCBDA).
- Wang, Z., Sacks, R., Ouyang, B., Ying, H., & Borrmann, A. (2024). A Framework for Generic Semantic Enrichment of BIM Models. *J. Comput. Civ. Eng.*, 38. <https://doi.org/10.1061/jccee5.cpeng-5487>.
- Wassouf, Z., Egger, M., Neuberg, F., van Treeck, C., & Rank, E. (2006). Produktmodell basierte Simulation des Ressourcenbedarfs von Bauwerken. *Bauingenieur*, 81.
- Wei, J., Chen, G., Huang, J., Xu, L., Yang, Y., Wang, J., & Sadick, A.-M. (2021). BIM and GIS applications in bridge projects: A critical review. *Applied Sciences*, 11(13), 6207.
- Wormald, R. M., Hopwood, J., Humphreys, P. N., Mayes, W., Gomes, H. I., & Rout, S. P. (2022). Methanogenesis from mineral carbonates, a potential indicator for life on Mars. *Geosciences*, 12(3), 138.
- Wood, G. (2014). Ethereum: A secure decentralised generalised transaction ledger. *Ethereum project yellow paper*, 151(2014), 1-32.
- Wu, Chih-Hung; Fang, Wen-Chang. (2011). Combining the Fuzzy Analytic Hierarchy Process and the fuzzy Delphi method for developing critical competences of electronic commerce professional managers; *Qual Quant*, Vol. 45, 751–768.

- Wu, J., & Zhang, J. (2019). New automated BIM object classification method to support BIM interoperability. *Journal of Computing in Civil Engineering*, 33(5).
- Xiong, X., Adan, A., Akinci, B., & Huber, D. (2013). Automatic creation of semantically rich 3D building models from laser scanner data. *Automation in construction*, 31, 325-337.
- Xue, F., & Lu, W. (2020). A semantic differential transaction approach to minimizing information redundancy for BIM and blockchain integration. *Automation in construction*, 118, 103270.
- Xue, F., & Lu, W. (2020). A semantic differential transaction approach to minimizing information redundancy for BIM and blockchain integration. *Automation in Construction*, 117.
- Yusoff, J., Mohamad, Z., & Anuar, M. (2022). A Review: Consensus Algorithms on Blockchain. *Journal of Computer and Communications*. DOI: 10.4236/jcc.2022.109003.
- Ye, X. (2019, November 12). Combining BIM with smart contract and blockchain to support digital project delivery and acceptance processes. ResearchGate. Link
- Yang, A., Han, M., Zeng, Q., & Sun, Y. (2021). Adopting building information modeling (BIM) for the development of smart buildings: a review of enabling applications and challenges. *Advances in Civil Engineering*, 2021, 1-26.
- Ye, X., Sigalov, K., & König, M. (2020). Integrating BIM- and cost-included information container with Blockchain for construction automated payment using billing model and smart contracts. 37th International Symposium on Automation and Robotics in Construction (ISARC 2020), 1-8.
- Young, S. J., & Jamieson, L. M. (2001). Delivery methodology of the Delphi: A comparison of two approaches. *Journal of Park and Recreation Administration*, 19(1), 42-58.
- Zhang, K., Zhang, Y., Li, Y., Liu, X., & Lu, L. (2024). A Blockchain-Based Anonymous Attribute-Based Searchable Encryption Scheme for Data Sharing. *IEEE Internet of Things Journal*, 11, 1685-1697. <https://doi.org/10.1109/JIOT.2023.3290975>.
- Zhang, P., Zhou, M., Zhao, Q., Abusorrah, A., & Bamasak, O. (2021). A Performance-Optimized Consensus Mechanism for Consortium Blockchains Consisting of Trust-Varying Nodes. *IEEE Transactions on Network Science and Engineering*, 8, 2147-2159. DOI: 10.1109/TNSE.2021.3079415.
- Zhang, X. (2020). Automatic underground space security monitoring based on BIM. *Computer Communications*, 157, 85-91.
- Zabin, A., Khalil, B., Ali, T., Abdalla, J. A., & Elaksher, A. (2020). A semi-automated method for integrating textural and material data into as-built BIM using TIS. *Advances in Computational Design*, 5(2), 127-146.

- Zhou, K., Wang, C., Wang, X., Chen, S., & Cheng, H. (2022). A Novel Scheme to Improve the Scalability of Bitcoin Combining IPFS With Block Compression. *IEEE Transactions on Network and Service Management*, 19, 3694-3705. DOI: 10.1109/TNSM.2022.3199346.
- Zheng, R., Jiang, J., Hao, X., Ren, W., Xiong, F., & Ren, Y. (2019). bcBIM: A blockchain-based big data model for BIM modification audit and provenance in mobile cloud. *Mathematical Problems in Engineering*, 2019.
- Zheng, X., & Lu, Y. (2021). Blockchain technology – recent research and future trend. *Enterprise Information Systems*, 16. DOI: 10.1080/17517575.2021.1939895.
- Zurek, R. W., Barnes, J. R., Haberle, R. M., Pollack, J. B., Tillman, J. E., & Leovy, C. B. (1992). Dynamics of the atmosphere of Mars. *Mars*, 835-933.

Annex

Provision of a Blockchain-Based Inspection Framework For Managing Building Information Modeling (BIM) (Case Study:Mars Building)

Provisión de un marco de inspección basado en blockchain para la gestión de modelado de información de construcción (Estudio de Caso: Edificios en MARTE)

PhD Thesis 2024

Author: Amirhossein Javaherikhah (Master's Degree in Construction Management)

Supervisor: Mercedec Valiente López (Dr. Architecture)

Annexes

A. Actividad form

Table A.1: Actividad Form

ACTIVIDADES FORMATIVAS - DOCTORADO 1ª MATRÍCULA: 01/10/2020 Fecha límite de depósito: 30/09/2025											
  POLITÉCNICA				Fecha de actualización: 22-08-2024							
				Doctorando: AMIRHOSSEIN JAVAHERIKHAH							
				Directora de tesis: María Mercedes Valiente López							
ACTIVIDAD	DENOMINACIÓN	HORAS MÍNIMAS	OBLIGATORIEDAD	DESCRIPCIÓN	DOCUMENTACIÓN A ENTREGAR/REALIZAR	REALIZADO	FECHA	DURACIÓN	CÓMPUTO DE HORAS	DOCUMENTOS	COMPLETADO
1	SEMINARIOS INVESTIGADORES	12	SI	5 sesiones presenciales	Resumen del seminario y certificado de asistencia	El Lenguaje de la luz; La importancia de la luz en la creación de atmosferas espaciales	04/10/2021 al 07/10/2021	16	47.5	Certificado asistencia	SI
						La impresión 3D para construir grandes estructuras impresas en hormigón	3/22/2022	6		Certificado asistencia	
						3D Printing lab (UPM-UNIT6. Drawing techniques)	9/14/2022	3		Certificado asistencia	
						Smart Rehabilitation 3.0 Project	10/27/2022	5		Certificado asistencia	
						Writing a Proposal	4/7/2023	5		Certificado asistencia	
						Sustainability for Design, Construction, and Manufacturing	4/4/2023	5		Certificado asistencia	
						Blockchain and Smart Contracts Security	4/5/2023	1.5		Certificado asistencia	
						La tierra como material de construcción en el siglo XXI	3/23/2023	6		Certificado asistencia	
2	PRESENTACIÓN DE RESULTADOS PROPIOS	3	SI	Durante el 2º año	Al menos un seminario por semestre de 1,5 h. Recogida de hoja de firmas.	Presentación de resultados I al grupo de investigación PEPCYMAE	5/6/2022	1.5	4.5	Certificado asistencia	SI
						Presentación de resultados al grupo de investigación TEMA	6/8/2022	1.5		Certificado asistencia	
						Presentación de resultados II al grupo de investigación PEPCYMAE	9/28/2022	1.5		Certificado asistencia	

3	PRESENTACIÓN DE COMUNICACIÓN NACIONAL/INTERNACIONAL - CONGRESOS	20	SI	Asistencia a 1 congreso y la presentación de 1 ponencia	Certificado de asistencia y/o presentación de ponencia.	ICERI 2021 - "The Architecture of Ideal Learning Environments"	08/11/2021 al 10/11/2021	20	240	Certificado ponencia	SI
						1st INTERNATIONAL MINERAL POSTER EXHIBITION - "A Brief Review at Industrial Construction"	11/05/2022 al 13/05/2022	20		Certificado presentación	
						BIMIC 2021 - "Application of Blockchain in BIM: a systematic review"	24/11/2021 al 26/11/2021	20		Certificado ponencia	
						BIMIC 2021 - "The Effect of Building Information Modeling on Project Planning, Control and Management"	24/11/2021 al 26/11/2021	20		Certificado ponencia	
						CITE 2022 - "Technology and Nanotechnology in Smart buildings"	23/03/2022 al 25/03/2022	20		Certificado ponencia	
						EDULEARN 2022 - "3D Printers' Impact on the Future of Construction"	04/07/2022 al 06/07/2022	20		Certificado ponencia	
						CITE 2023 - "A review of the application of prefabricated structures using building information modeling"	22/03/2023 al 24/03/2023	20		Certificado ponencia	
						CITE 2023 - "An overview of the impact of renewable energies in the architecture of zero energy buildings"	22/03/2023 al 24/03/2023	20		Certificado ponencia	
						APEGA 2023 - "Building information modeling for precast concrete components in developed nations"	9/30/2023	20		Certificado ponencia	
						BIMIC 2023 - "Exploring the geographical, structural materials and construction techniques on Mars"	11/24/2023	20		Certificado ponencia	
						BIMIC 2023 - "A path to human habitation"	11/24/2023	20		Certificado ponencia	
						ETICONG 2023 - "Construction on Mars"	7-8/10/2023	20		Certificado ponencia	
4	PRESENTACIÓN DE RESULTADOS PROPIOS AL CENTRO	20	SI	Durante el 3er año	Al menos un seminario por semestre. Recogida de hoja de firmas.	Presentation de resultados al centro I	6/7/2022	5	20	Certificado asistencia	SI
						Presentation de resultados al centro II	2/27/2023	5		Certificado asistencia	
						Presentation de resultados al centro III	9/15/2022	5		Certificado asistencia	
						Presentation de resultados al centro IV	5/6/2022	5		Certificado asistencia	
5	ARTÍCULO CIENTÍFICO	30	SI	Al menos 1 artículo a revista JCR	Envío de la publicación y justificante de aceptación del mismo para su publicación	Developing an Inspector-Centric Blockchain-Enabled Conceptual Framework for BIM Management in Mars Buildings	11/13/2023	30	90	BUILDINGS JCR Q2 - https://doi.org/10.3390/buildings13112858	SI
						Determining the Essential Criteria for Choosing Appropriate Methods for Maintenance and Repair of Iraqi Healthcare Building Facilities	6/27/2023	30		BUILDINGS JCR Q2 - https://doi.org/10.3390/buildings13071629	
						Effective Factors for Implementing Building Information Modeling Using Fuzzy Method to Manage Buildings on Mars	11/30/2023	30		BUILDINGS JCR Q2 - https://doi.org/10.3390/buildings13122991	

6	FORMACIÓN METODOLÓGICA Y TÉCNICA	4	SI	Al menos 1 seminario durante el primer año.	Certificado de asistencia y memoria de objetivos, contenidos y conclusiones de la actividad realizada.	Python programming for beginner	01/07/2022 al 20/07/2022	35	58.75	Certificado asistencia	SI
						Getting Started with Python	4/7/2023	15		Certificado asistencia	
						Excel: Power Query for Beginners"	4/1/2023	0.5		Certificado asistencia	
						Python for Engineers and Scientists	4/7/2023	1.5		Certificado asistencia	
						Learning MATLAB	4/7/2023	1		Certificado asistencia	
						Learning Gantt Charts	4/7/2023	1		Certificado asistencia	
						Conducting a SWOT Analysis	4/8/2023	0.75		Certificado asistencia	
						Python Essential Training	4/7/2023	4		Certificado asistencia	
7	FORMACIÓN EN COMUNICACIÓN, DIFUSIÓN Y DIVULGACIÓN DE LA INFORMACIÓN	4	OPCIONAL	Durante el 2º año	Certificado de asistencia y memoria de objetivos, contenidos y conclusiones de la actividad realizada.	La información científica: recursos de apoyo a la investigación	1/13/2023	3	9.5	Certificado asistencia	SI
						Writing Speeches	4/7/2023	2		Certificado asistencia	
						Teaching with Technology	4/7/2023	2.5		Certificado asistencia	
						Become a Teacher	4/7/2023	0.5		Certificado asistencia	
						Teaching Techniques: Blended Learning	4/7/2023	1.5		Certificado asistencia	
8	FORMACIÓN EN GESTIÓN DE LA INVESTIGACIÓN	4	OPCIONAL	Durante el 3er año	Supervisión del director de tesis y anotación en el Documento de Actividades del doctorando	Learning How to Increase Learner Engagement	4/7/2023	4	5.5	Certificado asistencia	SI
						Time Management Fundamentals	4/6/2023	1.5		Certificado asistencia	
9	MOVILIDAD. ESTANCIAS EN CENTROS DE INVESTIGACIÓN	480	OPTATIVA	Al menos 3 meses	Supervisión del director de tesis y anotación en el Documento de Actividades del doctorando				0		NO, pero no es una actividad obligatoria

B. Questionnaire form

Dear expert

This questionnaire is aimed at academic research with the topic of providing a blockchain-based inspection framework for building information modeling (BIM) management in Mars buildings. Therefore, variables have been considered for this research, and you are asked to choose the importance of each variable in the subject from 1 to 10.

The factors affecting the information management of Martian buildings are shown in the above table. The researcher made this questionnaire because there was no valid and approved questionnaire in this field, and there was no research available to extract the required items with its help. Therefore, by using the library studies that took place, these criteria were extracted so that those buildings can be controlled and managed using BIM in Martian buildings. Therefore, elites and researchers in the field of Mars should screen these criteria so that finally, the final criteria can be extracted, and with the help of the ranking of these factors, the most important criteria can be ranked and based on the obtained rankings, the proposed framework can be explained.

Table B.1: Questionnaire form

objects	Variables	very unimportant	unimportant	medium	important	very important
Building components	Celling					
	Walls					
	Meteor protector					
	Facilities required					
	Air exchange					
The interior of the building	Air temperature					
	Air pressure					
	Ambient oxygen					
	Ambient carbon dioxide					
	Ambient humidity					
	Amount of light					

If necessary, if you have variables or other items in mind, you can enter them in the box below.

Expert Number 1

Alejandro Serrano Borlaff



Affiliation: NASA

Title: NASA Postdoctoral Fellow Astronomer

Email: a.s.borlaff@nasa.gov

Biography: He studied Physics at the Universidad Complutense de Madrid in Spain from 2008 to 2013. Following his undergraduate studies, he pursued a specialization in Astrophysics, earning a Master's degree from the same university in 2013-2014. Subsequently, he embarked on his Ph.D. journey at the Instituto de Astrofísica de Canarias, where he was actively involved in the operations and support of the GHaFaS Fabry-Pérot integral field spectrograph at the William Herschel Telescope located in La Palma, Roque de Los Muchachos, from 2014 to 2018.

In 2019, he transitioned to the European Space Agency as a visiting scientist, contributing to the Euclid Space Telescope project. Shortly after, he was honored to be selected as a NASA Postdoctoral Fellow at the Ames Research Center in California, where he is currently positioned. He continues his research endeavors at NASA Ames, primarily focusing on the Euclid mission. Additionally, he is involved in developing new space telescopes such as DUNES. His research interests extend to exploring the magnetic field of external galaxies utilizing the SOFIA telescope, as well as investigating the outer regions of galaxies using a range of multiwavelength telescopes, including Chandra, VLA, and GTC, spanning from X-ray to radio wavelengths, and incorporating optical, near-infrared, and far-infrared observations.

His comments can be seen in the tables below.

Table B.2: Expert Opinion

5	4	3	2	1	Variables	objects
*					Celling	Building components
*					Walls	
				*	Meteor protector	
				*	Facilities required	
	*				Air exchange	
	*				Air temperature	The interior of the building
				*	Air pressure	
	*				Ambient oxygen	
				*	Ambient carbon dioxide	
				*	Ambient humidity	
				*	Amount of light	

If necessary, if you have variables or other items in mind, you can enter them in the box below.

However, I have a few questions. The questions in the form were fundamental and not discriminatory. Allow me to explain. Mars environment is far more extreme than anything on Earth. Imagine asking, "How important is the roof or the walls To an Antarctica base. It would not matter much if you have a great roof if the walls are not equally good. The same goes for air temperature; it is a matter of survival. If you were asking, "What is more important, HQ video communication with your family on Earth vs. Rest activities on Mars base," we could enable a debate,

Expert Number 2

Díaz Michelena, Marina



Affiliation: National Institute of Aerospace Technology

Title: Space magnetometers and planetary magnetism researcher

Email: diazma@inta.es

Biography: Marina Díaz Michelena is a doctor of physics specializing in the conception and development of magnetometric devices for space applications and advanced magnetometry techniques for characterization of the magnetic signature of geological structures considered terrestrial analogs of Mars and the Moon.

She works at the National Institute of Aerospace Technology, where she directs the Space Magnetism Laboratory. He has worked on different space missions, such as ROSETTA, NANOSAT-01, NANOSAT-1B, OPTOS, and MetNet. He is currently on an extensive European mission to Mars, Exomars 2020, in collaboration with Russia, where he leads the AMR instrument to characterize the magnetic environment of the surface of the Red Planet.

Likewise, it has designed and built a facility for the characterization of the magnetic signature of space equipment, which is unique in Spain and unique in the world, where subsystems of the Juice, Solar Orbiter, Small Geo, Lisa Pathfinder, GOCE missions have been tested. , SEOSAT, SENTINEL as well as the S80, U212 and RRU Tigre submarines.

Him comments can be seen in the tables below.

Table B.3: Expert Opinion

5	4	3	2	1	Variables	objects
	*				Celling	Building components
*					Walls	
			*		Meteor protector	
		*			Facilities required	
*					Air exchange	
		*			Air temperature	The interior of the building
			*		Air pressure	
	*				Ambient oxygen	
				*	Ambient carbon dioxide	
			*		Ambient humidity	
				*	Amount of light	

If necessary, if you have variables or other items in mind, you can enter them in the box below.

For Mars buildings, you have essential life-sustaining functions, such as O₂/N₂, temperature, CO₂ removal, etc. Then, you need to provide electrical power that can withstand nights and be reliable, communications, and airlocks to come in and out, including dust control. On Mars, buildings need to be protected from wind and dust storms, which are quite prevalent.

Expert Number 3

Ehsan Asna Ahsari



Affiliation: Assistant Professor at the Nottingham Trent University

Title: Construction Management and Quantity Surveying

Email: ehsan.asnaashari@ntu.ac.uk

Biography: As an experienced lecturer and passionate researcher, he brings knowledge to academia and the construction industry. Currently serving as an Associate Professor in the Department of Civil Engineering, specializing in Project Management, at Nottingham Trent University in England, he is dedicated to shaping the next generation of professionals in the field.

His research interests are focused primarily on construction project management, lean construction principles, and building information modeling (BIM). With a keen understanding of industry trends and academic insights, he actively advances methodologies and practices that enhance efficiency, sustainability, and innovation within construction projects.

His comments can be seen in the tables below.

Table B.4: Expert Opinion

5	4	3	2	1	Variables	objects
*					Celling	Building components
	*				Walls	
				*	Meteor protector	
		*			Facilities required	
		*			Air exchange	
				*	Air temperature	The interior of the building
				*	Air pressure	
				*	Ambient oxygen	
				*	Ambient carbon dioxide	
				*	Ambient humidity	
				*	Amount of light	

If necessary, if you have variables or other items in mind, you can enter them in the box below.

These are personal opinions, and my opinion may differ from that of others.

Expert Number 4

Hadi sarvari



Affiliation: Birmingham City University

Title: Construction Management Expert

Email: h.sarvari@khuisf.ac.ir

Biography: He is a postdoctoral fellow at The Hong Kong Polytechnic University and an assistant professor at Islamic Azad University, with over six years of experience in teaching and research in construction management. His mission is to advance the knowledge and practice of construction contract management, public-private partnership (PPP) projects, and building information modeling (BIM) in civil engineering and infrastructure development.

He has authored and co-authored multiple scientific articles and books in reputable journals and publishers, such as the International Journal of Construction Management, Journal of Facilities Management, Sustainability, and the Iranian Journal of Fuzzy Systems. He has also received several awards and honors, such as the Best Lecturer Award in 2018 and the Distinguished Researcher Award in 2022, for his contributions to the educational and research fields. He is a reviewer and editorial board member for several international journals and conferences, and he collaborates with academic and industry partners to conduct impactful and innovative research projects.

His comments can be seen in the tables below.

Table B.5: Expert Opinion

5	4	3	2	1	Variables	objects
*					Celling	Building components
*					Walls	
			*		Meteor protector	
		*			Facilities required	
	*				Air exchange	
	*				Air temperature	The interior of the building
				*	Air pressure	
*					Ambient oxygen	
				*	Ambient carbon dioxide	
				*	Ambient humidity	
				*	Amount of light	

If necessary, if you have variables or other items in mind, you can enter them in the box below.

Although construction has not yet begun on Mars, this research is a valuable resource for organizations venturing into this uncharted territory.

C. Results

Experts' opinions are classified using Excel software and presented in the figure below for systematic analysis and organization. Using Excel features, such as the sort tool, the comments are divided into separate categories, allowing for a more straightforward interpretation and understanding of the data. This method improves the identification of experts' opinions, helps decision-making processes, and informs subsequent actions or strategies based on the analysis performed.

Figure C.1: presents expert opinions categorized using Excel software

PAKAR	SKALA LIKERT																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	5	5	1	1	4	4	1	5	1	1	1						
2	5	4	2	3	5	3	2	4	1	2	1						
3	4	5	1	3	3	1	1	1	1	1	1						
4	5	5	2	2	4	4	1	5	1	1	1						

The figure below presents numerical values derived from the opinions of experts using fuzzy Delphi formulas. These values, obtained through a rigorous process combining expert input and fuzzy logic techniques, represent the assessments or predictions made by each expert within the given context. The application of fuzzy Delphi methodology allows for the aggregation of diverse expert perspectives while considering the uncertainties inherent in the data, resulting in quantifiable outputs that capture the collective wisdom of the experts involved.

Figure C.2: numerical values derived from the opinions of experts using fuzzy Delphi formulas

1			2			3			4			5			6			7			8			9			10			11		
0.6	0.8	1	0.6	0	1	0	0	0.2	0	0	0.2	0.4	0.6	0.8	0.4	0.6	0.8	0	0	0.2	0.6	0.8	1	0	0	0.2	0	0	0.2	0	0	0.2
0.6	0.8	1	0.4	0.6	0.8	0	0.2	0.4	0.2	0.4	0.6	0.6	0.8	1	0.2	0.4	0.6	0	0.2	0.4	0.4	0.6	0.8	0	0	0.2	0	0.2	0.4	0	0	0.2
0.4	0.6	0.8	0.6	0.8	1	0	0	0.2	0.2	0.4	0.6	0.2	0.4	0.6	0	0	0.2	0	0	0.2	0	0	0.2	0	0	0.2	0	0	0.2	0	0	0.2
0.6	0.8	1	0.6	0.8	1	0	0.2	0.4	0	0.2	0.4	0.4	0.6	0.8	0.4	0.6	0.8	0	0	0.2	0.6	0.8	1	0	0	0.2	0	0	0.2	0	0	0.2
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
0.550	0.750	0.950	0.550	0.550	0.950	0.000	0.100	0.300	0.100	0.250	0.450	0.400	0.600	0.800	0.250	0.400	0.600	0.000	0.050	0.250	0.400	0.550	0.750	0.000	0.000	0.200	0.000	0.050	0.250	0.000	0.000	0.200
m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3

In the figure below, numerical values have been derived for each expert by employing their opinions and applying fuzzy Delphi formulas to identify ineffective factors for removal. Through this process, the expertise of each participant is leveraged to evaluate the relevance and significance of various factors, utilizing fuzzy logic techniques to handle uncertainties and nuances in the data. The resulting numbers provide insights into which factors are considered

ineffective by the experts, enabling informed decisions regarding their elimination from consideration in subsequent analyses or decision-making processes.

Figure C.3: numerical values have been derived for each expert by employing their opinions and applying fuzzy Delphi formulas

PAKAR	ITEM																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0.1	0.6	0.1	0.4	0.0	0.3	0.1	0.4	0.0	0.1	0.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	0.1	0.2	0.1	0.2	0.3	0.0	0.2	0.1	0.0	0.2	0.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	0.2	0.3	0.1	0.2	0.3	0.6	0.1	0.8	0.0	0.1	0.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4	0.1	0.3	0.1	0.1	0.0	0.3	0.1	0.4	0.0	0.1	0.0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
5	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
6	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
7	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
8	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
9	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
10	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
11	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
12	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
13	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
14	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
15	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
16	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Nilai d setiap item	0.115	0.312	0.141	0.222	0.153	0.301	0.106	0.406	0.000	0.106	0.000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Nilai d konstruk	0.169																

In the figure below, Delphi formulas were utilized to identify significant factors while iteratively eliminating ineffective ones based on expert consensus. Through this process, experts' opinions were systematically gathered, analyzed, and refined to collectively agree on the importance of various factors within the given context. By employing the Delphi methodology, which involves multiple rounds of feedback

and adjustment, a consensus was achieved, identifying significant factors while discarding those considered ineffective. This iterative approach ensures that the final selection of factors reflects a well-informed and consensus-driven decision-making process.

Figure C.4: Delphi formulas were utilized to identify significant factors

ITEM	1			2			3			4			5			6			7			8			9			10			11		
	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3	m1	m2	m3
JMLAH SETUP UNSUR	2.20	3.00	3.80	2.20	2.20	3.80	0.00	0.40	1.20	0.40	1.00	1.80	1.80	2.40	3.20	1.00	1.60	2.40	0.00	0.20	1.00	1.60	2.20	3.00	0.00	0.00	0.80	0.00	0.20	1.00	0.00	0.00	0.80
FLUZZ EVALUATION	3.000			2.733			0.533			1.667			2.400			1.667			0.400			2.267			0.267			0.400			0.267		
SKOR	1			2			7			6			3			5			8			4			10			8			10		
PURATA SETUP UNSUR	0.550	0.750	0.950	0.550	0.550	0.950	0.000	0.100	0.300	0.100	0.250	0.450	0.400	0.600	0.800	0.250	0.400	0.600	0.000	0.050	0.250	0.400	0.550	0.750	0.000	0.000	0.200	0.000	0.050	0.250	0.000	0.000	0.200
KEPERCA OF FLUZZ NUMBER	0.750			0.683			0.133			0.267			0.600			0.417			0.100			0.567			0.067			0.100			0.067		
SKOR	1			2			7			6			3			5			8			4			10			8			10		

D. Fuzzy AHP

Table D.1 below represents the input matrix containing experts' opinions, serving as the foundation for further analysis and decision-making processes. This matrix

encapsulates each expert's diverse perspectives and insights and is structured for systematic evaluation. Each row typically corresponds to a specific expert, while columns represent different criteria or factors under consideration. By aggregating and synthesizing these opinions, valuable information is extracted to inform subsequent steps, such as prioritization, consensus-building, or decision-making, contributing to a comprehensive understanding of the subject.

Table D.1 represents the input matrix containing experts' opinions

Question Number	12	13	14	15	16	23	24	25	26	34	35	36	45	46	56
1	1.0	5	1	4	3	4	0.5	3	2	0.16	0.33	0.25	4	3	0.5
2	1.0	4	1	3	2	4	0.5	2	2	0.2	0.5	0.33	5	2	0.33
3	2.0	4	2	4	3	3	1	4	3	0.33	0.5	0.33	4	3	0.5
4	10	5	1	4	2	4	0.33	3	3	0.16	0.33	0.25	5	2.4	0.5
Average	1.2	4.5	1.2	3.7	2.4	3.7	0.5	2.9	2.4	0.2	0.4	0.3	4.5	2.4	0.5

```
function [ weights, CompMat, fuzzyTFN ,fuzzyCompMatCell] = FuzzyAHP(
CompMat, A )
```

```
% fuzzy tfn and inverse fuzzy tfn constants
```

```
fuzzyTFN = {[1 1 1 ] [1.000 1.000 1.000]
```

```
 [1 2 3 ] [0.333 0.500 1.000]
```

```
 [2 3 4 ] [0.250 0.333 0.500]
```

```
 [3 4 5 ] [0.200 0.250 0.333]
```

```
 [4 5 6 ] [0.166 0.200 0.250]
```

```
 [5 6 7 ] [0.142 0.160 0.200]
```

```
 [6 7 8 ] [0.125 0.142 0.166]
```

```
 [7 8 9 ] [0.111 0.125 0.142]
```

```
 [9 9 9 ] [0.111 0.111 0.111]];
```

```
fuzzyCompMatCell={};
```

```
%%
```

```
[m, n] = size(CompMat);
```

```
for i=1:m
```

```
    for j=i+1:m
```

```
        CompMat(j,i) = 1 / CompMat(i,j);
```

```
    end
```

```
end
```

```
for i=1:m
```

```

for j=1:n
    i;
    criteria = CompMat(i,j);
    if criteria >= 1
        fuzzyCompMatCell{i,j} = fuzzyTFN{ round(criteria) ,1 };
    else
        a=round(1/criteria);
        fuzzyCompMatCell{i,j} = fuzzyTFN{ a ,2 };
    end
end
end

%%
% find sum of every l,m,u value for the triangular fuzzy number
for i=1:m
    vec = [fuzzyCompMatCell{i,:}];
    mExtendAnalysis{1,i} = sum(reshape(vec,3,[]));
end

vec = [mExtendAnalysis{1,:}];
mExtendAnalysisSum = sum(reshape(vec,3,[]));

for i=1:m
    vec = [mExtendAnalysis{1,i}];
    for j=1:3
        val = mExtendAnalysisSum(1,4-j);
        valSum(1,j) = (vec(1,j))*(1/val);
    end
    mExtendAnalysis{1,i} = valSum;
end

%%
degreeOfPossibility = zeros(m*(m-1),3);
rowIndex = 1;
for i=1:m
    for j=1:m
        if i~=j
            degreeOfPossibility(rowIndex,[1 2]) = [i j];
            M1 = mExtendAnalysis{1,i};
            M2 = mExtendAnalysis{1,j};
            if M1(1,2) >= M2(1,2)
                degreeOfPossibility(rowIndex,3) = 1;
            elseif M2(1,1) >= M1(1,3)
                degreeOfPossibility(rowIndex,3) = 0;
            end
        end
    end
    rowIndex = rowIndex + 1;
end

```

```

        else
            degreeOfPossibility(rowIndex,3) = (M2(1,1)-M1(1,3))/((M1(1,2)-
M1(1,3))-(M2(1,2)-M2(1,1)));
        end
        rowIndex = rowIndex + 1;
    end
end
end

%%
% normalized weight calculation
weights = zeros(1,m);
for i=1:m,
    weights(1,i) = mean(degreeOfPossibility([find(degreeOfPossibility(:,1) == i),
[3])));
end
weights = weights/sum(weights);

end

```

E. Information obtained from Python Part 1

https://colab.research.google.com/drive/1cRDrtF2QBPGx0UvvGOh_GT62312pAMLf?usp=sharing

This section of the code initializes the sensors employed in the system, assigning a distinct identifier to each sensor for identification and data tracking. The system can accurately distinguish between individual sensors by assigning unique IDs, enabling precise data collection and analysis. This step ensures that data from each sensor is attributed correctly and can be easily referenced throughout the system's operation. The unique IDs are crucial in managing the sensor network and facilitating cracksless communication and integration within the overall system architecture.

Figure E.1: Python code

```
Import time
import random
ID_Oxygen= random.randint(1,1000)
ID_Temperature = random.randint(1,1000)
ID_AirChange = random.randint(1,1000)
ID_Wall = random.randint(1,1000)
ID_Roof = random.randint (1,1000)
ID_Facilities = random.randint(1,1000)
print (ID_Oxygen,"\n",ID_Temperature,"\n",ID_AirChange,"\n",
ID_Wall,"\n",ID_Roof,"\n", ID_Facilities)
656
338
187
829
833
252
```

In this segment, the coding function for information is implemented to facilitate data conversion into a coded format suitable for processing or transmission. This function is essential for encoding data in a manner that preserves its integrity and allows for efficient handling within the system. By transforming raw data into a coded format, information can be compressed, encrypted, or structured to meet specific requirements or standards. This coding process enables the efficient transmission and storage of data while ensuring its security and reliability throughout various stages of operation.

Figure E.2: Python code

```
import hashlib
data = []
class Block:
    T_ID=0

    next=None
    hash=None
    nonce=0
    previous_hash=0x0

    def __init__(self,data):
        self.data=data

    def hash(self):
        h=hashlib.sha256()
        h.update(
            str(self.T_ID).encode('utf-8') +
            str(self.data).encode('utf-8') +
            str(self.previous_hash).encode('utf-8') +
            str(self.nonce).encode('utf-8')
        )
        return h.hexdigest()

    def __str__(self):
        return "Block Hash: " + str(self.hash()) + "\nT_ID: " +
str(self.T_ID) + "\nBlock Previous: " + str(self.previous_hash)+"\n---
-----"
```

This section outlines the procedure for adding a new block to the blockchain, thereby upholding the integrity and security of the distributed ledger system. The process typically involves several steps, including validating the transactions within the new block, generating a cryptographic hash for the block, verifying its authenticity through consensus mechanisms such as proof of work or proof of stake, and appending it to the existing chain. By adhering to these protocols, the blockchain network maintains its immutability and trustworthiness, as each new block is securely linked to the preceding blocks, creating a transparent and tamper-resistant record of transactions.

Figure E.3: Python code

```
class Blockchain:

    maxNonce=2**32
    diff =10
    target=2** (256-diff)

    block=Block(data)
    head=block

    def add(self,block):
        block.previous_hash=self.block.hash()
        block.T_ID=self.block.T_ID+1
        self. Block.next=block
        self.block=self.block.next

    def mine(self,block):
        for n in range(self.maxNonce):
            if int(block.hash(),16)<=self.target:
                self.add(block)
                print(block)
                break
            else:
                block.nonce+=1
```

In this section, upon receiving the information, the system generates an XML file to encapsulate the data in a structured format, facilitating its transmission. The XML file serves as a standardized means of representing the information, organizing it into hierarchical elements with associated attributes and values. This structured format ensures compatibility and interoperability across different systems and platforms. Once the XML file is generated, it is transmitted to its intended destination using appropriate protocols or communication channels, enabling efficient data exchange while preserving the integrity and fidelity of the information.

Figure E.4: Python code

```
From xml.dom import minidom
import xml. etree.ElementTree as ET
import os
from google.colab import files
import datetime
blockchain = Blockchain()
```

```

def add_Item():
    Oxygen = random.randint(0,30) #%
    Temperature = random.randint(18,40) #C
    AirChange = random.randint(0,10)  #%
    Wall = random.randint (0,20)
    if Wall <= 15:
        Wall=0 #0: Normal
    if Wall >15 and Wall<=18:
        Wall=1 #1: cracked
    if Wall > 18:
        Wall = 2 #2: Broken
    Roof = random.randint (0,20)
    if Roof <= 15:
        Roof=0 #0: Normal
    if Roof >15 and Roof<=18:
        Roof=1 #1: cracked
    if Roof > 18:
        Roof = 2 #2: Broken
    Facilities = random.randint (0,20)
    if Facilities <= 10:
        Facilities=0 #0: Normal
    if Facilities >10 and Facilities<=18:
        Facilities=1 #1: cracked
    if Facilities > 18:
        Facilities = 2 #2: Broken
    timestamp=datetime.datetime.now()
    d = (ID_Oxygen,Oxygen) , (ID_Temperature,Temperature) ,
    (ID_AirChange,AirChange) , (ID_Wall,Wall) , (ID_Roof,Roof) ,
    (ID_Facilities,Facilities) , ("time",timestamp)
    data.append(d)
    blockchain.mine(Block("Block "+ str(d)))
    return data

```

In this segment, the final block is appended to the blockchain, signifying the completion of a transaction or data record within the decentralized ledger system. This process typically involves verifying the integrity of the new block by validating its transactions and ensuring consensus among network participants. Once validated, the new block is securely linked to the existing chain through cryptographic hashing techniques, preserving the immutability and transparency of the ledger. The addition of the final block represents the culmination of a transaction or data entry, providing a permanent and tamper-proof record within the blockchain network.

Figure E.5: Python code

```
B = add_Item()
sen = ""
for I in b:
    usrconfig = ET.Element("Round")
    Round = ET.SubElement(usrconfig, "Round")
    for j in i:
        s=str(j[0])
        b=str(j[1])
        sen = s + " = " + b
        Sensor = ET.SubElement(usrconfig, "Sensor")
        Sensor.text = sen
    tree = ET.ElementTree(usrconfig)
tree.write("Output.xml", encoding='utf-8', xml_declaration = True)
#files.download('Output.xml')
Block Hash:
5fa8e7c898b15f1a1fe6db6eafc5142bec508a42b0f7757635e4b80508421ec0
T_ID: 4
Block Previous:
43c0922f5c8fa7462a0875ec802c5557a18825533ac361ea26d06ba2d1ffdb52
```

This section compares the data extracted from the XML file with the data stored in the blockchain to verify consistency and integrity. This process involves parsing the XML file to extract relevant information and then querying the blockchain to retrieve corresponding data. Subsequently, a comparison is conducted to ensure that the data from the XML file matches the corresponding records stored in the blockchain. Any discrepancies or inconsistencies detected during this comparison indicate potential data tampering or errors, prompting further investigation or corrective measures to maintain the integrity of the blockchain ledger. This verification step plays a crucial role in ensuring the data's accuracy and trustworthiness in the decentralized network.

Figure E.6: Python code

```
While blockchain.head != None:
    print(blockchain.head)
    blockchain.head=blockchain.head.next
Block Hash:
6ec59c67c590d5fc018afe2775f224f047a1fe570c487953f2dcb348ea9abd63
T_ID: 0
Block Previous: 0
```

```
Block Hash:
f6ac7bcbcd432d27d058c655b4444a873a0d6932c23b37d6821171b4d7b69bcf7
T_ID: 1
Block Previous:
66eb4682d40dbff22bd95bd5e41d103fb60486082620a92c5e72696605c8126a
```

```

Block Hash:
3449994414ecb0857c3e31b0bd732c2aa193e51766b4580103d465036c74f51e
T_ID: 2
Block Previous:
f6ac7bcbdd432d27d058c655b4444a873a0d6932c23b37d6821171b4d7b69bcf7


---


Block Hash:
43c0922f5c8fa7462a0875ec802c5557a18825533ac361ea26d06ba2d1ffdb52
T_ID: 3
Block Previous:
3449994414ecb0857c3e31b0bd732c2aa193e51766b4580103d465036c74f51e


---


Block Hash:
5fa8e7c898b15f1a1fe6db6eafc5142bec508a42b0f7757635e4b80508421ec0
T_ID: 4
Block Previous:
43c0922f5c8fa7462a0875ec802c5557a18825533ac361ea26d06ba2d1ffdb52


---



```

In this section, upon successful verification of the information as correct, it is transmitted to the robots for further processing or action. This step involves sending the validated data to the designated robots or automated systems, enabling them to execute predefined tasks or take appropriate actions based on the received instructions. By transmitting verified information to the robots, the system ensures cracksless coordination and execution of tasks, optimizing efficiency and productivity in various operational scenarios. This integration between data verification and robot control facilitates real-time decision-making and automation, enhancing the overall performance and effectiveness of the system.

Figure E.7: Python code

```

mytree = ET.parse('Output.xml')
myroot = mytree.getroot()
s = []
for i in myroot:
    s.append(((str(i.text)).split("\n"))))
a=[]
For i in s:
    for j in i:
        a.append(j.split("="))
lst =[]
for i in a[1:]:
    lst1=(i[0],i[1])
    lst.append(lst1)
block = Blockchain()
c = block.mine(Block("Block "+ str(lst)))
if c == block.mine(Block("Block "+ str(b))):
    print("True")

```

```

Block Hash:
095aed2b243fafad4c1d2cdbb78b46e6a74110ec89cd309a6364a38368d8c056
T_ID: 1
Block Previous:
6ec59c67c590d5fc018afe2775f224f047a1fe570c487953f2dcb348ea9abd63
-----
Block Hash:
5df61b2b1989e889ec2e30254dd04fccccd36924c6c7d9f4eba44396ae949d7ae
T_ID: 2
Block Previous:
095aed2b243fafad4c1d2cdbb78b46e6a74110ec89cd309a6364a38368d8c056

```

F. Information obtained from Python Part 2

<https://colab.research.google.com/drive/1mjkSHTjGDiNSFX7IxGFDziDEH0ycAgPZ?usp=sharing>

This section defines variables within the JSON file, specifying the data structure and content to facilitate efficient parsing and manipulation. By establishing clear definitions for each variable, including their names, types, and hierarchical relationships, the JSON file becomes a standardized blueprint for organizing and representing data. This structured approach streamlines the parsing process, allowing software applications to access and extract relevant information from the JSON file easily. Additionally, well-defined variables enable efficient data manipulation and transformation, empowering developers to perform various operations such as filtering, sorting, and aggregating data precisely and accurately.

Figure F.1: Python code

```

my_system = platform.uname()
System={my_system.system}
Node_Name= {my_system.node}
Release= {my_system.release}
Version= {my_system.version}
Machine= {my_system.machine}
Processor= {my_system.processor}

```

This section encompasses managing and handling customer information, encompassing data collection, storage, and processing for various business operations or services. It involves establishing robust procedures and systems for capturing customer data, ensuring its accuracy, confidentiality, and compliance with relevant regulations such as

GDPR or CCPA. Additionally, it includes implementing secure storage solutions, such as databases or cloud platforms, to safeguard customer information from unauthorized access or breaches. Furthermore, this section addresses data processing activities, such as analysis, segmentation, and personalization, to derive actionable insights and deliver tailored customer experiences. Overall, effective management of customer information is crucial for building trust, enhancing customer satisfaction, and driving business growth.

Figure F.2: Python code

```
import datetime
uniquecode=input("insert your uni code: ")
name=input("insert your First name: ")
family=input("insert your Last name: ")
Address=input("insert your Address: ")
user_sing=input("insert your sign: ")
timestamp=datetime.datetime.now()
insert your uni code: a
insert your First name: b
insert your Last name: d
insert your Address: rvrdf
insert your sign: 30
```

This section creates a JSON file containing relevant data and transmits it to the company for further processing or analysis. This process involves compiling pertinent information, such as customer profiles, transaction records, or market insights, into a structured JSON format. Once the JSON file is generated, it is transmitted securely to the company's servers or designated recipients using appropriate communication protocols. Upon receipt, the company can leverage the data for various purposes, including business intelligence, customer relationship management, or decision-making. This streamlined data exchange approach ensures efficient information transfer while maintaining data integrity and security throughout the transmission process.

Figure F.3: Python code

```
From trait lets. traitlets import Unicode
import json

sampleDict = {
    "System": str(System),
```

```

    "Node Name": str(Node_Name),
    "Release":str(Release),
    "Version":str(Version),
    "Nat_Code": str(unicode),
    "name": str(name),
    "family":str(family),
    "Address":str(Address),
    "user_sing":str(user_sing),
    "timestamp": str(timestamp)

}
jsonData = json.dumps(sampleDict)
with open("request.json", "w") as outfile:
    outfile.write(jsonData)

```

```

From google.colab import files
y = jsonData.encode('utf-8')
files.download('request.JSON')

```

In this section, the information successfully arrives at the company's designated destination or system for further processing or analysis. This stage marks the culmination of the data transmission process, where the JSON file containing relevant information reaches its intended recipient within the company's infrastructure. Upon arrival, the data is ingested into the company's systems or databases, ready for subsequent processing, analysis, or utilization in various business operations. This crackless transfer of information ensures that the company can leverage the data effectively to gain insights, make informed decisions, and drive business strategies forward.

Figure F.4: Python code

```

With open('request.json', 'r') as an open file:

    # Reading from JSON file
    json_object = json.load(open file)

print(json_object)
print(type(json_object))
{'System': '"{\`Linux\`}'," 'Node Name': '"{\`749a3b916e97\`}'", 'Release':
'"{\`5.10.147+\`}"', 'Version': '"{\`#1 SMP Sat Dec 10 16:00:40 UTC 2022\`}'",
'`name': `b`,`family': `d`,`Address': `rvrdf`,`user_sing': `30`,
'timestamp': `2023-01-11 09:50:12.361892`}
<class `dict`>

```

In this segment, sensors are allocated to the customer, with each sensor assigned a unique identifier for effective tracking and management purposes. This process involves associating specific sensors with individual customers to monitor their usage, behavior, or environmental conditions. The system can accurately track and manage sensor deployments by assigning unique identifiers to each sensor, ensuring proper maintenance, calibration, and data collection. Additionally, these identifiers facilitate cracksless integration with other systems or databases, enabling efficient retrieval and analysis of sensor data for actionable insights or decision-making. Overall, allocating unique identifiers to sensors enhances the effectiveness and reliability of customer monitoring and management processes.

Figure F.5: Python code

```
import time
import random
sensor_data=[]
ID_Oxygen=1
ID_Temperature=2
ID_Air_Change=3
ID_Roof=4
ID_Wall=5
ID_Facilities=6
def sensor():
    sensor_data.append(ID_Oxygen)
    sensor_data.append(ID_Temperature)
    sensor_data.append(ID_Air_Change)
    sensor_data.append(ID_Roof)
    sensor_data.append(ID_Wall)
    sensor_data.append(ID_Facilities)
    return sensor_data
sensor=sensor()
print(sensor)
[1, 2, 3, 4, 5, 6]
```

In this section, the information is digitally signed by both contracting parties, ensuring authenticity, integrity, and commitment to the terms of the agreement. Digital signatures are cryptographic techniques that provide a secure way to validate the signatories' identity and ensure the signed document's integrity. By digitally signing the information, both parties demonstrate their consent and agreement to the terms outlined in the document. Additionally, digital signatures offer tamper-evident protection, as any

modifications to the signed document would invalidate the signature. This process enhances trust and confidence in the transaction, providing a verifiable and legally binding record of the parties' commitments.

Figure F.6: Python code

```
Company_sign=input("Please Enter your token for signature the damage  
report: ")  
data = str(json_object) + " _ " + str(sensor) + " _ " +company_sign  
print(data)  
Please enter your token for signature on the damage report: 30  
{'System': "{ 'Linux' }," 'Node Name': "{ '749a3b916e97' }", 'Release':  
"{ '5.10.147+' }", 'Version': "{ '#1 SMP Sat Dec 10 16:00:40 UTC 2022' }",  
'name': 'b,' 'family': 'd', 'Address': 'rvrdf,' 'user_sing': '30',  
'timestamp': '2023-01-11 09:50:12.361892'} _ [1, 2, 3, 4, 5, 6]
```

From this juncture, all data about the smart contract is securely stored within the blockchain, guaranteeing transparency, immutability, and trustworthiness of the transactional records. Smart contracts are self-executing contracts with the terms of the agreement directly written into code. By storing these contracts on a blockchain, every transaction and change is recorded across multiple nodes in the network, making the data highly resistant to tampering or manipulation. This ensures transparency as all parties can access and verify the contract details, immutability as the records cannot be altered retroactively, and trustworthiness as the decentralized nature of the blockchain removes the need for intermediaries, reducing the risk of fraud or error. Overall, storing smart contracts on the blockchain provides a secure and reliable framework for executing and enforcing agreements.

Figure F.7: Python code

```
import hashlib  
class Block:  
    T_ID=0  
    data=data  
    next=None  
    hash=None  
    nonce=0  
    previous_hash=0x0  
  
    def __init__(self,data):  
        self.data=data
```

```

def hash(self):
    h=hashlib.sha256()
    h.update(
        str(self.T_ID).encode('utf-8')+
        str(self.data).encode('utf-8')+
        str(self.previous_hash).encode('utf-8')+
        str(self.nonce).encode('utf-8')
    )
    return h.hexdigest()

def __str__(self):
    return "Block Hash: " + str(self.hash())+ "\nT_ID: "+
str(self.T_ID) + "\nBlock Previous: "+ str(self.previous_hash)+"\n---
-----"

Class Blockchain:

    maxNonce=2**32
    diff =10
    target=2**(256-diff)

    block=Block("Step1")
    head=block

    def add(self,block):
        block.previous_hash=self.block.hash()
        block.T_ID=self.block.T_ID+1
        self. Block.next=block
        self.block=self.block.next

    def mine(self,block):
        for n in range(self.maxNonce):
            if int(block.hash(),16)<=self.target:
                self.add(block)
                #print(block)
                break
            else:
                block.nonce+=1

import time
#!pip install pympler
from pympler import size
start=time.time()
blockchain=Blockchain()
size = size of.asizeof(blockchain)
for n in range(1000000):
    s=""
    s = blockchain.mine(Block("Block "+ str(n)))
    size += sizeof.asizeof(s)

```

```

while blockchain.head != None:
    print(blockchain.head)
    blockchain.head=blockchain.head.next
end=time.time()
len=print(end-start)
print(size)

```

Streaming output truncated to the last 5000 lines.

```

Block Previous:
6fe3c9ab6b6df43c697c8c627c87c2f508f5f87458134075318014157aca1386
-----
Block Hash:
1da87f60c6958bd6e22deeb720fa2a20a4a3064941424ee07f8c8b620effcf32
T_ID: 998752
Block Previous:
48f1e73ba36e5977d22b5ae2c557f6deee883fd96f8bc0565489d0a712099eab
-----
Block Hash:
635b0e9231178d642deb28ddeeac8245bab03e41191112538c7f3df95e35350f
T_ID: 998753
Block Previous:
1da87f60c6958bd6e22deeb720fa2a20a4a3064941424ee07f8c8b620effcf32
-----
Block Hash:
85d67bd226917d7d134ce0975b61e47c6b98096542ab3fe241a040538a00c897
T_ID: 998754
Block Previous:
635b0e9231178d642deb28ddeeac8245bab03e41191112538c7f3df95e35350f
-----

```

G. Standard BIM

- **EXPRESS specification**

This formal specification is provided in the EXPRESS language.

Express Specification

(*

ISO_12006_3_VERSION_3

EXPRESS specification:

*)

SCHEMA ISO_12006_3_VERSION_3;

(*

- **xtdDate**

xtdDate is a defined data type of simple data type STRING that is used to contain an alphanumeric representation of a date. It is recommended that the date format “YYYY.MM.DD” should be used.

EXAMPLE The 31st day of May in the year 2000 should be written as “2000.05.31”.

EXPRESS specification:

*)

TYPE xtdDate = STRING; END_TYPE;

(*

- **xtdGlobalUniqueID**

xtdGlobalUniqueID is a defined data type of simple data type STRING that holds an identifier that is globally unique.

Typically, the identifier is generated using an algorithm such as that published by the Object Management Group which is based on the IP address of the computer that generates the identifier.

There are implementations of the above algorithm that can be used to create an identifier.

An identifier is a unique 128-bit number. It is desirable to compress the identifier size to reduce overhead. Implementers shall compress the identifier down to a 22-

character string using a compression algorithm with 64 characters for the base. The encoding of the base 64-character set is shown below:

1	2	3	4	5	6
<u>0123456789012345678901234567890123456789012345678901234567890123</u>					
"0123456789ABCDEFGHIJKLMNopQRSTUVWXYZabcdefghijklmnopqrstuvwxyz_\$";					

EXAMPLE The 22-character string “93f09e4A_899402a9\$D013” is a globally unique identifier.

Every concept within a library can only have one globally unique identifier. Globally unique identifiers of similar concepts in different, separately developed libraries may differ. This part of ISO 12006 does not give a mechanism that automatically evaluates similar concepts with different globally unique identifiers across libraries. Evaluation of concepts between libraries to ascertain equivalence must be done separately.

NOTE The algorithm is explained at <http://www.opengroup.org/dce/info/draft-leach-uuids-guids-01.txt>.

EXPRESS specification:

*)

TYPE xtdGlobalUniqueID = STRING; END_TYPE;

(*

- **xtdLabel**

xtdLabel is a defined data type of simple data type STRING that is a set of alphanumeric UNICODE characters used to nominate an object.

EXPRESS specification:

*)

TYPE xtdLabel = STRING; END_TYPE;

(*

- **xtdText**

xtdText is a defined data type of simple data type STRING that is a set of alphanumeric UNICODE characters used to annotate an object.

EXPRESS specification:

*)

TYPE xtdText = STRING; END_TYPE;

(*

- **xtdVersionID**

xtdVersionID is a defined data type of simple data type STRING that is a set of alphanumeric UNICODE characters used to identity the version of an object.

EXAMPLE “1A”, “12”, “1.1” are types of versioning.

EXPRESS specification:

*)

TYPE xtdVersionID = STRING; END_TYPE;

(*

- **xtdToleranceTypeEnum**

xtdToleranceTypeEnum is an enumeration type giving the range of possible types of tolerances which can be applied to a value. Allowed selections are:

Realvalue Defined type of equal type as the value that expresses the tolerance as a real value. Percentage Defined type that expresses the tolerance as a percentage of the value.

EXPRESS specification:

*)

TYPE xtdToleranceTypeEnum = ENUMERATION OF (REALVALUE,
PERCENTAGE); END_TYPE;

(*

- **xtdValueRoleEnum**

xtdValueRoleEnum is an enumeration type giving the range of possible types of interpretation which can be applied to a value. Allowed selections are:

Nominal Defined type of denominating the value of type nominal. Maximum
Defined type of denominating the value as a maximum value. Minimum
Defined type of denominating the value as a minimum value.

EXPRESS specification:

*)

```

TYPE xtdValueRoleEnum = ENUMERATION OF (NOMINAL,
MAXIMUM, MINIMUM);
END_TYPE;
(*)

```

- **xtdValueTypeEnum**

xtdValueTypeEnum is an enumeration type giving the range of possible simple value types from which a selection can be made. Allowed selections are:

xtdString Defined type of simple type STRING for descriptive purposes.
xtdNumber Defined type of simple type STRING.

xtdInteger Defined type of simple type INTEGER. xtdReal Defined type of simple type REAL.
xtdBoolean Defined type of simple type BOOLEAN.
xtdLogical Defined type of simple type LOGICAL.

EXPRESS specification:

```

*)
TYPE xtdValueTypeEnum = ENUMERATION OF (XTDSTRING,
XTDNUMBER, XTDINTEGER, XTDREAL, XTDBOOLEAN, XTDLOGICAL);
END_TYPE;
(*)

```

- **xtdActivity**

xtdActivity is a specialization of xtdObject that represents an activity or process that modifies an xtdSubject.

EXAMPLE "bricklaying" represents the activity or process of bringing together bricks and mortar to create a wall or other element of construction.

EXPRESS specification:

```

*)
ENTITY xtdActivity SUBTYPE OF(xtdObject);
END_ENTITY;
(*)

```

- **xtdActor**

xtdActor is a specialization of xtdObject that represents an agent that acts upon an xtdSubject within an xtdActivity.

An actor can be a person, profession, organizational unit, equipment.

EXAMPLE 1 “carpenter” is an xtdActor. EXAMPLE 2 “ISO” is an xtdActor.

EXAMPLE 3 “crane” may be used as an xtdActor.

EXPRESS specification:

*)

ENTITY xtdActor

SUBTYPE OF(xtdObject); END_ENTITY;

(*

- **xtdBag**

xtdBag is a specialization of xtdCollection that has no constraints on the things that can be members of the collection.

A collection of actors and activities and subjects may be collected together within an instance of xtdBag.

EXPRESS specification:

*)

ENTITY xtdBag

SUBTYPE OF(xtdCollection); END_ENTITY;

(*

- **xtdCollection**

xtdCollection represents a group or collection of things. An xtdCollection can be one of xtdNest or xtdBag.

EXPRESS specification:

*)

ENTITY xtdCollection

ABSTRACT SUPERTYPE OF (ONEOF(xtdNest, xtdBag))

SUBTYPE OF(xtdRoot); END_ENTITY;

(*

- **xtdDescription**

xtdDescription holds the description or definition of a thing by means of text.

EXAMPLE “A door leaf is the part of a door that opens to allow people or goods to pass” is the definitive description in English for the object “door leaf”.

EXPRESS specification:

*)

ENTITY xtdDescription

SUBTYPE OF(xtdLanguageRepresentation); Description : xtdText;

INVERSE

is_description_of : SET [1:?] OF xtdRoot FOR Descriptions; END_ENTITY;

(*

Attribute definition:

- **Description**

an instance of xtdText that holds the description or definition

- **xtdExternalDocument**

xtdExternalDocument is used to represent external documents, books or other written information.

EXAMPLE 1 “ISO 31” is a document. EXAMPLE 2 “NS 3420” is a document.

EXPRESS specification:

*)

ENTITY xtdExternalDocument;

UniqueID : xtdGlobalUniqueID;

Names : SET [1:?] OF xtdName; END_ENTITY;

(*

Attribute definitions:

UniqueID

globally unique identifier for the external document

Names

set of language-dependent names of the external document

- **xtdLanguage**

xtdLanguage represents the language in which names, descriptions, values and references are expressed including its designation in itself and in English.

EXPRESS specification:

*)

ENTITY xtdLanguage; LanguageNameInEnglish : xtdLabel;

LanguageNameInSelf : OPTIONAL xtdLabel;

Comments : OPTIONAL LIST [1:?] OF xtdText;

UniqueID : xtdGlobalUniqueID; END_ENTITY;

(*

Attribute definitions:

- **LanguageNameInEnglish**

name of the language in which the identifying descriptive attribute is expressed in the form in which the language is known in English

The name should be interpreted in a non-case sensitive way

Examples of English language names, according to ISO 3166-1[1], are given below.

EXAMPLE 1“English” is the ISO 3166-1 name for all types of English.

EXAMPLE 2“German” is the name in English of the language spoken in Germany and surrounding countries.

- **LanguageNameInSelf**

name of the language in which the identifying descriptive attribute is expressed in the form in which the language is known in itself

EXAMPLE 1 “Deutsch” is the name by which the German language is known to German language speakers. EXAMPLE 2 “Norsk nynorsk” is the name of a particular form of the Norwegian language.

EXAMPLE 3 “British English” is the name of the form of the English language which is characterized by the spelling and intonation used within the British Isles and certain other parts of the world.

- **Comments**

optional list of comments for the language used

- **UniqueID**

globally unique identifier for the language

- **xtdLanguageRepresentation**

xtdLanguageRepresentation is a representation of the language used to specify a name, a description, a value or a reference.

EXPRESS specification:

*)

ENTITY xtdLanguageRepresentation

ABSTRACT SUPERTYPE OF (ONEOF(xtdName, xtdDescription));
LanguageName : xtdLanguage;

UniqueID : xtdGlobalUniqueID; END_ENTITY;

(*

- **xtdLanguage**

xtdLanguage represents the language in which names, descriptions, values and references are expressed including its designation in itself and in English.

EXPRESS specification:

*)

ENTITY xtdLanguage; LanguageNameInEnglish : xtdLabel;

LanguageNameInSelf : OPTIONAL xtdLabel;

Comments : OPTIONAL LIST [1:?] OF xtdText;

UniqueID : xtdGlobalUniqueID; END_ENTITY;

(*

Attribute definitions:

- **LanguageNameInEnglish**

name of the language in which the identifying descriptive attribute is expressed in the form in which the language is known in English

The name should be interpreted in a non-case sensitive way.

Examples of English language names, according to ISO 3166-1[1], are given below.

EXAMPLE 1“English” is the ISO 3166-1 name for all types of English.

EXAMPLE 2“German” is the name in English of the language spoken in Germany and surrounding countries.

- **LanguageNameInSelf**

name of the language in which the identifying descriptive attribute is expressed in the form in which the language is known in itself

EXAMPLE 1“Deutsch” is the name by which the German language is known to German language speakers. EXAMPLE 2 “Norsk nynorsk” is the name of a particular form of the Norwegian language.

EXAMPLE 3“British English” is the name of the form of the English language which is characterized by the spelling and intonation used within the British Isles and certain other parts of the world.

- **Comments**

optional list of comments for the language used

- **UniqueID**

globally unique identifier for the language

- **xtdLanguageRepresentation**

xtdLanguageRepresentation is a representation of the language used to specify a name, a description, a value or a reference.

EXPRESS specification:

*)

ENTITY xtdLanguageRepresentation

ABSTRACT SUPERTYPE OF (ONEOF(xtdName, xtdDescription));

LanguageName : xtdLanguage;

UniqueID : xtdGlobalUniqueID; END_ENTITY;

(*

Attribute definitions:

- **LanguageName**

name of the language used for the xtdLanguageRepresentation

- **UniqueID**

globally unique identifier for the language representation

- **xtdMeasureWithUnit**

xtdMeasureWithUnit is a specialization of xtdObject that makes an xtdProperty measurable by associating a unit to a value.

EXAMPLE 1 “1m” is an instance of xtdMeasureWithUnit with a unit component “m” and a value component “1”. EXAMPLE 2 “AB88” is an instance of xtdMeasureWithUnit with a value component “AB88” and no unit component.

EXPRESS specification:

*)

ENTITY xtdMeasureWithUnit SUBTYPE OF(xtdObject);

UnitComponent : OPTIONAL xtdUnit;

ValueDomain : OPTIONAL LIST [1:?] OF xtdValue; END_ENTITY;

(*

Attribute definitions:

- **UnitComponent**

unit in which the value is expressed

- **ValueDomain**

value domain for the measure for the given unit

- **xtdNam**

xtdName is a language-dependent name given to an object. An object may have several names in the same language and names do not need to be unique for a single object.

EXAMPLE 1 “beam” and “truss” are both English names for the same object.

EXAMPLE 2 “bjelke” is the Norwegian name for the English “beam”.

EXPRESS specification:

*)

ENTITY xtdName

SUBTYPE OF(xtdLanguageRepresentation); Name : xtdLabel;

INVERSE

is_name_of : SET [1:?] OF xtdRoot FOR Names; END_ENTITY;

(*

Attribute definition:

- **Name**

label holding the name of the object

- **xtdNest**

xtdNest is a specialization of xtdCollection that only allows things of the same type to be members of the collection.

EXAMPLE “Window properties” is an xtdNest whose members are only instances of xtdProperty.

EXPRESS specification:

*)

ENTITY xtdNest

SUBTYPE OF(xtdCollection); WHERE

WR1 : SIZEOF(QUERY(Result <* SELF\xtdRelCollects.RelatedThings | NOT(TYPEOF(SELF\xtdRelCollects.RelatingCollection) = TYPEOF(Result)))) = 0 ;

END_ENTITY;

(*

Formal Propositions:

WR1 The type of the Collection shall always be the same as the type of each thing, i.e. the Collection and all things that are members of it are of the same type.

- **xtdObject**

xtdObject is a specialization of xtdRoot that is the abstract entity from which xtdProperty, xtdMeasureWithUnit, xtdActor, xtdUnit, xtdSubject, xtdValue and xtdActivity are derived.

EXPRESS specification:

*)

ENTITY xtdObject

ABSTRACT SUPERTYPE OF (ONEOF(xtdSubject, xtdActivity, xtdUnit, xtdProperty, xtdMeasureWithUnit, xtdActor, xtdValue))

SUBTYPE OF(xtdRoot); END_ENTITY;

(*

- **xtdProperty**

xtdProperty is a specialization of xtdObject that is used to qualify or quantify an xtdObject.

EXAMPLE 1 “Width” is an xtdProperty.

EXAMPLE 2 “Door width” is an xtdProperty used to qualify the “Width” of the xtdSubject “door”. EXAMPLE 3 “Heat transfer” is an xtdProperty.

EXAMPLE 4 “Colour” is an xtdProperty. EXAMPLE 5 “Duration” is an xtdProperty. EXAMPLE 6 “Comfort” is an xtdProperty.

- **xtdNest**

xtdNest is a specialization of xtdCollection that only allows things of the same type to be members of the collection.

EXAMPLE “Window properties” is an xtdNest whose members are only instances of xtdProperty.

EXPRESS specification:

*)

ENTITY xtdNest

SUBTYPE OF(xtdCollection); WHERE

WR1 : SIZEOF(QUERY(Result <* SELF\xtdRelCollects.RelatedThings | NOT(TYPEOF(SELF\xtdRelCollects.RelatingCollection) = TYPEOF(Result)))) = 0 ;

END_ENTITY;

(*

Formal Propositions:

WR1 The type of the Collection shall always be the same as the type of each thing, i.e. the Collection and all things that are members of it are of the same type.

- **xtdObject**

xtdObject is a specialization of xtdRoot that is the abstract entity from which xtdProperty, xtdMeasureWithUnit, xtdActor, xtdUnit, xtdSubject, xtdValue and xtdActivity are derived.

EXPRESS specification:

*)

ENTITY xtdObject

ABSTRACT SUPERTYPE OF (ONEOF(xtdSubject, xtdActivity, xtdUnit, xtdProperty, xtdMeasureWithUnit, xtdActor, xtdValue))

SUBTYPE OF(xtdRoot); END_ENTITY;

(*

- **xtdProperty**

xtdProperty is a specialization of xtdObject that is used to qualify or quantify an xtdObject.

EXAMPLE 1 “Width” is an xtdProperty.

EXAMPLE 2 “Door width” is an xtdProperty used to qualify the “Width” of the xtdSubject “door”. EXAMPLE 3 “Heat transfer” is an xtdProperty.

EXAMPLE 4 “Colour” is an xtdProperty. EXAMPLE 5 “Duration” is an xtdProperty. EXAMPLE 6 “Comfort” is an xtdProperty.

EXPRESS specification:

*)

ENTITY xtdProperty SUBTYPE OF(xtdObject);

END_ENTITY;

(*

- **xtdRelActsUpon**

xtdRelActsUpon is a specialization of xtdRelAssociates representing one xtdObject acting upon one or more other xtdObjects.

EXAMPLE 1 "A column supports a beam". EXAMPLE 2 "A bricklayer lays bricks".

EXPRESS specification:

*)

ENTITY xtdRelActsUpon

SUBTYPE OF(xtdRelAssociates); WHERE

WR1 : SIZEOF(QUERY(Result <* RelatedObjects | RelatingObject:= Result)) = 0;

END_ENTITY;

(*

Formal Propositions:

WR1 The instance to which the attribute relating object points shall not be contained in the set of related objects.

- **xtdRelAssignsCollections**

xtdRelAssignsCollections is a specialization of xtdRelationship that represents the assignment of one or more instances of xtdCollection to an xtdObject.

EXPRESS specification:

*)

ENTITY xtdRelAssignsCollections SUBTYPE OF(xtdRelationship);

RelatingObject : xtdObject; RelatedCollections : SET [1:?] OF xtdCollection;

END_ENTITY;

(*

Attribute definitions:

- **RelatingObject**

object to which the collections are assigned

- **RelatedCollections**

set of collections that is assigned to an object

- **xtdRelAssignsMeasures**

xtdRelAssignsMeasures is a specialization of xtdRelationship that represents the assignment of one or more instances of xtdMeasureWithUnit to an xtdProperty.

EXPRESS specification:

*)

ENTITY xtdRelAssignsMeasures SUBTYPE OF(xtdRelationship);

RelatingProperty : xtdProperty;

RelatedMeasures : SET [1:?] OF xtdMeasureWithUnit; MethodOfInterpretation
: OPTIONAL xtdName;

END_ENTITY;

(*

Attribute definitions:

- **RelatingProperty**

property to which the measures with unit are assigned

- **RelatedMeasures**

set of measures with unit that is assigned to a property

- **MethodOfInterpretation**

optional explanation for the value component of a measure with unit

EXAMPLE “Upper bound” is the method of interpretation for a measure with unit representing the upper bound of a bounded value.

- **xtdRelAssignsProperties**

xtdRelAssignsProperties is a specialization of xtdRelationship that represents the assignment of one or more instances of xtdProperty to an xtdObject.

EXAMPLE “door height” is an xtdProperty assigned to the xtdObject “door”.

EXPRESS specification:

*)

ENTITY xtdRelAssignsProperties SUBTYPE OF(xtdRelationship);

RelatedProperties : SET [1:?] OF xtdProperty; RelatingObject : xtdObject;

END_ENTITY;

(*

Attribute definitions:

- **RelatedProperties**

set of properties that is assigned to an object

- **RelatingObject**

object to which the properties are assigned

- **xtdRelAssignsPropertyWithValues**

xtdRelAssignsPropertyWithValues is a specialization of xtdRelationship that is a ternary relationship representing the assignment of one or more related values from a complete set of values of a related property on to a relating object.

EXPRESS specification:

*)

ENTITY xtdRelAssignsPropertyWithValues SUBTYPE OF(xtdRelationship);

RelatedProperty : xtdProperty;

RelatingObject : xtdObject;

RelatedValues : LIST [1:?] OF UNIQUE xtdValue; END_ENTITY;

(*

Attribute definitions:

- **RelatedProperty**

property that contains the complete list of values in which RelatedValues is selected

- **RelatingObject**

object to which the list of values is assigned

- **RelatedValues**

list of values selected from the complete set of values of the related property

- **xtdRelAssignsUnits**

xtdRelAssignsUnits is a specialization of xtdRelationship that represents the assignment of one or more instances of xtdUnit to an xtdMeasureWithUnit.

EXPRESS specification:

*)

ENTITY xtdRelAssignsUnits SUBTYPE OF(xtdRelationship);

RelatingMeasure : xtdMeasureWithUnit;

RelatedUnits : SET [1:?] OF xtdUnit; END_ENTITY;

(*

Attribute definitions:

- **RelatingMeasure**

measure to which the units are assigned

- **RelatedUnits**

set of units that is assigned to a measure

- **xtdRelAssignsValues**

xtdRelAssignsValues is a specialization of xtdRelationship that represents the assignment of one or more instances of xtdValue to an xtdMeasureWithUnit.

EXPRESS specification:

*)

```

ENTITY xtdRelAssignsValues SUBTYPE OF(xtdRelationship);
RelatingMeasure    : xtdMeasureWithUnit;
RelatedValues      : LIST [1:?] OF UNIQUE xtdValue; END_ENTITY;
(*)

```

Attribute definitions:

- **RelatingMeasure**

measure to which the values are assigned

- **RelatedValues**

list of values that is assigned to a measure

- **xtdRelAssociates**

xtdRelAssociates is a specialization of xtdRelationship that represents the association of a relating xtdObject to a set of related instances of xtdObject.

EXPRESS specification:

*)

```

ENTITY xtdRelAssociates

```

```

SUPERTYPE OF (ONEOF(xtdRelComposes, xtdRelGroups, xtdRelSpecializes,
xtdRelActsUpon))

```

```

SUBTYPE OF(xtdRelationship); RelatingObject    : xtdObject;

```

```

RelatedObjects      : SET [1:?] OF xtdObject; WHERE

```

```

WR1 : SIZEOF(QUERY(Result <* RelatedObjects | RelatingObject:= Result)) =
0;

```

```

END_ENTITY;

```

(*

Attribute definitions:

- **RelatingObject**

object that is the target of the relationship

- **RelatedObjects**

set of objects that is associated with a target object

Formal Propositions:

WR1 The instance to which the attribute relating object points shall not be contained in the set of related objects.

- **xtdRelCollects**

xtdRelCollects is a specialization of xtdRelationship that represents the collecting of arbitrary entities into an xtdCollection. xtdCollection is instantiated as either an xtdNest or an xtdBag.

EXPRESS specification:

*)

ENTITY xtdRelCollects

SUBTYPE OF(xtdRelationship);

RelatedThings : SET [1:?] OF xtdRoot;

RelatingCollection : xtdCollection; END_ENTITY;

(*

Attribute definitions:

- **RelatedThings**

set of things making up a collection

- **RelatingCollection**

collection of things where each instance in the collection is an object or relationship

- **xtdRelComposes**

xtdRelComposes is a specialization of xtdRelAssociates that represents an xtdObject as being composed of other instances of xtdObject. The composition relationship can be applied recursively so that a composed xtdObject can be a part of another composed xtdObject.

EXAMPLE A “door frame” and a “door leaf” are parts of the (whole) “door set”.

EXPRESS specification:

*)

ENTITY xtdRelComposes

SUBTYPE OF(xtdRelAssociates); WHERE

WR1 : SIZEOF(QUERY(Result <* SELF.RelatedObjects |
NOT(TYPEOF(SELF.RelatingObject) = TYPEOF(Result)))) = 0 ;

WR2 : SIZEOF(QUERY(Result2 <* RelatedObjects | RelatingObject:= Result2))
= 0;

END_ENTITY;

(*

Formal Propositions:

WR1 The type of the relating object shall always be the same as the type of each related object, i.e. instances of xtdSubject are composed only of other instances of xtdSubject.

WR2 The instance to which the attribute relating object points shall not be contained in the list of related objects.

- **xtdRelDocuments**

xtdRelDocuments is a specialization of xtdRelationship that handles the documentation of objects by relating objects to the documents where they are described. Each document can relate to many objects.

EXPRESS specification:

*)

ENTITY xtdRelDocuments

SUBTYPE OF(xtdRelationship);

RelatedObjects : SET [1:?] OF xtdObject;

RelatingDocument : xtdExternalDocument; END_ENTITY;

(*

Attribute definitions:

- **RelatedObjects**

set of objects that are described in the external document

- **RelatingDocument**

external document describing the related objects

- **xtdRelGroups**

xtdRelGroups is a specialization of xtdRelAssociates that represents the grouping of a set of related instances of xtdObject into a relating xtdObject.

EXPRESS specification:

*)

ENTITY xtdRelGroups

SUBTYPE OF(xtdRelAssociates); WHERE

WR1 : SIZEOF(QUERY(Result <* RelatedObjects | RelatingObject:=: Result)) = 0;

END_ENTITY;

(*

Formal Propositions:

WR1 The instance to which the attribute relating object points shall not be contained in the List of related objects.

- **xtdRelSequences**

xtdRelSequences is a specialization of xtdRelationship that represents the sequencing between two instances of xtdActivity. The relating xtdActivity precedes the related xtdActivity in a sequence.

EXPRESS specification:

*)

ENTITY xtdRelSequences

SUBTYPE OF(xtdRelationship);

RelatingActivity : OPTIONAL xtdActivity;

RelatedActivity : OPTIONAL xtdActivity; WHERE

WR1 : RelatedActivity:<>: RelatingActivity;

WR2 : EXISTS(RelatingActivity) OR EXISTS(RelatedActivity); END_ENTITY;

(*

Attribute definitions:

- **RelatingActivity**

reference to the preceding activity in a sequence

- **RelatedActivity**

reference to the succeeding activity in a sequence

Formal Propositions:

WR1 The relating activity shall not point to the same instance as the related activity.

WR2 Either the relating activity or the related activity must be asserted.

- **xtdRelSpecializes**

xtdRelSpecializes is a specialization of xtdRelAssociates that represents the specialization of a supertype into one or more subtypes, ensuring that a subtype is more constrained than the supertype.

EXAMPLE 1 “outer door” is a specialization of “door”. EXAMPLE 2 “space” is the generalization of “room”.

EXPRESS specification:

*)

ENTITY xtdRelSpecializes SUBTYPE OF(xtdRelAssociates);

WHERE

WR1 : SIZEOF(QUERY(Result <* RelatedObjects | RelatingObject:=: Result)) = 0;

WR2 : SIZEOF(QUERY(Result <* SELF.RelatedObjects | NOT(TYPEOF(SELF.RelatingObject) = TYPEOF(Result)))) = 0 ;

END_ENTITY;

(*

Formal Propositions:

WR1 The instance to which the attribute relating object points shall not be contained in the list of related objects.

WR2 The type of the relating object shall always be the same as the type of each related object, i.e. an instance of `xtdSubject` can only be a specialization of another instance of `xtdSubject`.

- **xtdRelationship**

`xtdRelationship` is a specialization of `xtdRoot`. It is an abstract entity that represents the objectification of relationships, allowing for additional attributes to be added to the entity.

EXPRESS specification:

*)

ENTITY `xtdRelationship`

ABSTRACT SUPERTYPE OF (ONEOF(`xtdRelAssociates`,
`xtdRelAssignsProperties`, `xtdRelAssignsMeasures`, `xtdRelCollects`,
`xtdRelAssignsCollections`, `xtdRelSequences`, `xtdRelDocuments`,
`xtdRelAssignsUnits`, `xtdRelAssignsValues`, `xtdRelAssignsPropertyWithValues`))

SUBTYPE OF(`xtdRoot`);

`ViewSelector` : OPTIONAL `xtdName`; END_ENTITY;

(*

Attribute definition:

ViewSelector

optional attribute used to qualify the relationship for the purpose of creating different views of the data

EXAMPLE The `ViewSelector` “IFC 2x2” can be used to identify a relationship originating from the IFC 2x2 model.

- **xtdRoot**

`xtdRoot` is the abstract entity through which basic services of identifying, naming, versioning, description and referencing can be applied to instances of subtypes of `xtdObject`, `xtdRelationship` and `xtdCollection`.

EXPRESS specification:

*)

ENTITY `xtdRoot`

ABSTRACT SUPERTYPE OF (ONEOF(`xtdObject`, `xtdRelationship`,

```

xtdCollection));
VersionDate : OPTIONAL xtdDate;
VersionID   : OPTIONAL xtdVersionID;
UniqueID    : xtdGlobalUniqueID;
Descriptions : OPTIONAL SET [1:?] OF xtdDescription;
Names       : SET [1:?] OF xtdName; END_ENTITY;
(*)

```

Attribute definitions:

- **VersionDate**

date of the last revision of the reference data object

- **VersionID**

version number for the reference data version of the object

- **UniqueID**

global unique identifier for the object

- **Descriptions**

optional set of language-dependent descriptions of the object

- **Names**

set of language-dependent names of the object

- **xtdSubject**

xtdSubject is a specialization of xtdObject that is subject to description by associated properties and activities. An xtdSubject can be physical or logical.

EXAMPLE 1 “Roof” is an xtdSubject. EXAMPLE 2 “Lobby” is an xtdSubject.
EXAMPLE 3 “Control system” is an xtdSubject. EXAMPLE 4 “Road” is an xtdSubject.

EXAMPLE 5 “Airport” is an xtdSubject. EXAMPLE 6 “Software” is an xtdSubject.

EXPRESS specification:

*)

```
ENTITY xtdSubject SUBTYPE OF(xtdObject);
```

END_ENTITY;

(*

- **xtdUnit**

xtdUnit is a specialization of xtdObject that represents a scale that enables a value to be measured.

EXAMPLE 1 “metre” is an xtdUnit which can be represented by the symbol “m”.

EXAMPLE 2 “W/m.K” is an xtdUnit used with the property “thermal conductivity”.

EXPRESS specification:

*)

ENTITY xtdUnit

SUBTYPE OF(xtdObject); END_ENTITY;

(*

- **xtdValue**

xtdValue is a specialization of xtdLanguageRepresentation that can hold the description of a value of an xtdProperty.

EXAMPLE “Vertikaal schuivend” is the Dutch value for “Vertical sliding”.

EXPRESS specification:

*)

ENTITY xtdValue

SUBTYPE OF(xtdObject);

LowerTolerance : OPTIONAL xtdText;

NominalValue : OPTIONAL xtdText;

UpperTolerance : OPTIONAL xtdText;

ValueType : OPTIONAL xtdValueTypeEnum;

ValueRole : OPTIONAL xtdValueRoleEnum;

ToleranceType : OPTIONAL xtdToleranceTypeEnum; END_ENTITY;

(*

Attribute definitions:

- **LowerTolerance**

optional lower tolerance for the value

- **NominalValue**

optional text string holding the nominal value

- **UpperTolerance**

optional upper tolerance for the value

- **ValueType**

optional select type to define the type of value

- **ValueRole**

optional select type for the role of the value

- **ToleranceType**

optional select type to define the type of tolerance for the value

*) END_SCHEMA;

- **EXPRESS long form specification**

This formal specification is provided in the EXPRESS language.

SCHEMA ISO_12006_3_VERSION_3;

TYPE xtdDate = STRING; END_TYPE

TYPE xtdGlobalUniqueID = STRING; END_TYPE;

TYPE xtdLabel = STRING; END_TYPE;

TYPE xtdText = STRING; END_TYPE;

TYPE xtdToleranceTypeEnum = ENUMERATION OF (REALVALUE,
PERCENTAGE);

END_TYPE;

TYPE xtdValueRoleEnum = ENUMERATION OF (NOMINAL,
MAXIMUM, MINIMUM);

END_TYPE;

TYPE xtdValueTypeEnum = ENUMERATION OF (XTDSTRING,
XTDNUMBER, XTDINTEGER, XTDREAL, XTDBOOLEAN, XTDLOGICAL);
END_TYPE;

TYPE xtdVersionID = STRING; END_TYPE;

ENTITY xtdActivity SUBTYPE OF(xtdObject);

```

END_ENTITY;

ENTITY xtdActor
SUBTYPE OF(xtdObject); END_ENTITY;

ENTITY xtdBag
SUBTYPE OF(xtdCollection); END_ENTITY;

ENTITY xtdCollection
ABSTRACT SUPERTYPE OF (ONEOF(xtdNest, xtdBag))
SUBTYPE OF(xtdRoot); END_ENTITY;

ENTITY xtdDescription
SUBTYPE OF(xtdLanguageRepresentation); Description : xtdText;
INVERSE
is_description_of : SET [1:?] OF xtdRoot FOR Descriptions; END_ENTITY;

ENTITY xtdExternalDocument; UniqueID : xtdGlobalUniqueID;
Names : SET [1:?] OF xtdName; END_ENTITY;

ENTITY xtdLanguage; LanguageNameInEnglish : xtdLabel;
LanguageNameInSelf : OPTIONAL xtdLabel;
Comments : OPTIONAL LIST [1:?] OF xtdText;
UniqueID : xtdGlobalUniqueID; END_ENTITY;

ENTITY xtdLanguageRepresentation
ABSTRACT SUPERTYPE OF (ONEOF(xtdName, xtdDescription));
LanguageName : xtdLanguage;
UniqueID : xtdGlobalUniqueID; END_ENTITY;

ENTITY xtdMeasureWithUnit SUBTYPE OF(xtdObject);
UnitComponent : OPTIONAL xtdUnit;
ValueDomain : OPTIONAL LIST [1:?] OF xtdValue; END_ENTITY;

ENTITY xtdName
SUBTYPE OF(xtdLanguageRepresentation); Name : xtdLabel;
INVERSE
is_name_of : SET [1:?] OF xtdRoot FOR Names; END_ENTITY;

ENTITY xtdNest

```

```

SUBTYPE OF(xtdCollection); WHERE
WR1 :      SIZEOF(QUERY(Result < *
      SELF\xtdRelCollects.RelatedThings |
NOT(TYPEOF(SELF\xtdRelCollects.RelatingCollection) = TYPEOF(Result)))) =
0 ;

END_ENTITY;

ENTITY xtdObject

ABSTRACT SUPERTYPE OF (ONEOF(xtdSubject, xtdActivity, xtdUnit,
xtdProperty, xtdMeasureWithUnit, xtdActor, xtdValue))

SUBTYPE OF(xtdRoot); END_ENTITY;

ENTITY xtdProperty SUBTYPE OF(xtdObject);

END_ENTITY;

ENTITY xtdRelActsUpon

SUBTYPE OF(xtdRelAssociates); WHERE
WR1 : SIZEOF(QUERY(Result < * RelatedObjects | RelatingObject:= Result)) =
0;

END_ENTITY;

ENTITY xtdRelAssignsCollections SUBTYPE OF(xtdRelationship);
RelatingObject      : xtdObject; RelatedCollections : SET [1:?] OF xtdCollection;
END_ENTITY;

ENTITY xtdRelAssignsMeasures SUBTYPE OF(xtdRelationship);
RelatingProperty    : xtdProperty;
RelatedMeasures     : SET [1:?] OF xtdMeasureWithUnit; MethodOfInterpretation
: OPTIONAL xtdName;
END_ENTITY;

ENTITY xtdRelAssignsProperties SUBTYPE OF(xtdRelationship);
RelatedProperties : SET [1:?] OF xtdProperty; RelatingObject      : xtdObject;
END_ENTITY;

ENTITY xtdRelAssignsPropertyWithValues SUBTYPE OF(xtdRelationship);
RelatedProperty : xtdProperty; RelatingObject : xtdObject;
RelatedValues    : LIST [1:?] OF UNIQUE xtdValue; END_ENTITY;

```

```

ENTITY xtdRelAssignsUnits SUBTYPE OF(xtdRelationship);
RelatingMeasure : xtdMeasureWithUnit; RelatedUnits    : SET [1:?] OF xtdUnit;
END_ENTITY;

ENTITY xtdRelAssignsValues SUBTYPE OF(xtdRelationship);
RelatingMeasure : xtdMeasureWithUnit; RelatedValues   : LIST  [1:?] OF
UNIQUE xtdValue;
END_ENTITY;

ENTITY xtdRelAssociates
SUPERTYPE      OF  (ONEOF(xtdRelComposes,      xtdRelGroups,
        xtdRelSpecializes, xtdRelActsUpon))
SUBTYPE OF(xtdRelationship); RelatingObject : xtdObject; RelatedObjects : SET
[1:?] OF xtdObject;
WHERE
WR1 : SIZEOF(QUERY(Result <* RelatedObjects | RelatingObject:=: Result)) =
0;
END_ENTITY;

ENTITY xtdRelationship
ABSTRACT      SUPERTYPE      OF      (ONEOF(xtdRelAssociates,
xtdRelAssignsProperties,      xtdRelAssignsMeasures,      xtdRelCollects,
xtdRelAssignsCollections,      xtdRelSequences,      xtdRelDocuments,
xtdRelAssignsUnits, xtdRelAssignsValues, xtdRelAssignsPropertyWithValues))
SUBTYPE OF(xtdRoot);
ViewSelector : OPTIONAL xtdName; END_ENTITY;

ENTITY xtdRelCollects
SUBTYPE OF(xtdRelationship);
RelatedThings    : SET [1:?] OF xtdRoot; RelatingCollection : xtdCollection;
END_ENTITY;

ENTITY xtdRelComposes
SUBTYPE OF(xtdRelAssociates); WHERE
WR1 :      SIZEOF(QUERY(Result <*      SELF.RelatedObjects      |
NOT(TYPEOF(SELF.RelatingObject) = TYPEOF(Result)))) = 0 ;
WR2 : SIZEOF(QUERY(Result2 <* RelatedObjects | RelatingObject:=: Result2)) =

```



```

0;

END_ENTITY;

ENTITY xtdRelDocuments
SUBTYPE OF(xtdRelationship);

RelatedObjects    : SET [1:?] OF xtdObject; RelatingDocument :
xtdExternalDocument;

END_ENTITY

ENTITY xtdRelGroups
SUBTYPE OF(xtdRelAssociates); WHERE
WR1 : SIZEOF(QUERY(Result < * RelatedObjects | RelatingObject := Result)) =
0;

END_ENTITY;

ENTITY xtdRelSequences
SUBTYPE OF(xtdRelationship); RelatingActivity : OPTIONAL xtdActivity;
RelatedActivity : OPTIONAL xtdActivity;

WHERE
WR1 : RelatedActivity < > RelatingActivity;
WR2 : EXISTS(RelatingActivity) OR EXISTS(RelatedActivity); END_ENTITY;

ENTITY xtdRelSpecializes SUBTYPE OF(xtdRelAssociates); WHERE
WR1 : SIZEOF(QUERY(Result < * RelatedObjects | RelatingObject := Result)) =
0;

WR2 : SIZEOF(QUERY(Result < * SELF.RelatedObjects |
NOT(TYPEOF(SELF.RelatingObject) = TYPEOF(Result)))) = 0 ; END_ENTITY;

ENTITY xtdRoot
ABSTRACT SUPERTYPE OF (ONEOF(xtdObject, xtdRelationship,
xtdCollection)); VersionDate : OPTIONAL xtdDate;

VersionID : OPTIONAL xtdVersionID; UniqueID : xtdGlobalUniqueID;

Descriptions : OPTIONAL SET [1:?] OF xtdDescription; Names : SET [1:?] OF
xtdName;

END_ENTITY

ENTITY xtdSubject SUBTYPE OF(xtdObject);

```

```

END_ENTITY;

ENTITY xtdUnit

SUBTYPE OF(xtdObject); END_ENTITY;

ENTITY xtdValue

SUBTYPE OF(xtdObject); LowerTolerance : OPTIONAL xtdText;

NominalValue      : OPTIONAL xtdText; UpperTolerance : OPTIONAL xtdText;
ValueType  : OPTIONAL xtdValueTypeEnum; ValueRole:      OPTIONAL
xtdValueRoleEnum;

ToleranceType : OPTIONAL xtdToleranceTypeEnum; END_ENTITY;

END_SCHEMA;

```

Amirhossein Javaherikhah

Doctor of Engineering

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Linkdin: Amirhossein Javaherikhah

ResearchGate: Amirhossein Javaherikhah

Birthday:19/06/1994

OBJECTIVE

Professional Experience in Building Management and Space Exploration With extensive experience in building management, I have implemented innovative techniques, including blockchain technology, to manage buildings remotely. I have also contributed to a Mars simulation project, developing strategies to protect buildings and ensure the safety of astronauts against potential hazards such as radiation exposure and extreme temperatures. My research is critical to advancing our understanding of constructing and managing structures on Mars, demonstrating my commitment to finding creative solutions to the challenges of space exploration.

WORK EXPERIENCE

Construction consulting, Municipality, Razan Iran 2017 - 2020

Responsibilities:

- Supervision of infrastructure projects
- Reviewing and writing reports for construction projects

Education, High school, Razan Iran 2016 - 2019

Responsibilities:

- Teaching private lessons

Site Manager, Kosha Karan Arzhan Company, Karaj Iran 2014 - 2015

Responsibilities:

- Writing a daily report
- Write the required materials
- Checking the safety of the site
- Supervision of construction drawings

EDUCATION

Doctor of Philosophy (PhD) of Technological Innovation in Building, Polytechnic University of Madrid, Spain 2020 - 2024
Thesis Research: Presentation Of Blockchain-Based Inspection Framework for Managing Building Information Modelling (BIM) On

Mars Building.

2017 - 2019

Master Degree of Construction Management, Islamic Azad University, Iran

Thesis Research: Factors Influencing the Safety Enhancement and Cost Reduction in the Construction Site Layout

2014 - 2016

Bachelor Degree of Civil Engineering, Hoshmand Sazeh University of Applied Sciences, Iran

Thesis Research: Bolt-on prefabricated buildings

2012 - 2014

Associate Degree of Municipal Engineering, Shahrdari University Tehran Applied Science, Iran

ADDITIONAL SKILLS

Microsoft Office package: Microsoft Word, Excel, PowerPoint
Statistical operation: SPSS, Fuzzy Delphi, AHP, ANP, MCDM
Programming: AutoCAD, Etabs, MSP, BMS, Python

HONOR

Second place in the conference 3rd Building and Management International Conference (BIMIC) Nov 2021

ORGANIZATIONS

Member of elite association abroad
Member of the American Society of Engineers (ASCE)
Member of the Engineering System Organization (IRAN)
Member of Project Management Institute (PMI)

PUBLICATIONS

- **Diagnosing and evaluating the health and safety of workers at the workshop using the phase and AHP information systems**
It will be submitted to the journal in 2024.
- **BIM and blockchain, a reliable solution to control the information management of Mars buildings**
It will be submitted to the journal in 2024.
- **Investigating and ranking the factors affecting the destruction of human life on Mars**
It will be submitted to the journal in 2024.
- **Identifying and prioritizing success factors affecting portfolio management of construction projects**
It will be submitted to the journal in 2024.
- **Investigating the delay factors caused by the performance of the contractor, employer and consultant in construction projects with the Delphi ANP approach**
It will be submitted to the journal in 2024
- **Effective Factors for Implementing Bim Using Fuzzy Method to Manage Buildings On Mars**

PUBLICATIONS

Submitted to MDPI Building Journal · Nov 16, 2023

- **Developing an Inspector-Centric Blockchain-Enabled Conceptual Framework for BIM Management in Mars Buildings**

Submitted to MDPI Building Journal · Nov 13, 2023

- **Determining the Essential Criteria for Choosing Appropriate Methods for Maintenance and Repair of Iraqi Healthcare Building Facilities**

Submitted to MDPI Building Journal · Jun 24, 2023

- **Construction in Space: Mission to Mars**

It will be submitted to the Conferences 2024

- **Exploring The Geographical, Structural Materials, And Construction Techniques On Mars**

Submitted to the 5th Building and Management International Conference (BIMIC) · Nov 22, 2023

- **Exploring Mars Data: A Path to Human Habitation**

Submitted to the 5th Building and Management International Conference (BIMIC) · Nov 22, 2023

- **Construction on Mars**

Submitted to the 5th International Congress on Engineering, Technology & Innovation · Oct 7, 2023

- **Building Information Modeling for Precast Concrete Components in Development Nations**

Submitted to the APEGA Congreso Internacional · Sep 30, 2023

- **A Review of the Application of Prefabricated Structures Using Building Information Modeling**

Submitted to the 8th International Conference on Technological Innovation in Building · Mar 24, 2023

- **An Overview of the Impact of Renewable Energy in The Architecture of Zero Energy Buildings**

Submitted to the 8th International Conference on Technological Innovation in Building · Mar 24, 2023

- **The Role of Blockchain Technology in the Future of Construction**

Submitted to Springer Nature Book Switzerland AG Journal · Feb 23, 2023

- **3D Printers Impact on the Future of Construction**

Submitted to the 14th International Conference on Education and New learning Technologies · Jul 4, 2022

- **Technology and Nanotechnology in Smart Buildings**

Submitted to the 7th International Conference on Technological Innovation in Building · Mar 23, 2022

- **The Effect of Building Information Modeling on Project Planning, Control and Management**

Submitted to the 3rd Building and Management International Conference · Nov 24, 2021

- **Application of blockchain in BIM: a systematic review**
Submitted to the 3rd Building and Management International Conference · Nov 24, 2021
- **The Architecture Of Ideal Learning Environments**
Submitted to the 14th International Conference of Education, Research and Innovation · Nov 8, 2021
- **A Brief Review at Industrial Construction**
Submitted to the 1st International Itineral Poster Exhibition · May 11, 2022
- **A quick look at Building Information modeling**
Submitted to the 4th Conference of Construction & Project Management · Jan 25, 2018

CERTIFICATES

Career Essentials in Project Management

Institute: Microsoft

(BMS) Building Management System

Institute: QAL UK

AutoCAD & AutoCAD 2024 Essential Training

Institute: QAL UK & LinkedIn

(BIM) Building Information Modeling & BIM Coordinator

Institute: QAL UK & LinkedIn

Python Programming for Beginner & Python Essential Training

Institute: QAL UK & LinkedIn

Construction Management: Introduction to Lean Construction

Institute: Project Management Institute (PMI)

Project Management: Foundations and Initiation

University of Colorado Boulder

Astrobiology and the Search for Extraterrestrial Life

University of Edinburgh

Construction Project Management

Columbia University in the city of New York

University Teaching

University of Hong Kong

Pathway to Space

University of Colorado Boulder

Specialized Module on Cities and Climate Change

United Nations Institute for training and research

The search for water on Mars

The open University

Sustainable Neighborhoods

Johns Hopkins University

Construction Management: Technology on the Jobsite
LinkedIn Learning

Getting Started as a Project Coordinator
LinkedIn Learning

Courses

3D Printing Build Large Structures Printed in Concrete

Place of the course: Universidad Politécnica de Madrid

Academic Research Foundations

Place of the course: Universidad Politécnica de Madrid

Glocal classes and activities: 3d printing lab (upm-unit6. Drawing techniques (from hand drawing to computer programs... 3d printing)

Place of the course: Universidad Politécnica de Madrid

Earth as Construction Material in the 21st Century

Place of the course: Universidad Politécnica de Madrid

Rehabilitation in Europe. Renovation Wave and Next Generation UE

Place of the course: Universidad Politécnica de Madrid

Scientific information: research support resources

Place of the course: Universidad Politécnica de Madrid

Teaching English as a Foreign Language

TEFL Professional Institute

Writing Articles

LinkedIn Learning

Teaching with Technology

LinkedIn Learning

SPSS Statistics Essential Training

LinkedIn Learning

Securing the IoT: Introduction

LinkedIn Learning

Project Management: International Projects

Project Management institute

Getting Started with Python

LinkedIn Learning

Artificial Intelligence: How Project Managers Can Leverage AI

Project Management institute

Getting Started as a BIM Coordinator

LinkedIn Learning

I. Publications and scientific dissemination during the doctorate.

This doctoral study resulted in two pending papers in a relevant peer-reviewed journal and a conference paper presentation at a Spanish conference. The following sections contain the original manuscripts of the articles and conference certificates listed.

Scientific journal articles:

- Effective Factors for Implementing Bim Using Fuzzy Method to Manage Buildings On Mars
- Developing an Inspector-centric Blockchain-enabled Conceptual Framework for BIM Management in Mars Buildings

Conference paper:

- Application of blockchain in BIM: a systematic review
- The Role of Blockchain Technology in the Future of Construction
- A Review of the Application of Prefabricated Structures Using Building Information Modeling
- An Overview of the Impact of Renewable Energy in The Architecture of Zero Energy Buildings
- 3D Printers Impact on the Future of Construction
- A Brief Review of Industrial Construction
- Technology and Nanotechnology in Smart Buildings
- The Effect of Building Information Modeling on Project Planning, Control and Management
- The Architecture of Ideal Learning Environments
- Exploring The Geographical, Structural Materials, And Construction Techniques On Mars
- Exploring Mars Data: A Path to Human Habitation
- Construction on Mars
- Building Information Modeling for Precast Concrete Components in Developed Nations

The appendix includes the publication certificates for the two stated articles and the presentation certificates for eight conference presentations.

Published articles.

Journal: MDPI (Building)

Article name: Effective Factors for Implementing Bim Using Fuzzy Method to Manage Buildings On Mars

Authors: Amirhossein Javaherikhah, Mercedes Valiente López

Address: UPM Higher Technical School of Building, D090 of Building Technology, Av. Juan de Herrera, 6, 28040 Madrid, Spain.

doi: [//doi.org/10.3390/buildings13122991](https://doi.org/10.3390/buildings13122991)

Accepted: 16/11/2023

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Figure I.1: Article Certificate



EFFECTIVE FACTORS FOR IMPLEMENTING BIM USING FUZZY METHOD TO MANAGE BUILDINGS ON MARS

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Abstract: Ever since mankind has known the world around him and space, he has been trying to find a suitable alternative for his current residence, the earth. Many attempts have been made to identify Mars as the next human settlement. In this research, two main criteria for Mars buildings and their information management were extracted by checking the library of studies on Mars. These two main criteria are the components of the building and the internal components of the building. The criteria for building components include walls, roofs, meteor protection, installations, and windows (air exchange), and internal building components include air temperature, air pressure, ambient oxygen, ambient carbon dioxide, humidity, and light. These criteria were given to the experts, and after the opinions of the experts using the fuzzy Delphi method, the criteria of the wall, roof, facilities, air exchange, ambient temperature, and oxygen level were given to the experts in the form of a paired questionnaire. The results of the experts' paired questionnaire were analysed using the fuzzy AHP method, and the criteria of walls, roofs, and air exchange were given the first priority; the criteria of ambient temperature and oxygen level were given the second priority; and the criteria of the facilities were given the last priority. As a suggestion, it can be stated to the researchers that these priorities should be implemented on the blockchain platform so that the building information management system (BIM) works well in Mars buildings and is protected against any intrusion or damage.

Keywords: Mars; Earth; BIM; blockchain; expert analysis

1. Introduction

Mars is the fourth planet from the sun. Its diameter is only half the diameter of the earth. But the characteristics of the earth are many, and these characteristics lead us to believe that there is life on Mars. It is even possible that intelligent beings live on Mars. These ideas should be confirmed after unmanned space probes pass by Mars and send information to Earth. These space explorers revealed that Mars is a cold and dry planet that is more like the Moon than the Earth [1]. Large areas of the surface of Mars are covered with holes. The density of the Martian atmosphere is incredibly low, similar to that of the Earth's atmosphere at an altitude of 50 km above sea level. This atmosphere is mostly composed of carbon dioxide and a small amount of water [2]. Oxygen and nitrogen have not been found in it, although there is probably a small amount

of them. Because the air is so thin, ultraviolet radiation, which is dangerous to most living things, easily reaches the surface of Mars from space [3]. At one time, large parts of the surface of Mars were covered with water, and the polar caps are composed of frozen water. The samples taken by the explorers from the Martian soil returned after the water warmed up [4]. Among the planets, Mars has attracted the attention of scientists more than others. This has two main reasons.

- Among the planets that are far from the Sun, Mars is the closest to Earth. In its orbit, Mars sometimes comes relatively close to the Earth, is located at a distance of about 56 million kilometres from it, and is one of the brightest objects in our night sky. The colour of this planet is orange-red, and it can be seen easily with the naked eye. Mars is called the red planet.

- Mars and Earth are similar to each other in several ways. The duration of a Martian day is only about 40 minutes shorter than ours. Mars has an atmosphere. Like the earth, it has seasons and a cap of ice on its poles. At one time, many scientists believed that there might be a yard on this planet [5].

Since then, a number of unmanned space explorers have gone to Mars, and reports have sent many pictures back to Earth. These documents almost assure us that there is no life on this planet, but maybe the previous climate of Mars was more suitable for life. Unfortunately, the Martian atmosphere is not breathable for humans and consists of carbon dioxide and a small amount of water vapour. It should also be said that the atmosphere of Mars is very thin, and the average atmospheric pressure there is only about one hundredth of the pressure on Earth [6].

These features of Mars and its unique topography and landforms have sparked intense interest in Mars exploration and the possibility of future Martian migration. In the future, the Mars exploration missions of various countries around the world will continue to advance with the aim of further investigating the external environmental conditions and internal structure of Mars and laying the foundation for the further realisation of the human mission to Mars [7]. Therefore, Mars buildings are extremely important for building information management. Because these researchers are at the beginning of their journey. Therefore, building information management in these buildings will be different. Building Information Modeling (BIM) is a set of policies, processes, and interacting technologies that produce a method for managing basic building design and project data throughout the life cycle of a building [8]. Blockchain is a public, digital, decentralised document of data, assets, and all related transactions that is executed and shared among network participants. Although most associated with digital cryptocurrencies such as Bitcoin, blockchain is considered an emerging technology that

could transform the current digital operational landscape and business practises of finance, computing, government services, and virtually every industry in existence [9].

Therefore, in this research, by examining the environmental conditions on the surface of Mars, we are trying to present and identify the factors that must be observed in Martian buildings for the continuation of life. Therefore, the management of these factors requires an impenetrable and secure system, for which blockchain is considered an emerging and reliable technology. But to what extent these factors should be controlled and which factors can be dangerous for humans need further investigation. In this research, with a library approach, we are trying to find studies that have been done for the continuation of life and also construction on the surface of Mars, and we have extracted the main and vital criteria with the help of experts and ranked these factors for the convenience of future researchers. We recommend that they read this article to learn about blockchain-based frameworks for building information management on the surface of Mars.

2. History

The very similarity of Mars to Earth is the main reason for researchers' curiosity about reaching more definitive results about the existence of life on this planet. In the middle of the 17th century, the observation of ice fragments was one of the first discoveries of similarities between Mars and Earth. In the 18th century, a person named William Herschel mentioned in a report the change in the volume of ice due to the changes in the atmosphere of each hemisphere of the planet in the summer and winter seasons [10]. By the middle of the 18th century, astronomers were talking with complete confidence about the similarities between Earth and Mars, such as the length of the day on Mars being almost the same as on Earth. They also knew that the similarity of the axial angle of Mars with the Earth suggests a variety of seasons, just like on Earth but twice as long. These observations led to an increase in the confidence factor about the existence of water

and land on this planet, as a result of which the possibility of living organisms increased significantly [11]. At the end of the 19th century, several theories about life on Mars were presented through telescope observations. In 1854, William Whewell from Cambridge University officially proposed the hypothesis that there is land, sea, and most likely life on Mars. In 1895, an American astronomer named Percival Lowell published a book called "Mars" about this planet and the water channels observed in it, stating that these channels indicate the existence of a very ancient civilization on Mars. This opinion prompted the English writer H. G. Wells to write the book "The War of the Worlds" in 1897 in connection with the unknown and strange creatures living on Mars, who were forced to leave it and turn it into a book. In 1965, clearer and more detailed images taken by the Mariner 4 spacecraft showed Mars without any rivers, seas, or signs of life. Investigations carried out in the Viking projects to photograph and test the presence of microbes on Mars also remained inconclusive [12]. Finally, in 1990, during a project called "Mars Global Surveyor", it was proven that Mars, unlike Earth, does not have a magnetic field, and therefore radiation is able to reach the surface of this planet. In addition, scientists emphasised that the absence of a magnetic field caused the solar winds to destroy most of the air on Mars over billions of years [13]. In recent years, following the studies conducted on the celestial rock ALH84001 and the discovery of fossilised microbes in it, various discussions about the existence of life on Mars have again been discussed and caused disagreements in the scientific community [14].

2.1. Atmosphere

The oxygen in the atmosphere of Mars is very low compared to that of Earth. This gas constitutes only 0.13% of the total atmosphere of Mars, while 21% of our Earth's atmosphere consists of oxygen. Carbon dioxide comprises 95.3% of the atmosphere of this planet. Other gases include nitrogen at 2.7%, argon at 1.6%, carbon monoxide at 0.7%, and water vapour at 0.3% [15].

2.2. Clouds

In the Martian atmosphere, clouds made of frozen carbon dioxide particles form at high altitudes. In addition, the formation of clouds and fog with water ice particles is very common. The foggiest time is in the early morning. At that time, the air is at its coldest, and as a result, the water vapour becomes dense [16].

2.3. Wind

Mars' atmosphere, like Earth's, has a general cycle and wind pattern that sweep across the planet. On Mars, the concentration and evaporation of carbon dioxide gas at the poles have a significant impact on the overall cycle. With the onset of winter, the carbon dioxide in the atmosphere is concentrated at the two poles. As a result, more carbon dioxide flows towards the poles to fill the void left by this gas. When spring arrives, the frozen carbon dioxide evaporates, and as a result, this gas flows in a direction away from the poles. The winds that blow on the surface of Mars are mostly calm and have a speed of about 10 kilometres per hour [17].

2.4. Dust Storm

One of the most obvious effects of the weather on Mars is the blowing of winds accompanied by dust. Small tornadoes can lift soil from the surface of the planet for a short period of time. These small winds are similar to terrestrial tornadoes. Severe dust storms start when the wind carries dust up into the atmosphere. At this time, the air around the soil particles is heated due to the absorption of sunlight. When warm air rises, the wind becomes stronger and carries more dust with it. As a result, the storm gets stronger. On a more severe scale, the dust storm can cover an area of more than 320 km or even several thousand km. Larger storms can cover the entire surface of the planet. Such storms are uncommon but can last for months. The strongest storms can make the entire surface of the planet invisible [18]. Such storms blew once in 1971 and again in 2001. Sandstorms occur mostly when the distance of Mars from the sun is small. The reason for this is that

during those times, the sun heats the atmosphere more [19].

2.5. Mass and density

The mass of Mars is equal to 42.6×10^{20} tones; this number can be written as 642 with 18 zeros in front of it. The mass of Earth is about 10 times that of Mars. Mars has a density of 3.933 grammes per cubic centimetre, which is around 70% of the density of Earth [20, 21].

2.6. Force of gravity

Because Mars is significantly smaller and less heavy than Earth, its gravity is much weaker, accounting for only 38% of Earth's. As a result, if a person stands on the surface of Mars, he will believe he has lost 62% of his body weight. Likewise, if a rock is dropped on Mars, it will reach the surface of the planet much slower than on Earth [22].

2.7. shell

The average thickness of the crust of Mars is about 50 km. Since the altitudes are higher in the southern hemisphere, it can be said that the thickness of the crust in the northern hemisphere is less. Most of the crust is probably composed of volcanic rocks called basalt. In addition to Mars, basalt is also found on the surface of the Earth and the Moon. Some other rocks on the surface of Mars, especially in the northern hemisphere, are called andesite. Andesite is also a type of volcanic rock that is found on Earth. The amount of silica in this stone is higher than in basalt. Silica is a combination of silicon and oxygen [23].

2.8. Plains

Many areas of Mars are plains. Most of these areas are located in the northern hemisphere. In the northern parts of the northern hemisphere, the flattest and smoothest regions of the solar system are located. The smoothness of these areas is most likely due to the sediments that created them. There are many reasons why water once flowed on the surface of Mars. The presence of water has

caused the formation and accumulation of sediments [24].

2.9. the valleys

Along the equator, there is a striking symbol on this planet. A large collection of valleys called Martian valleys. The Mariner 9 spacecraft discovered this phenomenon on the surface of Mars in 1971. The valley stretches from east to west, and its length is about 4,000 km, which is the width of Australia or the distance between Philadelphia and San Diego. Scientists believe that this system was created due to the cracking of a part of the crust. The unique valleys in the Martian valleys have a width of 100 km. The valleys connect to each other in the central part, which is 600 km wide. The depth of the valleys reaches 8 to 10 km in some places [25].

2.10. Volcanoes

Mars has the largest volcanic mountains in the solar system. The tallest of them, Olympus, has a height of 27 km and a diameter of 600 km and is surrounded by flat plains. The other three big volcanoes on Mars are Arsia, Askreus, and Paonis, and they are located in a high area called Tharsis. All these volcanoes, like the volcanoes of Hawaii, have a slope that gradually increases. Mars also has many other types of volcanoes. From small conical hills to plains covered with frozen molten material. Scientists do not know when the last volcanic eruption occurred on Mars, but minor eruptions may still occur on the planet [26].

2.11. Pits and impact areas

Many celestial rocks that have collided with Mars throughout its history have created holes in the surface of this planet. These impact pits are very rare in the ground for two reasons: 1) The pits that have been created before have been lost due to erosion. 2) The Earth's dense atmosphere prevents rocks from colliding and forming holes as a result. The holes on the surface of Mars are very similar to the holes on the moon, Mercury, and other objects in the solar system. The pits are deep and bowl-shaped.

Larger craters can have central peaks that are formed by post-impact crustal rebound. On Mars, the number of craters varies greatly from place to place. The surface of Mars in the southern hemisphere is very old and therefore has many craters. Other places, especially in the Northern Hemisphere, are younger and have fewer craters. Some volcanic mountains also have craters, and this indicates that not much time has passed since their eruption. The molten material of volcanoes can cover all existing holes. So, not much time has passed since the last eruptions, because otherwise the number of craters on volcanic mountains would be higher [27].

2.12. Polar sediments

The most interesting phenomena in the polar regions of Mars are thick masses of sedimentary material. These layers are formed by a combination of water, ice, and soil particles. These sediments have extended up to 80 degrees from each pole. The atmosphere has led to the deposition of layers over a long period of time. These layers are documents of the activities and seasonal changes of the weather over very long periods of time. One of the possibilities for climate change on Mars is the change in the longitudinal axis of this planet. These changes lead to a change in the amount of sunlight reaching different parts of the planet and, as a result, general changes in the weather on Mars. The amount of sediment that the atmosphere creates is directly related to past changes in climate. On top of the sedimentary layers in both hemispheres, there are water ice caps that remain in the form of ice throughout the year. These layers and the cap on them are several kilometres thick [28]. In the winter, seasonal caps that are formed from frozen layers also appear. These caps are well visible with telescopes on the ground. Seasonal caps consist of frozen carbon dioxide or dry ice, which is formed from carbon dioxide in the atmosphere. In the coldest days of winter, these layers extend up to 45 degrees towards the equator [28].

2.13. Formation of rock on Mars

Viking landers landed on Mars in 1976. They photographed a dry surface with large boulders located among gravel, sand, and mud. These were basalt stones. Some contained small holes from which gas was apparently released. On Earth, such basalts originate from volcanic lava filled with foamy gas. The rocks of Mars also probably had such a source. The soil of Mars is similar to the hardened soil of Earth's deserts [29].

2.14. The cause of red Mars

This entire planet is a vast desert. There is no water flowing on its surface, nor is there any water in its atmosphere. The colour photos show a completely dry and barren landscape covered with scattered rocks. The red colour of this planet is due to the rocks that have iron oxide (iron rust). Some of these stones are also found in the ground. Only the surface of Mars has this colour because the Viking ships excavated it and showed that there are dark-coloured rocks under the red dust. Due to the presence of red dust, even the sky of Mars can be seen in this colour. Sometimes big dust storms appear, and almost every ten years, a huge tornado occurs that engulfs the entire planet [30].

3. Buildings of Mars

3.1. Steel

Steel is almost the ideal building material and basic structural element for finding military equipment on Earth, with a history of thousands of years of technological development. Using steel has a very low learning curve. On earth, steel is one of the most important construction materials from an economic point of view. In 2005, the world produced 1.1 billion tonnes of steel. (This significantly exceeds aluminium production, about 30 million metric tonnes.) It is used for everything from car engines to bulldozers and skyscrapers. Steel will also be a significant material for space construction. For example, Stoker et al. proposed refining metallic iron from Martian iron oxides by first concentrating the iron oxides with acidic leeches, followed by hydrogen reduction [31].

On Earth, iron and steel are extracted from oxide sources ("iron ore"), usually hematite (Fe_2O_3) or magnetite (Fe_3O_4). On Earth, minerals are concentrated by geological processes that usually involve water and sometimes bacteria (e.g., banded iron formations). Ores are usually reduced from oxide to metal by carbothermal reduction.

3.2. Iron ore on Mars

Iron ore also exists on Mars. The MER-B (Opportunity) rover, which landed in the planum site meridian, found abundant hematite in the form of small (4–6 mm) spherules or "concretes", [32] informally known as "cranberries". Is known" (Fig. 1). These contain approximately 50% by weight of hematite [33]. Similar to Earth's rock deposits, Martian ores were concentrated and produced early in Mars' history by aqueous diagenesis. If a site on Earth as large as the landing site was rich in hematite, it would be considered an iron mine. It is an easily accessible mineral. Hematite clasts both exist in the soil, where they can be easily collected. And it is embedded in soft sedimentary rock that can be easily mined.

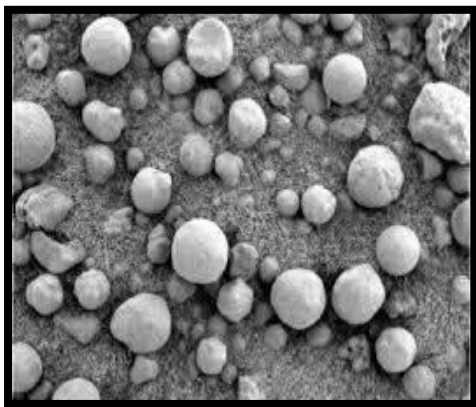


Figure 1. Iron ore on Mars The hematite plumes found at the Meridiani landing site of the MER-B "Opportunity" mission contain approximately 50% hematite by weight [34].

3.3. Meteorites on the surface of Mars

On Mars, while the atmosphere is thick enough to reduce small- to intermediate-mass meteorites enough to survive an impact, the carbon dioxide atmosphere and the

absence of liquid water allow nickel-iron meteorites to avoid oxidation, and iron remains in the reduced state for long periods, potentially for millions of years [34].

3.4. Iron-nickel as a resource on Mars

The discovery of reduced iron and nickel, an element present on the surface of Mars, will change the way we think about the issue of internal resources for construction. The ability to produce iron without energy-intensive processes and reduction means that producing steel on Mars would be much easier and significantly less energy-intensive than producing steel on Earth. They have almost perfect recirculation [34].

3.5. Steel processing technology

The production of steel, rather than simple iron, requires the addition of carbon in controlled amounts. There are various means of reducing carbon dioxide to elemental carbon. One simple technology proposed for other applications is to use the sabatier reaction of carbon dioxide with hydrogen to form water and methane, followed by the pyrolysis of methane to produce elemental carbon and hydrogen. The water produced in the Sabatier process can be electrolyzed to regenerate the original hydrogen reactant. There are also solutions for processing siderophile and carbonyl elements. So far, we have found that, based on observations, the structural characteristics of Earth and Mars are relatively similar [34]. Mars colonization is a rapidly growing area of study and interest. NASA is preparing to launch the 2020 Mars rover [35], as part of a larger push to establish a human presence on the Red Planet, while SpaceX expects to begin manned missions in 2024 [36]. Construction of safe and durable structures using locally produced materials is one of the fundamental needs of a Martian community [37]. Concrete, in example, has been constantly advocated as an important structural material, with a wide range of formulations and procedures presented [38]. A comparative assessment of several choices and an analysis of their compatibility to the particular circumstances of the Martian environment are required for

the successful use of concrete on the Red Planet.

3.6. Binders

In its most basic form, "concrete" is defined as a mixture of a binder and an aggregate (filler). Most binders necessitate the addition of water to the concrete formulation (ES is an exception). Additionally, though not necessarily essential, additives or admixtures may be added to affect the qualities of the concrete. On Earth, the use of OPC as a binder is so common that it is simply referred to as "cement." A binder, on the other hand, is any ingredient that causes the components of a mixture to cohere [17].

and alternative binders to OPC may be appropriate for Martian concrete. An important point is that various methods have been presented for making concrete on Mars, all of which have been tested in laboratory conditions. All these methods have been implemented using a 3D printer in laboratory conditions. All buildings on Mars are designed and built using 3D printers, which is proof that the buildings on Mars and Earth are different.

Therefore, different materials and tests must be done to finally reach a final model. But the point that should be noted is that all the structures must be constantly checked [39]. The research [40] shows the first manned mission to Mars. In this mission, in the first phase, robots and devices will be deployed on Mars to build structures, and in the second phase, these devices and robots will be used as a practical base to advance the goals of human habitation.

They are on Mars, and they start working. In this research, suggestions for the concrete used in Mars buildings using a 3D printer have been presented. Also, other equipment to be used on Mars for the continuation of human life, including the facilities required for structures, how to enter and exit, air conditioning, how to lay cables, how to use water, etc., have been stated, and finally, other methods The proposed methods have been compared. An important point in these articles is the use of a 3D printer for

designing structures. Also, the type of utility structure is of special importance. The research project [41].

shows how performance-based design tools can be implemented as an architectural design method that proposes an innovative approach to designing housing shells in extreme environmental conditions without human assistance. This research study attempts to use the environmental data disclosed by NASA and its habitat design requirements to develop a conceptual design for an innovative habitat form and then simulate it under Martian conditions to determine the structural behaviour of the habitat shell according to finite element analysis. As a result of these analyses, two established typologies of proposed habitation forms are presented in terms of their structural performance under the extreme loads of the Martian environment.

Internal radiation analysis is important to assess the cross-sectional thickness of the habitable crust and the amount of thickness needed to provide maximum radiation protection. Wind is also a major concern on Mars. In fact, the thickness of the housing shell section should be designed in such a way as to prevent the exchange of air inside and outside the housing, and this should be controlled with regard to ventilation. Also, this thickness should be such that it is resistant to the wind. Also, the location of windows and their resistance to settlement is something that should be taken into consideration. It is stated in the research [42].

that Mars provides plenty of the raw materials needed to establish a lasting, self-sufficient human colony on its surface. Due to the planet's vast distance from Earth, it is neither possible nor economically reasonable to provide a permanent, interplanetary supply. In-situ resource utilisation (ISRU) will be necessary to keep the Earth launch burden and mission costs as low as possible and to provide, apart from propellant and life support, a variety of construction materials. However, including outposts on other planets in the scope of human spaceflight also opens

up new psychological and sociological challenges. Crews will live in extreme environments under isolated and confined conditions for much longer periods of time than ever before. Therefore, the design of a Mars habitat requires careful consideration of the physiological as well as psychosocial conditions of living in space.

In this research, it is suggested to use bags of Martian rock that are not usable for shielding against the impact of meteorites. In fact, it can be said that according to the atmosphere of Mars, there is a possibility of meteorites hitting Mars, but according to the atmosphere prevailing on Mars, these meteorites do not have large dimensions [43]. According to the contents stated in this section, in fact, the criteria that can be extracted from these articles are criteria such as checking the walls, roofs, meteor protection, facilities required for the building, installing windows, and the amount of air exchange. Due to the Martian winds, it is in a suitable location.

4. Life on Mars

Every human being has basic needs to continue living. To some extent, these needs exist on earth in a God-given form. These needs, such as thirst and breathing, are easily available to humans due to the earth's atmosphere, and access to climate for breathing is easier than anything else. Even the earth, due to the ozone layer, has protected humans from the ultraviolet rays of the sun, which are very harmful and dangerous for humans. But in order to continue living on Mars, humans must appreciate these basic needs and not try to maintain them. Because Mars does not provide these facilities easily to humans.

The extraction of water from Mars and its frozen waters at the poles of Mars is itself an issue that is still at the centre of discussion among scientists in this field. The atmosphere of Mars does not absorb ultraviolet rays like the atmosphere of the Earth, and the atmosphere of Mars does not easily provide oxygen to humans. The fact that one day humans will migrate from Earth

to Mars is shrouded in uncertainty. But research to investigate the conditions and create living conditions on Mars can help mankind know more about this planet and also hope to have a new habitat.

Humans' irrational actions at the beginning of the industrial revolution, which is still ongoing, have faced the danger of destroying the earth. Of course, it is still too early to use the term destruction of the earth, and this may not happen for hundreds of years. But finally, one should search and do research about the replacement of the land so that, with the emergence of emergency conditions for the land, one can easily migrate to the new destination. Many studies and solutions have been done for the way of life and the shape and structure of Mars buildings, but a final and reliable model has not been reached yet. But the important point is that the air temperature, air pressure, ambient oxygen, ambient carbon dioxide, ambient humidity, and ambient light should be measured [44].

In general, we have two types of data that were extracted from the articles: The first type is about the components of the building that provide living conditions. Table 1 shows these variables.

Table 1. extracts variables.

walls	Building components
The roofs	
Meteor protector	
Facilities required for the building	
Window (Air Changes)	
air pressure	The indoor environment of the building
the air temperature	
Ambient oxygen	
Ambient carbon dioxide	
Ambient humidity	
amount of light	

5. Fuzzy Delphi

There was a temple in the ancient city of Delphi attributed to Apollo, the god of the sun, music, and poetry; it was named the

forerunner of Delphi. The Pythia was widely credited for his prophecies, inspired by Apollo, and was consulted before any important decision was made. Now, the ancient city of Delphi has been transformed into a modern city and still remains. Pythian oracles have also been replaced by a modern approach known as the Delphic technique. For the first time in the late 1950s, in research by the US RAND Corporation, Delphi was introduced to scientifically study the opinions of experts on the military defence project (Powell et al., 2004). The main goal of the Delphi method is to obtain the most reliable consensus of opinion from a group of experts through a set of intensive questionnaires with controlled feedback. Researchers can identify and prioritise problems and develop a framework for their diagnosis by obtaining the consensus of a group of experts using this process. Lynnstone and Turoff (1975) defined the Delphi technique as a method of structuring a group communication process so that this process is effective in allowing a group of people, as a whole, to deal with a complex problem. This definition has been adopted by several researchers. Hasson et al. (2000) argued that there are different types of Delphi techniques. Modified Delphi, policy Delphi, and real-time Delphi have been used. In general, three types of Delphi are used: traditional Delphi, policy Delphi, and decision Delphi. Using a series of questionnaires to collect data from a panel of selected participants, the Delphi technique is used as a tool and method for building consensus. Several studies have been conducted using the fuzzy Delphi technique. Kaufman and Gupta (1988) developed the fuzzy Delphi technique for forecasting. Ishikawa (1993) also developed the Delphi technique with triangular fuzzy numbers. The Delphi technique is a structured process for collecting data through successive rounds and finally reaching group consensus. Despite more than half a century of using the Delphi technique in scientific and academic research, there are still many uncertainties about this technique [45].

5.1. Fuzzy Delphi technique algorithm for screening

The Delphi technique with a fuzzy approach can be used to determine the importance of criteria and to screen key criteria. One of the major advantages of the fuzzy Delphi technique compared to the traditional Delphi technique for screening criteria is that it can be used remotely to summarise and sort items.

The fuzzy Delphi technique algorithm includes the following steps:

- Identifying a suitable spectrum for fuzzification of linguistic expressions
- Fuzzy accumulation of fuzzified values
- De-fuzzification
- Choice of threshold and screening criteria

In the fuzzy Delphi technique algorithm for screening, first a suitable fuzzy spectrum should be created to fuzz the linguistic expressions of the respondents. For this purpose, it is possible to use the methods of developing fuzzy spectra or common fuzzy spectra. For example, the triangular fuzzy spectrum for a five-point Likert scale on the importance of criteria is as follows:

Table 2. triangular fuzzy numbers with a five-point Likert scale.

Very important	Important	Medium	Unimportant	Very unimportant
(0.75,1,1)	(0.5,0.75,1)	(0.25,0.5,0.75)	(0,0.25,0.5)	(0,0,0.25)

In this research, this method of evaluating criteria is used.

After choosing or developing a suitable fuzzy spectrum, experts' opinions are collected and fuzzy. In the second stage, experts' opinions should be gathered. Several methods have been proposed for the fuzzy aggregation of experts' opinions. If an expert's opinion is represented as a triangular fuzzy number (l,

m, u), the simplest way to calculate the fuzzy average of experts' opinions is:

$$F_{AVE} = \frac{\sum l}{n}, \frac{\sum m}{n}, \frac{\sum u}{n}$$

After the fuzzy aggregation of experts' opinions, the values should be de-fuzzified. With the different methods that are used with the fuzzy approach, the researcher finally converts the final fuzzy values into a clear and understandable number. Typically, the sum of triangular and trapezoidal fuzzy numbers can be summarized by a clear value, which is the best mean. This operation is known as fuzzification. There are many and complex methods for fuzzification. One of the simplest fuzzification methods is average triangular fuzzy numbers:

$$\begin{aligned} F_{ave} &= (L, M, U) \\ x_m^1 &= \frac{L + M + U}{3} \\ x_m^2 &= \frac{L + 2M + U}{4} \\ x_m^3 &= \frac{L + 4M + U}{6} \\ \text{crisp number} &= Z^* = \max(x_{\max}^1, x_{\max}^2, x_{\max}^3) \end{aligned} \quad \begin{matrix} \\ \\ 2) \\ (\end{matrix}$$

The values do not vary much and are constantly close to M. M is the average obtained by summing the possible values of m from different triangular fuzzy numbers. However, the clear value is considered the maximum.

After choosing the appropriate method and unfuzzifying the values for screening, a threshold should be calculated. This threshold is usually 0.7, but it varies according to the opinion of the researcher in different studies. If the clear value of the unfuzzification of the collected expert opinions is greater than the threshold, the criterion is met. If the criterion is less than the threshold, it is removed.

6. Fuzzy AHP

Necessity of the fuzzy hierarchical analysis process: The AHP method has been widely used in choosing one option among other options, but in this method, pairwise comparisons are made for each level according to the purpose of choosing the best option using a nine-point scale. Therefore, the application of hourly AHP has some shortcomings, such as the fact that the AHP method (1) is mainly used for crisp decisions. (2) It examines a very unbalanced scale of judgement; (3) the uncertainties in individual judgements are not considered; and (4) the ranking of this method is almost imprecise. (5) Subjective judgements, choices, and performances of decision-makers have a lot of effects on AHP results. In addition, it is acceptable that people's evaluations of quality indicators are always subjective and therefore imprecise. Therefore, conventional and classical AHP seem to be insufficient and inefficient in accurately achieving the needs of decision-makers. In order to model this type of uncertainty in human preferences, fuzzy set theory should be combined with pairwise comparisons as an extension of the AHP technique. This hybrid decision-making technique provides a more detailed understanding of the decision-making process.

AHP is a multi-criteria decision-making tool that can construct complex problems hierarchically, thereby simplifying the evaluation of all criteria relevant to the decision to be made (Saaty, 1980). All options are compared separately based on each criterion using a preference scale, and a priority list of options is obtained for each criterion. The most commonly used preference scale is the 1–9 scale. Fuzzy AHP enables the decision analyst to provide a more realistic score for alternatives in cases where there are many uncertainties. Chang's (1992) development analysis model is one of them that depends on the probability of each criterion.

Triangular fuzzy numbers (l, m, and u) are used to create a pairwise comparison scale, and a pairwise comparison matrix is

constructed for each level in the hierarchy. Then, the subsets of each row in the matrix are calculated to have a new set. The overall triangular fuzzy values for the M_i criterion are obtained by calculation. Membership functions, which mean the average weight of the options in the corresponding matrix, are calculated using these values for each criterion. They are normalised, and the final importance weight of each criterion is obtained. To apply the process depending on this hierarchy, according to Chang's (1992) development analysis method, each criterion is considered, and for each criterion, the GI criterion is measured.

The fuzzy hierarchical process method is used for weighting and ranking criteria or research options. There are three methods for calculating the weights in the fuzzy AHP method: Chang's development analysis method, the improved fuzzy AHP method, and the Mykhailo fuzzy prioritisation method.

In this section, we explain the fuzzy AHP method based on Chang's development analysis approach.

Step 1: Forming a hierarchical research model

In this step, after identifying the criteria, sub-criteria, and research options, the hierarchical model of the research should be determined.

Step 2: Forming tables of paired comparisons and answering according to the following spectrum

In this step, as in the AHP method, pairwise comparisons should be created, and based on the following fuzzy spectrum, answer these paired comparisons. This 9-band spectrum is a fuzzy AHP; of course, you can use 5- or 7-band spectrums as well, but this 9-band spectrum is a standard spectrum.

Table 3. scale of fuzzy number.

Fuzzy number	Linguistic	Scale of fuzzy number
9	Perfect	(8,9,10)
8	Absolute	(7,8,9)
7	Very good	(6,7,8)
6	Fairly good	(5,6,7)
5	Good	(4,5,6)
4	Preferable	(3,4,5)
3	Not bad	(2,3,4)
2	Weak advantage	(1,2,3)
1	Equal	(1,1,1)

Step 3: Calculate the incompatibility rate of paired comparisons.

In this step, the inconsistency rate of pairwise comparisons should be checked, and if this rate is less than 0.1, it means that the pairwise comparison has proper stability and consistency. The inconsistency rate in fuzzy matrices can be calculated in two ways. First, the fuzzy pairwise comparison matrix is defuzzified, and then its inconsistency rate is calculated definitively, or it can be calculated using the Goss and Butcher inconsistency rate calculation method. Goose and Butcher's incompatibility rate is available on this site, which you can learn for free by searching.

Step 4: Integration of paired comparisons

When multiple respondents answered the pairwise comparisons, the geometric mean method was used to combine them. to obtain a merged pairwise comparison matrix. The integration of fuzzy matrices is such that the geometric mean of the first terms of all comparisons, the second terms, and the third terms are taken together.

Step 5: Calculation of weights by Chang's development analysis method

First, based on the following relationship, we obtain S_i values for each row of the fuzzy pairwise comparison matrix.

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j \right]^{-1}$$

where g_i is the objective set and are triangular fuzzy numbers. Then, based on the following relationship, we obtain the magnitude (degree of preference) of each S_i over S_k .

$$(4) \quad V(S_i > S_k) = \begin{cases} 1 & m_i \geq m_k \\ 0 & k_i \geq k_k \\ \frac{k_i - k_k}{(m_i - k_i) - (m_k - k_k)} & \text{otherwise} \end{cases}$$

In the last step, the raw weights are calculated using the following relationship, which is obtained by dividing each raw weight by the total raw weights, and the normal weight is obtained.

(5)

$$\begin{aligned} V(S \geq S_1, S_2, \dots, S_k) &= (V((S \geq S_1), (S \geq S_2), \dots, (S \geq S_k))) \\ &= \min(V((S \geq S_1), (S \geq S_2), \dots, (S \geq S_k))) \\ &= \min V(S \geq S_i) \quad i = 1, 2, \dots, k \end{aligned}$$

6.1. suggested method

After extracting the criteria shown in the table, these factors should be validated by experts, and with their opinions, it should be determined which of the variables are most needed in this research, which is achieved by using the fuzzy Delphi technique. be made Then these factors are ranked using fuzzy ranking, or fuzzy AHP, so that the level of warning can be determined based on them. After the implementation of this section, we will discuss the implementation of the proposed method based on blockchain and express the results.

7. Findings

In , which is written in two parts: fuzzy analysis and the results obtained from blockchain, the results obtained from the fuzzy analysis conducted on the results collected from the experts have been investigated. In this section, the fuzzy figures of each of the criteria against each other and the ranking based on the final weight obtained from the fuzzy AHP hierarchical analysis algorithm are presented. After this stage, the results of the integration of blockchain and BIM will be discussed.

7.1. suggested method

In this phase of the research, experts' opinions were collected about the evaluated criteria. In the process of implementing this stage, the questionnaire was provided to the experts, and the results obtained from this questionnaire are shown in Table 1.

Table 4. The results of the experts' answers.

Expe rt 4	Expe rt 3	Expe rt 2	Expe rt 1	Criteria	The main criteria
5	4	5	5	walls	Building components
5	5	4	5	The roofs	
2	1	2	1	Meteor protector	
				Facilities	
2	3	3	1	required for the building	
4	3	5	4	window	The indoor environment of the building
4	1	3	4	the air temperature	
1	1	2	1	air pressure	
5	1	4	5	Ambient oxygen	
1	1	1	1	Ambient carbon dioxide	
1	1	2	1	Ambient humidity	
1	1	1	1	amount of light	

After receiving the opinions of the experts, these opinions were analysed in fuzzy-delphi-analysis-v2-01 software, and the results are as follows: The obtained threshold was equal to 0.169, which included six criteria, and the rest of the criteria were excluded from the analysis. These criteria are shown in Table 2, along with their ranking and the points they obtained.

Table 5. Final
Criteria.

Rating	points	criteria
1	0/75	walls
2	0/683	The roofs
6	0/267	Facilities required for the building
3	0/6	Air exchange
5	0/417	environment temperature
4	0/567	Ambient oxygen

Of course, it should be mentioned that, according to some experts, criteria such as dealing with meteorites can be seen in the walls or roof, or they have no function in BIM and cannot be addressed in the BIM of a building. All the extracted criteria can be evaluated and are important in their own right, but due to the increase in the number of calculations, it is obvious that some of these criteria will be left out of the research cycle. Now, after extracting the criteria, they can be ranked, the results of which are given below.

Table 6. ranked of the results.

	Walls	The roofs	Facilities required for the building	Air exchange	Environment temperature	Ambient oxygen
walls	1	1.2	4.5	1.2	3.7	2.4
The roofs	*	1	3.7	0.5	2.9	2.4
Facilities required for the building	*	*	1	0.2	0.4	0.3
Air exchange	*	*	*	1	4.5	2.4
Environment temperature	*	*	*	*	1	0.5
Ambient oxygen	*	*	*	*	*	1

7.2. Ranking factors

In this section, the results and the results of the data collected from the questionnaires distributed to the experts will be discussed. In the first part, the data is reviewed, and then the other sections mentioned in the introduction are discussed. In this analysis, according to the method described in the previous part, four pairs of questionnaires

were distributed among the experts, which in this part are given to express the opinions of the experts involved in the research. In total, there are six main criteria that must be entered into BIM and stored on the blockchain for Mars buildings.

In this matrix, each number represents the share of superiority or non-superiority of the criterion according to experts in comparison with other criteria. For example, the coefficient (1.5), which is equal to 3.7, shows that according to the experts involved in the design, the criterion parameter of the wall is superior to the ambient temperature by a ratio of 3.7.

The obtained pair matrix should be examined from two perspectives:

- Inconsistency rate
- Being symmetrical

One of the features of this matrix is that the columns are symmetrical; that is, for example, the columns (1, 2) and (2, 1) are inversely proportional to each other, and each is equal to the inverse of the other. In this matrix, this criterion has been met in all regions, which will be approved from this point of view.

Regarding the inconsistency rate, it should be stated that a programme was written in MATLAB software to calculate this value, and it is connected to the main fuzzy analysis code of this research. If the condition of the inconsistency rate is not satisfied, the analyses related to that inconsistency matrix will not be carried out until this inconsistency is resolved. Regarding this matrix, it should be stated that the algorithm for calculating the inconsistency rate has shown a number of 0.225, which shows a rate much lower than 10%. So, for this reason and by observing the two stated conditions, we can be sure of the results obtained from this paired matrix.

It should be noted that there are two algorithms regarding the inconsistency rate in the fuzzy method: one is a common algorithm to calculate this rate, and the other

is to calculate the inconsistency rate of the fuzzy matrix obtained from the paired matrix. The important point is that if there is an inconsistency in the even matrix, there is no need to check the inconsistency rate with the fuzzy algorithm, and if in some cases the inconsistency rate exceeds 10%, this method will also be examined, and then a decision will be made to resolve this inconsistency.

7.3. Fuzzy distribution charts

In this section, the analysis results and fuzzy matrices are discussed. At the beginning, the image of each of the fuzzy number graphs presented for the fuzzy matrix has been presented, which can be seen for each variable.

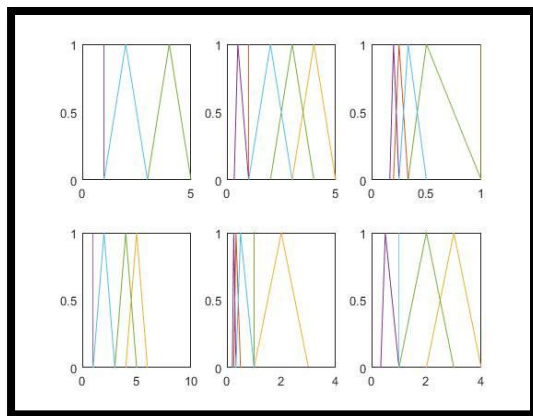


Figure 2. main variables as the fuzzy number diagram.

In the given figure, there are as many main variables as the fuzzy number diagram, each of which is related to the measurement of the variable compared to other variables in a fuzzy manner, which is produced by the fuzzification function in the provided program. These charts are also like paired matrices, and the degree of superiority can be determined from them. Graphs that have compact and low values correspond to inverse phase values, which indicate a low variable superiority ratio, and graphs that are open and have larger numbers indicate superiority over others. It can be seen that the first variable, which has the advantage over all, has a completely open and uncompressed graph.

7.4. Fuzzy final ranking

In this part, the final ranking of the criteria included in the research is evaluated, which is explained in detail below.

As it is clear in the figure, the first, second, and fourth criteria, which are the roof, wall, and air exchange, respectively, have the first rank and are of special importance from the experts' point of view. The fifth and sixth criteria are also in the next rank, which are the ambient temperature and the amount of oxygen in the environment. Finally, the last rank is assigned to the facilities, which have a lower degree of importance. Therefore, based on the opinions of our experts, we can now carry out our implementation.

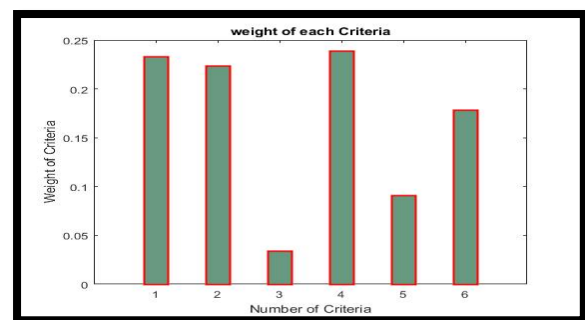


Figure 3. the final ranking of the criteria.

8. Conclusion

During human life on earth, man has caused the most damage to the environment and the earth, his residence. Therefore, some of these damages are irreparable, and the earth's ecosystem has undergone many changes. Therefore, some of these damages, such as ozone layer perforation, are irreparable. After people realised that they should be more concerned about their environment, they tried to compensate for the damages, but it was too late. After much research, the researchers came to the conclusion that they should choose a suitable alternative for the earth. According to its characteristics, Mars can be introduced as a substitute for Earth. Of course, considering current human technology, it seems that Mars is the only option. But Mars, in addition to its similarities with Earth, also has differences that affect human life on its surface. The atmosphere of Mars, the entry of ultraviolet rays, etc. are among these differences. In this research, two general criteria for building components and internal components of the building were extracted from a detailed study of Mars and library research. These criteria for building components include walls, roofs, meteor protection, facilities required for the

building, air exchange, and internal components. The building includes air temperature, air pressure, ambient oxygen, ambient carbon dioxide, ambient humidity, and light. Using the fuzzy Delphi method, the criteria of wall, roof, building facilities, air exchange, ambient temperature, and ambient oxygen were extracted as the final criteria and provided to the experts in the form of a paired questionnaire. The results of the experts' paired questionnaire were analysed using the fuzzy AHP method in MATLAB software, which showed that the criteria of roof, wall, and air exchange have high priority. The next priority included

ambient temperature and ambient oxygen level, and finally, the criteria for facilities were ranked last. Considering the fact that the buildings on Mars are of special importance and the slightest intrusion and failure in receiving information and processing it may put human lives in danger, it is suggested that the results of this article be implemented in the form of a blockchain framework. The reason for using blockchain is that this technology is emerging and has very high security. Therefore, information is fully protected, and less risk can threaten it and ultimately human life.

References

1. C. Li et al., "China's Mars exploration mission and science investigation," *Space Science Reviews*, vol. 217, no. 4, p. 57, 2021.
2. W. Hartmann, D. Winterhalter, and J. Geiss, "Chronology and physical evolution of planet Mars," *The Solar System and Beyond—Ten Years of ISSI*, ISSI Bern SR-003, pp. 211-228, 2005.
3. R. J. Lillis et al., "Photochemical escape of oxygen from Mars: First results from MAVEN in situ data," *Journal of Geophysical Research: Space Physics*, vol. 122, no. 3, pp. 3815-3836, 2017.
4. M. Nazari-Sharabian, M. Aghababaei, M. Karakouzian, and M. Karami, "Water on Mars—a literature review," *Galaxies*, vol. 8, no. 2, p. 40, 2020.
5. D. S. Portree, *Humans to Mars: fifty years of mission planning, 1950-2000* (no. 20). National Aeronautics and Space Administration, 2001.
6. C. A. Barth, "The atmosphere of Mars," *Annual Review of Earth and Planetary Sciences*, vol. 2, no. 1, pp. 333-367, 1974.
7. J. Appelbaum and D. J. Flood, "Solar radiation on Mars," *Solar Energy*, vol. 45, no. 6, pp. 353-363, 1990.
8. M. Kim et al., "Development and testing of in situ materials for human exploration of Mars," *High Performance Polymers*, vol. 12, no. 1, pp. 13-26, 2000.
9. M. Nofer, P. Gomber, O. Hinz, and D. Schiereck, "Blockchain," *Business & Information Systems Engineering*, vol. 59, pp. 183-187, 2017.
10. H. Rickman et al., "Water in the History of Mars: An Assessment," *Planetary and Space Science*, vol. 166, pp. 70-89, 2019.
11. M. H. Carr and J. W. Head III, "Geologic history of Mars," *Earth and Planetary Science Letters*, vol. 294, no. 3-4, pp. 185-203, 2010.
12. M. H. Carr, "The Fluvial History of Mars," *Philosophical Transactions of the Royal Society A: Mathematical, Physical, and Engineering Sciences*, vol. 370, no. 1966, pp. 2193-2215, 2012.
13. A. L. Albee, R. E. Arvidson, F. Palluconi, and T. Thorpe, "Overview of the Mars global surveyor mission," *Journal of Geophysical Research: Planets*, vol. 106, no. E10, pp. 23291-23316, 2001.
14. D. S. McKay et al., "Search for past life on Mars: possible relic biogenic activity in Martian meteorite ALH84001," *Science*, vol. 273, no. 5277, pp. 924-930, 1996.
15. D. Banfield et al., "The atmosphere of Mars as observed by InSight," *Nature Geoscience*, vol. 13, no. 3, pp. 190-198, 2020.
16. M. Vincendon, C. Pilorget, B. Gondet, S. Murchie, and J. P. Bibring, "New near-IR observations of mesospheric CO₂ and H₂O clouds on Mars," *Journal of Geophysical Research: Planets*, vol. 116, no. E11, 2011.
17. B. R. White, "Soil transport by winds on Mars," *Journal of Geophysical Research: Solid Earth*, vol. 84, no. B9, pp. 4643-4651, 1979.
18. C. Leovy, R. Zurek, and J. Pollack, "Mechanisms for Mars Dust Storms," *Journal of Atmospheric Sciences*, vol. 30, no. 5, pp. 749-762, 1973.
19. H. Wang and M. I. Richardson, "The origin, evolution, and trajectory of large dust storms on Mars during Mars years 24-30 (1999-2011)," *Icarus*, vol. 251, pp. 112-127, 2015.
20. D. Jontof-Hutter, J. F. Rowe, J. J. Lissauer, D. C. Fabrycky, and E. B. Ford, "The mass of the Mars-sized exoplanet Kepler-138 b from transit timing," *Nature*, vol. 522, no. 7556, pp. 321-323, 2015.
21. M. T. Zuber et al., "Density of Mars' south polar layered deposits," *Science*, vol. 317, no. 5845, pp. 1718-1719, 2007.
22. D. Smith et al., "An improved gravity model for Mars: Goddard Mars model 1," *Journal of Geophysical Research: Planets*, vol. 98, no. E11, pp. 20871-20889, 1993.
23. G. Schubert, S. Soloman, D. Turcotte, M. Drake, and N. Sleep, "Origin and thermal evolution of Mars," 1990.

24. K. L. Tanaka, J. A. Skinner, and T. M. Hare, *Geologic Map of the Northern Plains of Mars* US Department of the Interior, US Geological Survey, 2005
25. M. C. W. Group, "Channels and Valleys on Mars," *Geological Society of America Bulletin*, vol. 94, no. 9, pp. 1035–1054, 1983.
26. M. H. Carr, "The volcanoes of Mars," *Scientific American*, vol. 234, no. 1, pp. 32–43, 1976.
27. R. P. Sharp, "Mars: South Polar Pits and Etched Terrain," *Journal of Geophysical Research*, vol. 78, no. 20, pp. 4222–4230, 1973.
28. P. Thomas, S. Squyres, K. Herkenhoff, A. Howard, and B. Murray, "Polar deposits of Mars," *Mars*, pp. 767–795, 1992.
29. P. R. Christensen, "The spatial distribution of rocks on Mars," *Icarus*, vol. 68, no. 2, pp. 217–238, 1986.
30. P. Cattermole, *Mars: The Story of the Red Planet* Springer Science & Business Media, 2012.
31. C. Stoker et al., "The physical and chemical properties and resource potential of Martian surface soils," *Resources of Near-Earth Space*, pp. 659–707, 1993.
32. S. Squyres et al., "The Opportunity Rover's Athena Science Investigation at Meridiani Planum, Mars," *Science*, vol. 306, no. 5702, pp. 1698–1703, 2004.
33. B. Jolliff and A. S. Team, "Composition of Meridiani hematite-rich spherules: A mass-balance mixing-model approach," in *36th Annual Lunar and Planetary Science Conference*, 2005, p. 2269.
34. G. A. Landis, "Meteoritic steel as a construction resource on Mars," *Acta Astronautica*, vol. 64, no. 2–3, pp. 183–187, 2009.
35. J. Mustard et al., "Report of the Mars 2020 science definition team," *Mars Explor. Progr. Anal. Gr.*, vol. 150, pp. 155–205, 2013.
36. E. Musk, "Making life multi-planetary," *New Space*, vol. 6, no. 1, pp. 2–11, 2018.
37. D. Barker, G. Chamitoff, and G. James, "Resource utilisation and site selection for a self-sufficient martian outpost," 1998.
38. M. J. Werkheiser, M. Fiske, J. Edmunson, and B. Khoshnevis, "On the development of additive construction technologies for application to the development of lunar and martian surface structures using in-situ materials," in *AIAA SPACE 2015 conference and exposition*, 2015, p. 4451.
39. Y. Reches, "Concrete on Mars: Options, Challenges, and Solutions for Binder-Based Construction on the Red Planet," *Cement and Concrete Composites*, vol. 104, p. 103349, 2019.
40. B. Kading and J. Straub, "Utilising in-situ resources and 3D printing structures for a manned Mars mission," *Acta Astronautica*, vol. 107, pp. 317–326, 2015.
41. G. Dede, "Performance-driven design methodology for habitation shell design in extreme conditions on Mars," *Frontiers of Architectural Research*, vol. 11, no. 2, pp. 224–238, 2022.
42. M. Arnhof, "Design of a human settlement on Mars using in-situ resources," 2016: 46th International Conference on Environmental Systems
43. M. Bodiford, M. Fiske, R. Pope, and W. McGregor, "In-situ resource-based lunar and martian habitat structures development at NASA/MSFC," in *1st space exploration conference: Continuing the voyage of discovery*, 2005, p. 2704.
44. N. K. Muthumanickam, K. Park, J. P. Duarte, S. Nazarian, A. Memari, and S. Bilén, "BIM for parametric problem formulation, optioneering, and 4D simulation of a 3D-printed martian habitat: A case study of the NASA 3D-printed habitat challenge," in *Proceedings of the 5th Residential Building Design and Construction Conference*, 2020, pp. 4–6.
45. N. A. M. Saffie and K. A. Rasmani, "Fuzzy Delphi Method: Issues and Challenges," in *2016 International Conference on Logistics, Informatics, and Service Sciences (LISS)*, 2016, pp. 1–7: IEEE.

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Figure I.2: Article Certificate



Developing an Inspector-centric Blockchain-enabled Conceptual Framework for BIM Management in Mars Buildings

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Abstract: Due to the unique atmospheric conditions on Mars, the management of essential information in Mars buildings is of great importance. Even the smallest error or manipulation of data can create irreparable risks for residents. Martian buildings require a strong security shield to ensure accurate and unaltered data processing. In this article, the factors affecting the buildings of Mars and the lives of the inhabitants of Mars were identified and analyzed, and seven key factors were identified. These factors were then integrated into Mars building information systems using blockchain technology, defining four distinct alert levels for specific building conditions. This research is based on the simulation of Martian buildings, and there has been no laboratory case to test the proposed method until now. The findings showed that the proposed framework for Martian buildings was better than similar studies based on Earth, and there was no similar case to compare the results in Martian buildings. The ground-breaking integration of blockchain and building information modeling (BIM) on Mars opens up new opportunities for extraterrestrial building control methods and marks the beginning of the evolution of this field, but given that there is still no construction in the field of buildings on Mars, organizations and bodies that work in this field can use the results of this research to check the compatibility of the proposed method with Martian buildings.

Keywords: Building information modeling (BIM); Blockchain Technology; Building of Mars; Building information Security; Building management.

1. Introduction

Mars, a planet inside the The fourth planet from the sun in our solar system. Due to Mars' identical rotation period and tilt of its rotation axis relative to the plane of the ecliptic, its days and seasons closely resemble those of Earth. These characteristics of Mars, as well as its distinctive geography and landforms, have sparked a lot of interest in Mars exploration and the possibility of future Martian migration. The Mars exploration missions of many nations will continue to advance in the future with the goal of gaining a deeper understanding of the planet's outward climatic conditions and interior structure and laying the groundwork for a future human journey to Mars [1]. Therefore, Mars' structures are crucial for developing information management and its administration. because these studies are only starting their journeys. Consequently, building information management in various structures will change. Building Information Modeling (BIM) is a combination of regulations, procedures, and interoperating

technology that generates a way for managing fundamental a building's design and project data throughout its life cycle [2].

It may give a single presentation, data frame, and structure. The architecture of construction automation allows information and communication technology (ICT) to manage the life cycle information of structures. During the lifespan of a building, the fundamental characteristics of BIM may be summed up in four aspects: integration with various databases, facilitation of document management, Analysis and simulation of sustainability, as well as visualization of analytical procedures and outcomes. The most recent application of ICT architecture for BIM is conventional client-server architecture, some of which is based on existing systems. [3].

The impact of BIM on the architectural, engineering, construction, owner, and operator (AECOO) business has shifted [4]. BIM information transmission varies based on the kind of model and time period used and

introduces risks for participating parties, such as issuer responsibility, information susceptibility to infiltration, and information abuse. Consequently, these risks cause a slew of contractual, legal, security, and system issues that stymie the growth and convenience of BIM adoption at the industry level. [5]. According to the usage of BIM in Mars buildings, there is a need to offer information security. Due to the high level of security provided by Blockchain, these two approaches may be integrated to ensure the security and correctness of BIM information in the building. Mars made sure. Blockchain is a distributed, digital, public record of data, assets, and all associated transactions that network members perform and share.

Although blockchain is most commonly associated with digital currencies such as Bitcoin, it is seen as an emerging technology with the potential to transform the digital working environment and business practices in virtually every industry. transform [6]. The primary idea behind Blockchain is to create a distributed digital agreement that ensures data is decentralized across several nodes exchanging similar information and that no user has complete control over the network. This improves activity transparency and data security. While Blockchain was initially designed only for financial transactions, with the goal of creating a system that allows secure data transfer between two parties without the need for an intermediary, the tremendous destructive potential of Blockchain has become clear in recent years with the exponential growth of various cryptocurrencies. [6].

Blockchain will restructure current workflow routes in any company where it is used, emphasising trust and collaboration between members, and will provide several advantages, including collaborative learning, immediate data interchange, automated contract execution, and more [7]. By defining BIM transactions and storing them on a private blockchain, Mars buildings may be managed using this research. In addition, four normal levels, one emergency level, two emergency levels, and three emergency levels have been developed in an effort to create a framework for building control inspections.

Following is a description of Mars' history. The integration of BIM and blockchain will then be evaluated based on previous studies. In the subsequent section of the used approach, the specified transactions and four inspector-focused levels are described. Then, the implementation's outcomes are described, followed by a concluding statement. By conducting studies and research in the field of blockchain and its integration with BIM, similar research and studies have not been done in the field of integration of these two technologies in Martian buildings, and in general, no research has been done in the field of information management in Martian buildings.

so, the following research question are addressed in this research:

How could the blockchain technology and BIM be integrated for improving the information management of buildings on Mars?

To answer this question, the following objectives were determined:

Enhancing BIM security to maintain information security

Using BIM for Mars buildings

Integration of BIM and Blockchain

The biggest gap in this research is that, due to the fact that construction has not yet started on Mars, it is possible that the security and accuracy of information have not been addressed, which has a special place in Martian buildings. Is. Investigating Mars building information and its management is of particular importance because this importance is emphasized more with regard to weather conditions. Therefore, blockchain technology has been used as a suitable tool to provide security. Also, various aspects of using blockchain and its integration with BIM have been evaluated in the context of the work.

2. Research literature

2.1. About The Planet "MARS"

The Soviet Union launched the first Mars probe, 1960A, in 1960, which failed but marked the beginning of human exploration of the Red Planet. The Mars missions from the 1960s to the

1990s were summarized by Ouyang et al. (2011). The United States (8 launches, 6 successes) and the Soviet Union (6 launches, 2 successes) dominated Mars exploration (15 launches, 1 success) during that time. Mariner 9, part of the National Aeronautics and Space Administration's (NASA) Marine program, successfully reached Mars orbit for the first time in 1971, collected the first high-resolution images from Mars satellites, and functioned on Mars. It's been in orbit for more than a year. Near the end of the twentieth century, the Mars Orbiter was one of the most successful Mars exploration missions in history, providing in-depth studies of the Martian atmosphere, temperature, geology, and soil and rock composition [1].

By concentrating on morphological, geochemical, and mineralogical properties, the Mars rover gathered a body of information about the Martian soil. Compared to Viking, this mission used a lander with multispectral imaging capability. The extremely mobile rover, which was capable of performing studies on soil mechanics, was also equipped to analyze the elemental chemistry of soil and rock [9]. Table 1 provides information about the various minerals that are present in the soil on Mars. It summarizes the mineral composition of the soil and helps to understand the geological and environmental conditions on the planet.

Table 1. Mars soil mineralogy. (Sartipi,F, et al. 2020)

	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	SO ₃	Cl	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃
Pathfinder	2.2	7.5	8.3	48.6	5.4	0.6	0.3	6.3	1.1	17.5
Viking soil	.	6.0	7.2	43.4	7.4	0.8	.	5.8	0.6	18.2

Despite all the research and available information, the viability of the presented theories will not be thoroughly evaluated in real-world situations until a construction robot equipped with additive manufacturing technology arrives on Mars. NASA's aim to establish a livable habitat on the moon prior to launching the Mars mission is a smart strategy for researching the structural behavior of housing in interplanetary environments. In terms of productivity, speed, and affordability, additive

manufacturing is the most durable building method.

2-2. Mars Building

Team Zopherus

Zopherus, built by a group of Arkansas residents (Figure 1), won NASA's 3D Printing Habitat Challenge. The "huts" are pieced together to form a close-knit society using a variety of materials from Mars. A 3D printer is used to complete the construction, removing the need for human engagement and assuring that the structure is ready for human habitation upon arrival. A robot-built lander selects a good area to reside in the city and then installs a group of robots, which finally begin and end the design process [9].

Ai SpaceFactory: Marsha

The Ai Space Factory set out to develop the Marsha (Figure 2) when NASA launched its 3D-printed habitat competition in 2015. The double-insulated hub can withstand Martian atmospheric pressure, allowing all construction to be finished on Mars and eliminating the need to send completed structures aboard a space shuttle. Materials for this structure are readily available on Mars, with the team developing an emulsion of Martian basalt fibers and renewable bioplastics obtained from plantable plants. While these hubs are not shared places, they can easily accommodate 1-2 individuals and will provide those who migrate to Mars with their own space in the future [9].

Warith Zaki and Amir Amzar: Seed of Life

Malaysian designers Warith Zaki and Amir Amzar want to construct something like Ai Space with the seed of life (Figure 3). The plant is wrapped around a layer of ethylene tetrafluoroethylene (ETFE) and water is poured into the bamboo, freezing the structure and boosting protection by using robots to weave bamboo shoots (planted on Mars after locating a water source). Gives. The design of this pair is based on the idea of choosing against 3D printing, which is the theme of the building of most Martian structures, for the inhabitants of the planet's temperature. While bamboo alone may not be adequate to protect the construction, the researchers feel it is a more

practical technique to build habitable structures on Mars than 3D printing [9].

NASA, University of Arizona: Martian Greenhouse

While the majority of greenhouses (on Earth) are composed of glass, NASA and the University of Arizona Department of Agriculture have developed an inflatable greenhouse that grows vegetables on faraway planets (Figure 4). The 5 x 2-meter design can allow air reclamation, water recycling, trash recycling, and even absorb the carbon dioxide inhaled by Repurpose astronauts to ensure astronauts and potential citizens may maintain a vegetarian diet in space. This greenhouse has been compared to many biological systems on Earth, and it will undoubtedly be used when people travel to Mars [9].



2.3. Life on Mars

Water Drainage on Mars

Although the surface of Mars is currently cold and dry, there is ample evidence that the Red Planet was once partially covered with water. Researchers have theorized that life may have evolved on Mars when it was wet, and could even be hiding there in the subsurface now. "On Earth, water means life," says Alberto Firen, an astrobiologist at the Spanish Center for Astrobiology and Cornell University in Ithaca, New York. The surface of Mars is extremely dry today, but there are many clues that point to a much wetter past. "Evidence of past water may be a clue to finding extinct life on Mars, and if some of that water still exists on Mars, the prospect of

finding life will certainly increase." Water on Mars also has important implications for NASA research areas beyond NASA's astrobiology program. Even if life no longer lives on Mars, or never existed in the first place, water could still be vital to future life on Mars in the form of human colonies on the Red Planet. Water is not only useful for drinking, but also for radiation protection, and when split into hydrogen and oxygen, as fuel. The prospect of past, present and future life on Mars means that much of NASA's research on the Red Planet is focused on its water [8]. To address the issue of water drainage on Mars, researchers are actively exploring various methods. Optimal use of Mars resources is essential. One approach is to use existing subsurface water ice and recycle water into habitats. In addition, technologies for extracting water from the Martian atmosphere are being developed.

Establishing a Society on Mars

Humans are not made for Mars. Or rather, Mars was not made for us. It is important to understand the sacrifices that a huge company requires in order to succeed. Building a Mars colony is on everyone's mind. SpaceX is testing the Mars rover prototype. Jeff Bezos is funding a lunar gateway for manned missions to Mars. Humans are certainly getting closer to setting foot on the Red Planet. The success of a Mars colony depends on how we decide to overcome these challenges. Building Mars to support human life will still take centuries. This causes immigrants to live in land-dependent habitats for the first few generations. Independence from Earth requires the use of purely Martian resources. The time scale required for deployment on Mars includes resource consumption considerations. Mars has even fewer usable resources than Earth. Using growth patterns on Earth as a model, Martians will soon encounter a problem we're only just beginning to see on Earth. They estimate that a Martian society will run out of resources in the next few centuries. This means that a truly independent Mars colony would likely have an expiration date. Of course, unless we make fundamental changes [9]. The idea of having contractors on Mars means a more developed society. Establishing a Mars colony requires significant infrastructure, investment, and a sustainable source of income.

This could be through scientific research, resource extraction or even tourism in the future. This involves a gradual process, possibly starting with smaller research stations and expanding over time.

Revised Building Design

Given the unique challenges of Mars, such as its thin atmosphere and exposure to radiation, building designs must actually be adapted. Structures may need to be partially or fully underground for protection. Advanced materials and 3D printing technology are considered for construction. Designs should prioritize safety, radiation protection and efficient use of resources [10].

Of course, it should be taken into account that all the presented methods are theoretical, and an exact method for creating a building on Mars has not yet been officially presented. Also, research by researchers to prove the existence of water on Mars and how to use it is still ongoing. If life on Mars is certain and humans migrate to Mars to continue living, how is this migration done and how do humans migrate to Mars? What is the society formed in Mars and who are the contractors of Mars. These are questions that researchers are still looking for answers to, and this article is only a research in the direction of information management of Martian buildings and has no discussion about the construction method.

2.4. Research Review

In his PhD thesis in 1982, Chaum was the first known person to propose a blockchain-like technology [10]. Haber and Stornetta described a cryptographically secure chain of blocks in 1991 [11]. Bayer et al. added Merkel trees in the method in 1993 [12]. Szabo created "bit gold," a decentralized digital currency mechanism, in 1998 [13]. Nakamoto introduced Bitcoin, an electronic currency with a completely peer-to-peer network, in 2008 [14]. In addition, the term blockchain was initially used to describe the distributed ledger that underpins Bitcoin transactions in 2008 [15]. Butrin proposed Ethereum in his white paper in 2013 [16]. Ethereum development was crowdfunded in 2014, and the Ethereum network became operational on July 30, 2015. The launch of

Ethereum signaled the beginning of Blockchain 2.0 because, unlike all of the previous block-chain projects that concentrated on the development of altcoins (currency comparable to Bitcoin), Ethereum allows individuals to connect to each other through trustless distributed applications on its own blockchain. The Linux Foundation introduced Hyperledger's block-chain frameworks, which differ from Bitcoin and Ethereum, in 2015. There are eight blockchain frameworks, Hyperledger Explorer, and four libraries available through Hyperledger [17]. A unique technique known as SDT is presented in the work by Xue and Lu (2020) to remove data redundancy in BIM by using blockchain. SDT tracks local alterations and incorporates them into a BIM contract. This analysis discovered that adding a block to the blockchain takes 0.02 seconds and that the amount of redundant data has decreased significantly [18]. A decentralized framework was established in the study by Dounas et al. (2021) integrating BIM elements on the blockchain platform. The findings revealed that the participants were satisfied with the level of security provided by the blockchain without any engagement in improving the blockchain's security or structure. [19]. Research Using BIM (building modeling information technology), connected data, smart contracts, and blockchain, Ye et al. (2020) propose a system for automated payment. The billing model (BM) information model is created to connect data with the blockchain for automated payment [20]. Following a research of a business tool named BIMCHAIN, Pradeep et al. (2020) investigate a blockchain-based approach for improving BIM data interchange trust. According to the findings of this study, there are eight fundamental functional requirements for a blockchain-based application to address BIM challenges. [21]. Liu et al. (2019) investigate the roles and integrated strategy of BIM and blockchain in sustainable building design information management. The BIM user interface with blockchain technology is utilized for BIM transactions, while the BIM architecture + BC smart contract simplifies the settlement of BIM challenges for sustainable design [22]. Integration of BIM and blockchain into the implementation of smart contracts was considered by Shojaei et al. (2020). A blockchain network is presented in this study to handle a prototype building project. The proposed design does not employ the cryptocurrency component

of blockchain as a form of payment. The findings suggest that blockchain is an effective way for managing construction project contracts since it automates each transaction and keeps track of the project's progress [23].

According to research conducted and a study of various works on this subject, the need for information monitoring through Blockchain has not been highlighted. Blockchain monitoring does not imply that Blockchain as an authority supervises the proper execution of transactions, since this technology is incapable of doing so. The meaning of Blockchain is to monitor the correct execution of transactions; the central and intermediate role of Blockchain is to ensure that the information sent from actor x to actor y matches the transaction history information stored in the Blockchain; and simply storing the information in the Blockchain is a logical and efficient method for enhancing security. Consequently, the purpose of using Blockchain is to improve information transit and data security.

3. Research Methods

In the framework presented in this research, we have a non-exclusive public Blockchain in which all buildings and residents can become members and create smart contracts and exchange information. One of the conditions for membership in this Blockchain is to have sensors for all members of the building, which is both expensive and difficult to install. These sensors are the responsibility of the customer and then must be approved by the construction company. These sensors are different depending on the type of contract with the company; for example, if the type of contract is only to adjust the oxygen of the residence, the oxygen control sensors are installed in suitable places to reduce the oxygenation of the place. Send this information to the manufacturing company. Sensor information is stored in the cloud, and this information is then hashed and its hash placed in the non-exclusive public Blockchain. Every contract that is made creates a ledger in the Blockchain, and from now on, all transactions related to this contract are chained together in this ledger. And the hash of each block is stored in the next block, and this causes that if the smallest change is made in the hash of one block, the hash of other blocks will also change, and all the blocks in the network will

notice this change, and this will make the information in the It is Blockchain. Each client has a private and public key and a digital signature to authenticate them. Customers can have a different public key to communicate with each company to increase the security of their anonymity.

3.1. NEGOTIATION STAGE AND USER CONTRACT REQUEST

At first, the client becomes a member of the public, non-exclusive Blockchain. Customers can get the company's public key through the company's website or through Certification Authorities (CAs). The customer negotiates with the desired company about the terms, costs, and other matters of the contract, and then the customer requests the contract for the transaction. The company sends The structure of this transaction is as follows:

(1) "T_ID || Request _ Smart _ Contract || SP _ PK || User _ PK || Sing"

Table 2. Summary of transactions

TRANSACTION	DETAILS
T_ID	the unique number and hash of the current transaction
Request_Smart_Contract	the customer's smart contract request to the construction company
SP_PK	company's public key
User_PK	customer's public key
Sign	customer's signature

As shown in table number 2, In a blockchain network, transactions are processed and recorded as blocks, which are then added to the existing chain of blocks in a linear and immutable manner. Each transaction within a block is identified by a unique number called a transaction ID (T_ID). This ID serves as a reference to the specific transaction and allows users to easily trace the history and status of their transactions. When a customer requests a smart contract from a construction company, they submit their request to the blockchain network as a transaction. The details of the request, including the terms and conditions of the contract, are encoded in a data structure called Request_Smart_Contract. To ensure the security and authenticity of the transaction, the customer

signs the request with their private key and attaches their public key (User_PK) to the transaction. The construction company also attaches their public key (SP_PK) to the transaction. The customer's signature (Sign) serves as proof of their identity and authorization for the transaction. When the transaction is submitted to the network, it is processed and verified by the nodes in the network. If the transaction meets the necessary criteria and is approved by the network, it is added to the blockchain as a new block, which includes the transaction ID, the customer's request, and the signatures from both parties.

3.2. THE STAGE OF ENTERING INTO A SMART CONTRACT

The construction company prepares the contract and sends it to the customer. After receiving the contract, the customer signs it and then sends it to the desired company; the company also signs the contract and sends it to the Blockchain, and the construction company's signature is the creation of a new block. It is in the Blockchain. The structure of this transaction is as follows:

(2) "T_ID || P_T_ID || User _ PK || User _Sign || SP_ PK || SP_ Sign|| Rfe.contract.ID"

Table 3: Summary of transactions with Details

TRANSACTION	DETAILS
T_ID	unique number and hash of the current transaction
P_T_ID	hash of the previous transaction
User _ PK	customer's public key
User _Sign	customer's signature
SP_ Sign	public key and signature of the construction company
Rfe.contract.ID	field of contracts related to sensors

As shown in table number 3 In order to conclude contracts on the public Blockchain, there are specific conditions that must be met. One of these conditions is that the contracts must involve sensors, which are provided by the customer and installed by the construction company. Once the sensors are installed, the customer adds them to their cloud and defines a new key, which allows

the sensor data to be sent to the cloud. However, before the contract can be finalized, the construction company must confirm the correctness of the customer's sensors. This is typically done through a physical inspection of the sensors, which may include checking the accuracy of oxygen or temperature sensors, for example. The construction company will inform the customer of when the inspection will take place. Once the contract is signed and the sensors are verified, the sensor data must be stored in the Blockchain platform. This includes data from sensors used to control oxygen, temperature, and air exchange in the building's structure and side walls. This data is stored in a block in the public Blockchain, which creates a tamper-proof record of the sensor readings. By using the Blockchain to store sensor data, it is possible to ensure the integrity and accuracy of the data, as well as the security and transparency of the contract. This can help to reduce the risk of fraud or error in the sensor readings, while also providing a clear record of the contract terms and sensor data for monitoring and analysis.

3.3. SENSORS

There are many sensors in the discussion of intelligent building management using sensors. The number of building sensors can vary greatly depending on several factors, such as the size of the building, the purpose of the sensors, and the specific needs and goals of the residents or building managers. For this research, we have used 6 types of sensors, As shown in table number 4

Table 4: Sensors used

SENSOR
Oxygen
Temperature
Control
Celling
Wall
Facilities

3.4. OXYGEN SENSOR CONTROL

At this stage, the sensors measure the oxygen in the surrounding environment at certain time intervals (a time clock), and after the approval of the inspector, the data is stored in the Blockchain

platform. The structure of this transaction is as follows:

(3) "T_ID || P_T_ID || S_ID || Oxygen_content

Table 5: Summary of transactions with Details

TRANSACTION	DETAILS
T_ID	unique number and hash of the current transaction
P_T_ID	hash of the previous transaction
S_ID	desired sensor number
Oxygen_content	amount of oxygen in the environment

As shown in table number 5 In a blockchain-based system, T_ID (Transaction ID) refers to the unique identifier of the current transaction that is being recorded in the blockchain. Each transaction in the blockchain has a unique ID, which is generated using a hashing algorithm. Hashing is a process of converting the input data into a fixed-size output, which is unique to that data. The hash function used to generate T_ID ensures that it is virtually impossible to modify the transaction data without changing the ID. P_T_ID (Previous Transaction ID) refers to the hash of the previous transaction that was recorded in the blockchain. In a blockchain, each block contains a reference to the previous block in the chain, which creates a linked list of blocks. This linked list ensures the integrity and security of the blockchain, as any attempt to modify a previous transaction would invalidate all subsequent transactions in the chain. S_ID (Sensor ID) is a unique identifier of the sensor that is being monitored in the system. In the context of intelligent building management using sensors, S_ID may refer to the ID of a particular sensor that measures the oxygen content in the environment. Oxygen content is a measure of the amount of oxygen present in the environment. In the context of intelligent building management using sensors, measuring oxygen content can be important for ensuring the health and safety of occupants. For example, if the oxygen content falls below a certain threshold, it could indicate a ventilation problem or the presence of harmful gases, which could pose a risk to human health. By monitoring the oxygen content using sensors and recording the data in a blockchain-based system, building managers can ensure that they have an accurate and tamper-proof record of the environmental conditions in the building.

3.5. TEMPERATURE CONTROL SENSOR

This sensor shows the temperature of the environment, which can be used to control the temperature of a building in different places such as the commuter area, bedroom, living room, etc. The structure of this transaction is as follows:

(4) "T_ID || P_T_ID || S_ID || temperature"

Table 6: Summary of transactions with Details

TRANSACTION	DETAILS
T_ID	unique number and hash of the current transaction
P_T_ID	hash of the previous transaction
S_ID	desired sensor number
temperature	temperature is related to the ambient temperature

As shown in table number 6 In a blockchain-based system, T_ID (Transaction ID) is a unique identifier of the current transaction that is being recorded in the blockchain. This identifier is generated using a hashing algorithm that transforms the transaction data into a fixed-size, unique code. P_T_ID (Previous Transaction ID) refers to the hash of the previous transaction that was recorded in the blockchain. In a blockchain, each block contains a reference to the previous block in the chain, which creates a linked list of blocks. The P_T_ID ensures that the integrity of the blockchain is maintained, as any attempt to modify a previous transaction would invalidate all subsequent transactions in the chain. S_ID (Sensor ID) is a unique identifier of the sensor that is being monitored in the system. In the context of intelligent building management using sensors, S_ID may refer to the ID of a particular sensor that measures the ambient temperature in a specific zone or area of the building. In the context of intelligent building management using sensors, temperature sensors may be used to monitor the ambient temperature in different zones or areas of a building. By recording the temperature readings in a blockchain-based system, building managers can track changes in temperature over time and identify patterns or anomalies that may indicate issues with the heating, ventilation, and air conditioning (HVAC) system or other factors affecting the indoor environment.

3.6. CONTROL SENSOR

The sensor being discussed is related to monitoring the air exchange between a building and the environment, and it is important for this exchange to be zero. In other words, the sensor is designed to detect any air movement that may occur between the inside of the building and the outside. This is important because it helps to maintain a stable and comfortable environment inside the building, which is essential for the occupants. However, the sensor's importance becomes even more critical when considering a location like Mars. On Mars, the atmospheric pressure is very low, and any air pressure that enters the walls can be damaging. Therefore, it is essential to monitor the resistance of the external walls and ensure that they are able to withstand the pressure exerted by any air currents. To achieve this, two different sensors and transactions are required. The first sensor is an air exchange control sensor, which is used in areas where there is a higher possibility of air entering and exiting. This sensor will detect any air movement and alert the control system if there is a breach in the building's envelope. The second sensor is a wall resistance control sensor, which is used in areas where there is the greatest pressure against air currents. Typically, this is in the upper parts of the building. This sensor will detect any pressure exerted on the walls and alert the control system if there is any damage to the walls. Also, a sensor should be added to control the facilities so that it can be used to control the facilities and the place of their failure. Therefore, a transaction is added to the previous transactions to control the facilities. These transactions can be shown in a generalized form in a transaction that includes items such as sensor type, control type, and sensor values, as shown below:

(5) "T_ID || P_T_ID || S_ID ||
Type_Sensor||Type_Control|| Amount"

Table 7: Summary of transactions with Details

TRANSACTION	DETAILS
T_ID	unique number and hash of the current transaction
P_T_ID	hash of the previous transaction
S_ID	desired sensor number
Type_Sensor	type of sensor
Type_Control	type of control Sensor
Amount	Values Sensor

As shown in table number 7, In a blockchain network, transactions are recorded in blocks, and each block contains a hash of the previous block, creating a chain of blocks, hence the name blockchain. In the context of the sentence you provided, T_ID refers to the hash of the current transaction, which is a unique identifier for that particular transaction. It helps to ensure the integrity and security of the transaction by providing a unique identifier that can be used to verify the transaction's authenticity. P_T_ID, on the other hand, refers to the hash of the previous transaction. It is used to create a link between the current transaction and the previous transaction in the blockchain, which ensures the immutability and transparency of the network. S_ID is a variable that relates to the desired sensor number. It is used to identify the specific sensor that is being controlled or monitored by the transaction. Type_Sensor indicates the type of sensor being controlled or monitored by the transaction. There are three types of sensors: air exchange control, pressure control, and facility control. Type_Control indicates the type of control that the sensor is subject to. There are two types of controls: sensitive and non-sensitive. Sensitive controls are for air and pressure exchange, while non-sensitive controls are for facility control. Finally, the amount refers to the values that the sensors show, which are controlled or monitored by the transaction. These values could be anything from temperature to humidity, and they are used to trigger various actions in the blockchain network, such as opening or closing air vents or adjusting pressure levels in a controlled environment.

3.7. COMPONENTS OF BUILDINGS

In this part, the components of the building whose information is stored in the Blockchain by

sensors have been discussed. This part includes three parts of walls, roofs and facilities, each of which is described in detail below.

3.8. ROOF

The roof is one of the most important factors in building components, especially in Mars buildings. According to this point, the roofs in Mars buildings, in addition to determining the level of each floor of the building, should include things such as air conditioning and temperature control. Air control and the prevention of air flow between the floors are controlled using the air exchange control sensor, and temperature control is determined using the temperature sensor. Also, the height of the roofs should be such that it leads to the circulation of air containing oxygen and temperature control. Therefore, the information that can be stored in the block chain as building management for roofs is the type of roof, the type of material, the height of the roof, and the amount of load that each roof bears. Hence, this transaction is shown below:

(6) "T_ID || P_T_ID || R_ID || Roof_type || Material || Height || Load amount || Description"

Table 8: Summary of transactions with Details

TRANSACTION	DETAILS
T_ID	unique number and hash of the current transaction
P_T_ID	hash of the previous transaction
Roof_type	type of roof
Material	material used in the roof
Height	height of the roof
Load amount	amount of load placed on the roof
Description	description of the roof map



Figure1: type of ceiling

As shown in table number 8 and Figure 1, In a database management system, a transaction identifier (T_ID) is a unique identifier assigned to a transaction, which is a series of database

operations that are executed as a single logical unit of work. The T_ID helps in tracking the progress of a transaction and in managing concurrency control. The previous transaction identifier (P_T_ID) is the identifier of the transaction that was executed immediately before the current one. It helps in maintaining the consistency of the database and in detecting conflicts that may arise due to concurrent transactions. A roof identifier (R_ID) is a unique identifier assigned to a roof in a database that stores information about roofs on Mars (Figure 1). The type of roof is classified as sloping, flat, or dome-shaped, and each type may have an outer and inner roof. The material used in the roof depends on the type of soil on Mars. The height of the roof is an important parameter that determines its suitability for a particular application. The load amount refers to the amount of weight that the roof can support without collapsing or failing. This parameter is important in designing roofs for different purposes, such as residential, commercial, or industrial use. Finally, the description of the roof map includes information such as the size of the roof, the purpose for which it is intended, and any other relevant details. This information helps in managing and maintaining the database of roofs on Mars.

3.9. Wall

The second most important factor in Mars buildings is the wall. Walls are divided into several types. He pointed out the side wall, internal wall, retaining wall, shear, and opening shear. But there is a kind of wall on the surface of Mars, called the Guard Wall, which prevents meteorites from hitting the surface of Mars. Also, the thickness of the walls, the materials used in them, and the height of the walls can be added to the block chain as building management information. This transaction is described below:

(7) "T_ID || P_T_ID || W_ID || Wall_type || Material || thickness || Load amount || Description"

Table 9: Summary of transactions with Details

TRANSACTION	DETAILS
T_ID	unique number and hash of the current transaction
P_T_ID	hash of the previous transaction
W_ID	wall ID

Material	type of materials used in the wall
thickness	thickness of the wall
Load amount	the amount of load placed on the wall
Description	description of the wall map

In the above transaction, a transaction identifier (T_ID) is a unique identifier assigned to a transaction that helps in tracking the progress of the transaction and managing concurrency control. The T_ID is used to ensure that the database remains in a consistent state even when multiple transactions are being executed concurrently. The previous transaction identifier (P_T_ID) is the identifier of the transaction that was executed immediately before the current one. It helps in maintaining the consistency of the database and detecting conflicts that may arise due to concurrent transactions. A wall identifier (W_ID) is a unique identifier assigned to a wall in a database that stores information about walls on Mars. The type of wall is classified as simple, parallel arrangements with grids, solid parallel arrangements, empty and unreinforced parallel arrangements, and each type may have an outer and inner wall (Figure 2). The type of material used in the wall depends on the type of soil on Mars, and the thickness of the wall depends on its application. The load amount refers to the amount of weight that the wall can support without collapsing or failing. This parameter is important in designing walls for different purposes, such as residential, commercial, or industrial use. Finally, the description of the wall map includes information such as the size of the wall and any other relevant details. This information helps in managing and maintaining the database of walls on Mars.

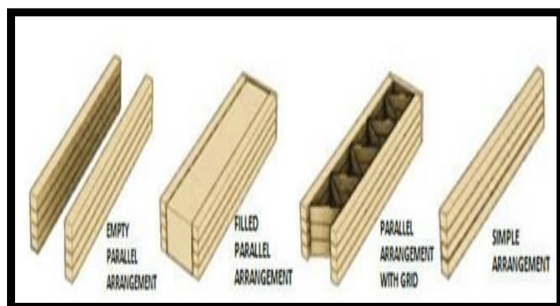


Figure 2: type of wall

3.10. FACILITIES

Building facilities are crucial components that provide life to a building and enable people to continue living and working in it. They are the infrastructure and equipment that support a safe, comfortable, and functional environment for the occupants. When it comes to Mars buildings, the types of facilities required are significantly different from those needed on Earth due to the harsh conditions on the planet. The first critical facility in a Mars building is the water supply system. This system must be able to provide hot and cold water for drinking, cooking, and sanitation. The water supply pipes must be designed to withstand the low-pressure environment on Mars, which is significantly different from Earth's atmospheric pressure. Additionally, the water system must include a way to purify and treat water for reuse to ensure sustainability. Another essential facility is the sewage collection system. To prevent contamination and health hazards, waste products must be collected and disposed of properly. Airtight pipes that can withstand pressure changes, extreme temperatures, and radiation exposure must be used for proper sewage collection and disposal. The waste must also be treated and processed safely for the environment and the occupants. Ventilation is also critical in a Mars building. It helps regulate the temperature and air quality in the building, preventing the buildup of harmful gases and allowing for the flow of fresh air. Vent pipes must be designed to withstand extreme temperatures and pressures while providing efficient airflow to prevent the spread of airborne illnesses. Fire safety is another crucial concern in any building, including Mars buildings. Fuel and fire extinguishing pipes must be installed throughout the building to provide quick access to fire suppression materials. These pipes must be designed to withstand the extreme temperatures and pressures of Mars, and the fire suppression materials must be carefully chosen to be effective in the low-pressure environment. Finally, electrical piping is essential for a Mars building's efficient operation. The electrical system must provide reliable power despite the harsh environmental conditions. Electrical piping in the form of ducts must be installed to protect the wiring from radiation exposure and extreme temperatures. There is a center in the Mars

buildings, and the corresponding transaction is to store the docket information. This information includes the location of the docket, the size of the docket, and the description of the docket, which is generally stored in the Blockchain. The types of facilities that can be used in a Mars building are cold and hot water pipes, sewage collection pipes, vent pipes, fuel and fire extinguishing pipes, and electrical piping,

(8) "T_ID || P_T_ID || D_ID || Location || Size || Description"

Table 10: Summary of transactions with Details

TRANSACTION	DETAILS
T_ID	unique number and hash of the current transaction
P_T_ID	hash of the previous transaction
D_ID	docket ID
Location	location of the docket
Size	size of the docket
Description	description of the docket map

As shown in table number a transaction identifier (T_ID) is a unique identifier assigned to a transaction, which helps in tracking the progress of the transaction and managing concurrency control. The T_ID is used to ensure that the database remains in a consistent state even when multiple transactions are being executed concurrently. The previous transaction identifier (P_T_ID) is the identifier of the transaction that was executed immediately before the current one. It helps in maintaining the consistency of the database and detecting conflicts that may arise due to concurrent transactions. A docket identifier (D_ID) is a unique identifier assigned to a docket in a database that stores information about dockets. The location of the docket indicates where the docket is currently located, such as a warehouse or a distribution center. The size of the docket indicates the physical dimensions of the docket, which can be important in determining how much space it will occupy during transportation or storage. The description of the docket map includes information about the items that have passed through the docket, such as the type of products, quantities, and any special handling requirements. In summary, the docket information is used to track the movement of

goods through the supply chain and to maintain an accurate inventory of products in storage. The information can be used to optimize logistics processes, improve order fulfillment accuracy, and reduce errors and delays.

4. SUGGESTED METHODS OF MEASUREMENT

As mentioned in the previous sections, three categories of general information can be stored in the block chain: smart contracts, information collected by sensors, and information used as building information management to control roofs, walls, and building facilities. Along with the description of each map Therefore, transactions are considered for each part, and these transactions are stored in the block chain after completion. In the proposed method, an inspector is considered a controlling element. This system includes an inspector that has four levels: normal, emergency 1, emergency 2 and emergency 3. The normal state is when all components of the building work properly and the state of the building is considered normal. The system is designed to identify any problems that may arise and classify them at the appropriate levels. If a problem occurs in any of the facilities, it will be evaluated and included in the emergency level 1. This could include a malfunctioning sensor or a damaged sensor. Even if a sensor reaches the end of its life, it is considered a problem and a warning is sent to the manufacturer. Technicians are given the opportunity to solve the problem before someone's life is endangered. In emergency level 2, temperature level control, oxygen level and air exchange level are controlled. Emergency Level 2 is activated if part of the building collapses, resulting in reduced oxygen levels, increased temperatures, and ultraviolet radiation. At this point, the robot rescue team is given a limited time to enter the damaged part and repair it. However, human life is not threatened at this level. If the problem continues and human lives are in danger, the situation will reach emergency level 3. Emergency level 3 is the most critical level and is activated when a part of the building is damaged by factors such as earthquakes, meteorites, or other factors. Any other type of damage at this level, the robot rescue forces are immediately sent to the place to save people's lives.

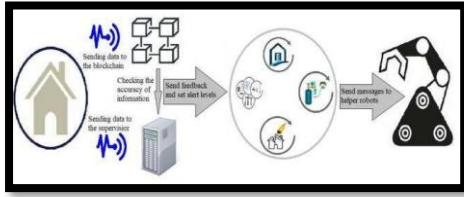


Figure 5: Proposed method and framework

As it is clear from Figure 5, at first, the data of Martian buildings is sent to it for storage on the blockchain platform. At the same time, the data is also sent to the supervisor, and after receiving the information, the supervisor compares it with the data stored in the blockchain, and if the data is correct, the alarm level of that house is determined. After determining the warning level, if necessary, a message is sent to the rescue robots to refer them to the desired location for assistance.

5. RESULTS OF ANALYSIS

In this part, two important and fundamental factors in Blockchain are examined. These two factors include the amount of memory consumed and the duration of adding a new block to the block chain, which are evaluated in the following two criteria for the transactions used. All these things have been done in the Python programming language and implemented on Google Collaborate. So, the proposed system for this research is the servers used by Google to run Python programs. In the following, each transaction has been evaluated.

5.1. CONTRACT

The first stage of the platform presented is the stage of signing a contract with customers, which should be done using a smart contract. These steps are as follows: first, the customer sends a request for a contract to the construction company, and the company sends and signs the contract after checking the profiles of the people or customers. The stages of the contract are shown in the figure below. It is worth noting that all the steps include the transactions presented in the previous section. Therefore, in these operations, no transaction should remain incomplete and should be completed. In fact, either a transaction or a step is completed and

stored in the Blockchain, or no transaction is made.

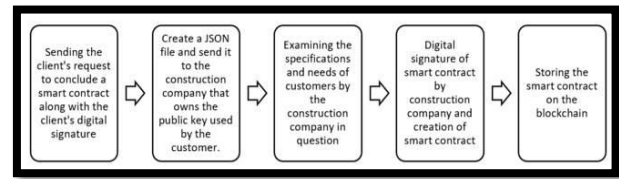


Figure 6: The stages of the contract between the customer and the manufacturer

As it is clear from the (figure 6) above, all movements are forward, and if the desired transaction is stopped at any stage, that transaction is lost and must be restarted from the beginning. In the first stage, each customer has a public token and a private token, where the private token of each person is the digital signature of that person. At this stage, the customer, having the public token of the desired company, sends his request and specifications to the company and signs the contract. After this step, the customer's request is sent to the desired company in the form of a JSON file (Figure 7). After checking the structure of the desired house and the customer's profile, the company signs the contract with the company's private token, sends the final contract to be stored in the Blockchain, and also sends the final version of the smart contract to the customer.

```

{
  "System": "'Linux'",
  "Node Name": "'749a3b916e97'",
  "Release": "'5.10.147'",
  "Version": "'#1 SMP Sat Dec 10 16:00:40 UTC 2022'",
  "Nat_Code": "3258747699",
  "name": "Amirhossein",
  "family": "Javaheri",
  "Address": "Madrid",
  "user sing": "30254790",
  "timestamp": "2023-01-11 09:50:12.361892"
}
  
```

Figure 7: Customer request specifications

As it is clear from the above figure, the profile of a customer has been sent to the company along with the system profile. The diagram below also shows the amount of memory consumed and the duration of creating and adding a block to the block chain, as well as minding that chain from one block to 10,000 blocks (Figure 8).

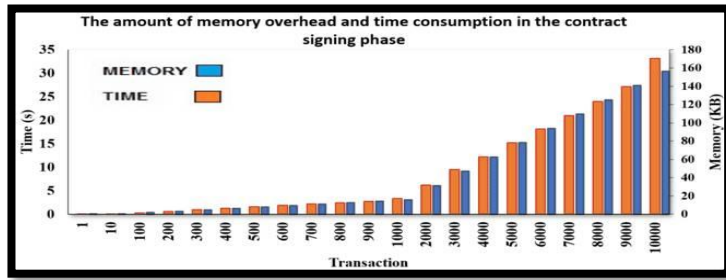


Figure 8: amount of memory consumed and the duration of creating in contract

5.2. Check the proposed method

In this part, a platform is designed to send data to the central server to check the warning level that was discussed in part 4. First of all, information is collected from sensors that are installed in the environment. Considering that this system has an intranet, this information is sent to the central server in the form of an XML file so that the inspector system can determine the warning level by checking the receipt of the XML files and matching them with the information stored in the blockchain. The flowchart of this system is shown in the figure below (Figure 9).



Figure 9: Flowchart of sending data to the central system

As it is clear from the figure above, since the exchange of information is within the company's internal network, then by using the XML file (Figure 10), the information can be sent to the main source of the company, and the received information is compared with the information inside the Blockchain, and after the correctness of the information is determined, the amount and level of warning should be issued. In this section, if the alarm level is at level 1, no message is sent to the technician and rescue robots, and if it is at the 1st to 3rd alarm level, depending on the alarm

level, robots specific to each alarm level are activated, and according to the ID of the sensors, they refer to the location of the accident.

```

<Round>
<Round/>
<Sensor>974 = 27</Sensor>
<Sensor>450 = 21</Sensor>
<Sensor>793 = 1</Sensor>
<Sensor>957 = 0</Sensor>
<Sensor>825 = 2</Sensor>
<Sensor>136 = 0</Sensor>
<Sensor>time = 2023-01-25 14:52:04.496617</Sensor>
</Round>

```

Figure 10: Sensors XML file

As you know, in the buildings on Mars, due to the importance and sensitivity of the matter of life, the information and the accuracy of the information must be checked to make sure which sensor and which house need the attention of the rescue team and if the information undergoes transformation and changes. and penetrate into the system, the costs of maintaining robots and using them will be heavy. Therefore, information processing is a very important step, and before leaking information to the central system using Blockchain, the accuracy of this information must be evaluated. The reason for using the XML file is to use a public Blockchain because it is not possible to de-hash the information in the public Blockchain, and according to the law, this should not be done. Based on this, according to the results of the research, from 1 to 12,000 pieces of data were created in the block chain, and it is inserted that the two variables of cost and time were evaluated.

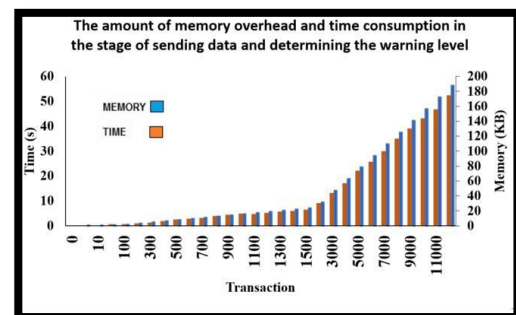


Figure 11: amount of memory consumed and the duration of creating in warning levels

As shown in the (Figure 11), the longest time to receive a response from the center is for 12,000 data points, which takes about 60 seconds. So it can be said that the time it takes to send data and

receive a response from the destination is an average time, which, although it may be effective to respond to some failures, may be dangerous for some other factors. One of the factors that may be dangerous for this period of time is related to the oxygen in the environment, for which, of course, solutions can be provided. For example, a separate framework can be created for the oxygen sensor so that the response speed can be increased and the response time can be reduced based on it, which, of course, with the increase in the number of oxygen sensors in the environment, is not much different from the designed framework. It will not have in general, the weakness of Blockchain work can be stated in this way: as the number of transactions increases, it will take more time to add a block to the previous block chain, and this is necessary to check the amount of oxygen in the environment, which is essential for the continuation of human life. It's dangerous.

6. Discussion

Considering that this issue and life on the planet Mars still have hidden dimensions and points, this research can be a precursor to the integration of BIM and blockchain for the information management of Mars buildings, which can be done by considering other limitations and expanding these models to finally reach a standard model. According to Xingyu et al. (2022), blockchain is an emerging distributed technology that ensures data integrity by providing decentralized, immutable, and traceable data storage. However, the direct integration of BIM with blockchain reduces the risk of leaking sensitive data, but the risk remains because blockchain is a transparent network to the extent that shared information (including sensitive data) can be disclosed to all members without access control [24]. Therefore, in order to deal with such possible risks, an inspection to check the data and the accuracy of the received information has been explained in the proposed framework so that, in case of sabotage or information leakage, the system has the ability to detect it. Therefore, the proposed framework in this field has an improvement in guaranteeing the quality of data and information compared to other similar methods. According to Celik et al. (2023), recent advances in building information modeling have shown new ways to integrate

processes and data with open data formats. In construction projects that generate and share multiple streams of BIM data, mechanisms to define priority, provenance, and appropriateness of information become necessary for consistent and traceable use of the data [25]. Therefore, in this research, by entering into a smart contract and determining the location of each sensor, the method of sending information and the origin of sending information are calculated in a completely accurate manner. Also, prioritization has been determined at four warning levels, which is in line with the results. Also, the literature has shown that several weaknesses of BIM, including the trust issue, the asset ownership issue, and the data reliability issue, can be addressed by incorporating blockchain into its processes [26–28]. Therefore, the first issue, which is data trust in Mars, must be verified with high accuracy; the issue of property ownership has also been reliably observed using smart contracts on the blockchain platform; and the issue of data reliability, in addition to considering the capacity of the blockchain, has also been verified by an inspector.

7. Conclusions

Finding another environment for the continuation of human life due to the exhaustion of the earth and the loss of its natural resources is an issue that will be addressed more in the coming years. One of the prerequisites of human life is to have a safe shelter, which is a little easier on earth due to the presence of sufficient oxygen, proper light, and water. So far, the closest and most similar planet to Earth for life is Mars, and due to its environmental conditions, more controls are needed for human vital elements. In this study, it has been tried to manage the information of Mars buildings by combining BIM and blockchain. In two main frameworks, eight main transactions were designed. The first framework is related to the conclusion of a smart contract between the customer and the support company for the construction of Mars buildings. The second framework is related to providing an inspector for building control, and by sending data from sensors and checking their accuracy, four warning levels were determined. The results of the research showed that in the first stage, which is the contract, for the number of 12,000 records, a duration of 30 seconds and a memory

amount of 175 kilobytes are required. For this purpose, it can be shown that the duration of adding a block to the block chain is a suitable value. And the amount of memory used is also suitable. In the second stage, which is the determination of the warning level, 12,000 records of 60 seconds duration and 180 kilobytes of memory are required, which can be said to be suitable for other events and transactions except oxygen control. Control. Considering that this issue and life on the planet Mars still have dimensions and hidden points, this research can be a precursor to the integration of BIM and blockchain for the information management of Mars buildings, which can be done by considering other limitations. Did. One of the limitations of this research was that the use of blockchain technology in BIM in Mars buildings has not been investigated. However, the use of blockchain

technology in the context of Mars buildings is unique and requires specialized approaches. There are also various areas that can be further explored in this research, such as the development of specific protocols and standards for BIM management in Mars buildings, the integration of various sensors and IoT devices for real-time monitoring and control of facilities, and the development of artificial intelligence-based algorithms. For predictive maintenance and abnormality detection. This is an exciting area of research that could help develop sustainable and safe habitats on Mars and other planets. This requires interdisciplinary collaboration between experts in BIM, blockchain, space engineering, and other related fields to create a comprehensive and effective solution.

REFERENCES

- [1] J. Liu *et al.*, "In-situ resources for infrastructure construction on Mars: A review," *International journal of transportation science and technology*, vol. 11, no. 1, pp. 1-16, 2022.
- [2] A. Babalola, S. Musa, M. T. Akinlolu, and T. C. Haupt, "A bibliometric review of advances in building information modeling (BIM) research," *Journal of Engineering, Design and Technology*, vol. 21, no. 3, pp. 690-710, 2023.
- [3] R. Zheng, J. Jiang, X. Hao, W. Ren, F. Xiong, and Y. Ren, "bcBIM: A blockchain-based big data model for BIM modification audit and provenance in mobile cloud," *Mathematical Problems in Engineering*, vol. 2019, 2019.
- [4] J.-Y. Wong *et al.*, "BIM-VR Framework for Building Information Modeling in Engineering Education," *International Journal of Interactive Mobile Technologies*, vol. 14, no. 6, 2020.
- [5] A. Erri Pradeep, T. Yiu, and R. Amor, "Leveraging blockchain technology in a BIM workflow: A literature review," in *International Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving data-informed decision-making*, 2019, pp. 371-380: ICE Publishing.
- [6] H. Saini, B. Bhushan, A. Arora, and A. Kaur, "Security vulnerabilities in Information communication technology: Blockchain to the rescue (A survey on Blockchain Technology)," in *2019 2nd International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT)*, 2019, vol. 1, pp. 1680-1684: IEEE.
- [7] N. O. Nawari and S. Ravindran, "Blockchain technology and BIM process: review and potential applications," *Journal of Information Technology in Construction*, vol. 24, 2019.
- [8] C. Q. Choi. (2016, 10). *Water on Mars: The Story So Far*. Available: <https://astrobiology.nasa.gov/news/water-on-mars-the-story-so-far/>
- [9] T. Witzens. (2019, 10). *How would we establish a society on Mars?* Available: <https://sciworthy.com/how-would-we-establish-a-society-on-mars/>
- [10] D. Katanich, "Plans for the first sustainable city on Mars unveiled," 2021.

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Figure I.3: Article Certificate



Application of blockchain in BIM: a systematic review

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ABSTRACT

A Blockchain Technology (BCT) is an emergent digital technology that in recent years has gained widespread traction in various industrial, public, and business sectors; primarily in financial and banking realms owing to the rapid increase of cryptocurrency valuation in recent years. A blockchain Technology (BCT) is, in essence, a decentralized ledger that records every transaction made in the network, known as a 'block', the body of which comprises of encrypted data of the entire transaction history. It was introduced as the working mechanism that formed the operational basis of Bitcoin, the first digital cryptocurrency to gain extensive mainstream appeal. The introduction of decentralized technology in any industry would require strengthened security, enforce accountability, and could potentially accelerate a shift in workflow dynamics from the current centralized architectures to a decentralized, cooperative chain of command and affect a cultural and societal change by encouraging trust and transparency. It was evident that the underlying principles characteristic of BCT functional attributes and secure digital infrastructure could find application in nearly any conceivable industry. BCT aims at creating a system that would be a robust self-regulating, self-monitoring and cyberresilient system that assures the facilitation and protection of truly efficient data exchange system.

This research depicts a survey of blockchain technology and its applications in the Architecture, Engineering, and Construction (AEC) industry and examines the potential incorporation within the Building Information Modeling (BIM) process. Furthermore, the paper investigates how employing distributed ledger technology (DLT) could be advantageous in the BIM workflow by emphasizing network security, on the other hand in the Looking around, we see a change in all aspects of the digital industry, education, or the economy. The digital sector has witnessed a larger volume of transformation. Significant work and changes and improvements have been made in the field of design and manufacturing industry. The digital sector, as well as the construction sector, are witnessing digital transfers. Technology is evolving in solving various problems arising from all industries. The Blockchain is also moving towards the construction industry. Combining blockchain with BIM (building information modeling) is a great combination. Blockchain is really useful in the manufacturing industry. The blockchain is a chain of linked blocks in which each block relates to the block before it. The main characteristic of blockchain is to ensure information security. All the information is held in the blockchain in a codified and hashed form that has been encrypted. The blockchain is used for the accuracy of information transacted between two actors. The overall structure of blocks in the blockchain consists of two main parts. The first one includes the main information of the block in hashed form and the second part includes the address of the prior block in hashed form. In different construction projects, these data can include the smart contracts concluded between the employer, contractor, and consultant and also the correspondences done with different organizations, evaluation of workers' work hours. The structural information is the most significant data in the sensitive projects the accuracy of which should be assessed, since filtering such information leads to heavy casualties. The research method is descriptive with the Goal of getting acquainted with blockchain and combining it with the construction industry and building information modeling.

Key words: blockchain, projects, BIM, construction, technology

Aplicación de blockchain en BIM: una revisión sistemática

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RESUMEN

Una tecnología Blockchain (BCT) es una tecnología digital emergente que en los últimos años ha ganado una tracción generalizada en varios sectores industriales, públicos y comerciales; principalmente en los ámbitos financiero y bancario debido al rápido aumento de la valoración de las criptomonedas en los últimos años. Una tecnología blockchain (BCT) es, en esencia, un libro mayor descentralizado que registra cada transacción realizada en la red, conocida como un "bloque", cuyo cuerpo se compone de datos cifrados de todo el historial de transacciones. Se introdujo como el mecanismo de trabajo que formó la base operativa de Bitcoin, la primera criptomoneda digital en obtener un gran atractivo general. La introducción de tecnología descentralizada en cualquier industria requeriría una seguridad reforzada, exigiría la rendición de cuentas y podría acelerar un cambio en la dinámica del flujo de trabajo de las arquitecturas centralizadas actuales a una cadena de mando descentralizada y cooperativa y afectar un cambio cultural y social fomentando la confianza y la transparencia. . Era evidente que los principios subyacentes característicos de los atributos funcionales de BCT y la infraestructura digital segura podían encontrar aplicación en casi cualquier industria imaginable. BCT tiene como objetivo crear un sistema que sea un sistema robusto de autorregulación, autocontrol y ciberresiliente que asegure la facilitación y protección de un sistema de intercambio de datos verdaderamente eficiente. Esta investigación describe una encuesta de la tecnología blockchain y sus aplicaciones en la industria de Arquitectura, Ingeniería y Construcción (AEC) y examina la incorporación potencial dentro del proceso de Modelado de Información de Construcción (BIM). Además, el documento investiga cómo el empleo de la tecnología de contabilidad distribuida (DLT) podría ser ventajoso en el flujo de trabajo BIM al enfatizar la seguridad de la red; por otro lado, en el análisis, vemos un cambio en todos los aspectos de la industria digital, la educación o el economía. El sector digital ha experimentado un mayor volumen de transformación. Se han realizado importantes trabajos y cambios y mejoras en el campo de la industria del diseño y la fabricación. El sector digital, así como el sector de la construcción, están siendo testigos de transferencias digitales. La tecnología está evolucionando para resolver varios problemas que surgen de todas las industrias. Blockchain también se está moviendo hacia la industria de la construcción. Combinar blockchain con BIM (modelado de información de construcción) es una gran combinación. Blockchain es realmente útil en la industria manufacturera. La cadena de bloques es una cadena de bloques vinculados en la que cada bloque se relaciona con el bloque anterior. La principal característica de blockchain es garantizar la seguridad de la información. Toda la información se mantiene en la cadena de bloques en forma codificada y cifrada. La cadena de bloques se utiliza para la precisión de la información que se transmite entre dos actores. La estructura general de bloques en la cadena de bloques consta de dos partes principales. La primera incluye la información principal del bloque en forma hash y la segunda parte incluye la dirección del bloque anterior en forma hash. En diferentes proyectos de construcción, estos datos pueden incluir los contratos inteligentes celebrados entre el empleador, el contratista y el consultor y también las correspondencias realizadas con diferentes organizaciones, evaluación de las horas de trabajo de los trabajadores. La información estructural es el dato más significativo en los proyectos sensibles, cuya precisión debe evaluarse, ya que el filtrado de dicha información conduce a un gran número de víctimas. El método de

investigación es descriptivo con el objetivo de familiarizarse con blockchain y combinarlo con la industria de la construcción y el modelado de información de construcción.

Palabras clave: blockchain, proyectos, BIM, construcción, tecnología

1. Introduction

Blockchain is a public digital and decentralized document of data, assets, and all related transactions performed and shared among the participants of the network. Although blockchain is significantly associated with cryptocurrencies like Bitcoin, it is considered an emerging distributed technology that can influence and evolve the operational current digital landscapes and financial trading methods, computations, public services, and almost every existing industry. The main hypothesis of blockchain is to create a digital distribution agreement. This ensures that data is decentralized across multiple nodes with similar information and no user has complete access to the network. This provides transparency of activity and increases data security. While it was originally developed for the financial transactions only, with the purpose of the creating of a system which provides the safe transaction of data between two parties without any mediator, the disruptive capacity of blockchain has become apparent with the exponential growth of various cryptocurrencies in recent years. With an emphasis on trust and collaboration between the participants, blockchain reorganizes the existing workflow of any organization where it is implemented and has many benefits including common learning, spontaneous data exchange, automatic contract execution, network security, and cooperation enhancement [1]

Building Information Modeling (BIM) is a set of common guidelines, processes, and technologies that enable a fundamental design management of building and project data throughout the life of the building's. This can create a unified data framework and organization. In construction automation, the architecture enables the Information and Communication Technology (ICT) to manage life of the buildings. During the building's lifetime, the radical features of BIM can be summarized in four aspects including integration with different databases, facilitation of documents management, the imagination of processes and analysis results, and representation of analysis and stability

assimilation. The most novel application of ICT architecture for Building Information Modeling is the traditional architecture of client-server service, which is partially based on traditional systems [2]. BIM is a modified phase that includes Architecture, Engineering, Construction, Owner, and Operator (AECOO) [3]. Information sharing in BIM varies in terms of, model type and intervals and poses dangers to participating beneficiaries such as server's responsibility, vulnerability of information to inference, and misuse of information. Therefore, these conditions develop a wide range of contractual, legal, security, and systemic challenges which prevent the development and adoption of BIM at the industry level [4].

The perfect digitalization of the construction industry is currently at the elementary level. However, with the advent of technologies such as BIM and intelligent digital technology, all participants, elements, and management of the design and construction process can cooperate on a common framework. In the construction industry, the production level, business, and management can be integrated to a considerable extent and the project data and management information are interconnected and the time will come that the sustainable building will be designed and built based on intelligent digital technology and BIM.

In the present research, the framework would be applied at user level for smart contracting and building management. Also in the present research, blockchain is considered as an inspector to monitor the accuracy of data. Since it lack computational power, it serves as a medium to store data. However, it is likely to verify the accuracy of data by referring to stored items in the blockchain.

Figure 1 depicts the general schema of blockchain technology. While initially developed solely for financial transactions with an aim to create a system that enables secure data transfer between two parties without the requirement of an intermediary, the tremendous disruptive potential of blockchain was later evident with the exponentially increasing development of various

cryptocurrencies in recent years. By placing emphasis on trust and cooperation between participants, blockchain radically reorganizes existing workflow paths in any organization in which it is implemented, bringing with it a plethora of benefits that include shared learning, instantaneous data exchange, automated contract execution, network security, and improved collaboration.

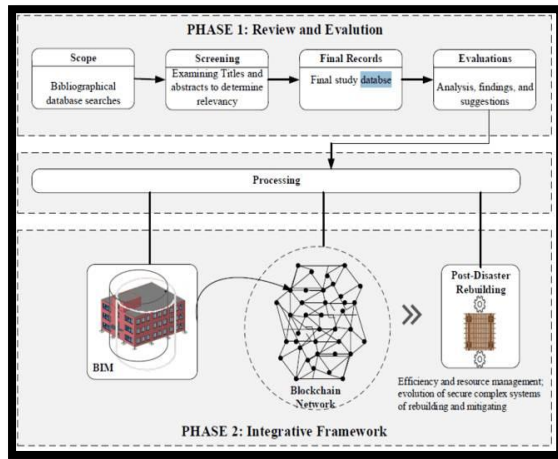


Figure 1: The outline of the research methodology. BIM, building information modeling

The chief hypothesis behind blockchain is the creation of a digital distributed consensus, ensuring that data is decentralized among several nodes that hold identical information and that no single actor holds the complete authority of the network. This enables transparency of activity and enhancement of data security. FIG. 2 depicts the general schema of blockchain technology.

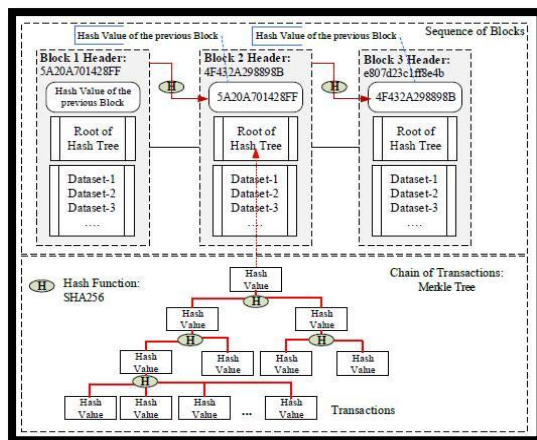


Figure 2: Outline of the concept of blockchain technology (BCT).

FIG. 2 illustrates that blockchain is composed of a linked list of blocks of transactions. Each block within the BC is recognized by a hash, generated using the SHA256 cryptographic hash algorithm on the header of the block. Also, each block references a previous block, through the (previous block hash) field in the block header. In this fashion, each block comprises the hash of its previous block inside its header. The sequence of hashes linking each block to its predecessor generates a chain going back to the first block ever created, known as the genesis block. All the transactions are stored in a schema referred to as the Merkle Tree. Such a tree save transaction at leaf nodes, and inner nodes encompass the combined hashes of their immediate subtrees (see FIG. 2). The advancement of BC technology in the finance sector has led to a surge of investors and implementation of newer BC applications and more technological innovations such as automatically executable contracts, which is known as Smart Contracts [5].

Literature Review

In this section, using Figure 2, we find that a lot of research on blockchain has been done in various fields. Now this research has been in the form of conferences, webinars, books or so on.

Sources	Key Aspects						
	BC T	BCT + AEC	BCT + BIM	Smart Contracts	Cybersecurity	Hyperledger Fabric (HLF)	Design Review
Peer-reviewed journal articles	38	4	2	2	18	6	8
Patents	1						
Conference/symposia proceedings	6	4	2	3	5	1	10
Dissertations	4	3	2	4	5		
Newspaper (relevant time) article	1						
Correspondence	1						
Websites and blogs	4					1	
Original documents/research	1	1			1	3	1
Govt/Organizational records	3						
Misc. (literary, art, audio, speech)	4						
Books							2

TABLE1: Summary of the literature related to the concept's indicators

2.Methodology

The research is designed as a non-experimental, retrospective–prospective study, which examines and curates blockchain technology and BIM integration. The research approach is based on a systematized review of the current development of Blockchain Technology. The

scope identification centers around collecting evidence through extensive literature review. The literature review provides definitions, background, historic development, current knowledge areas, and ongoing research efforts on each relevant area identified. The most prevalent fields discussed and researched currently are used to identify the keywords, which served to widen the search process in search tools such as Google Scholar, Mendeley, Microsoft Academic, Bielfeld Academic Search Engine (BASE), arXiv, WorldWideScience, ITcon Vol. 24 (2019), Nawari & Ravindran, pg. 213 RefSeek, Science.gov, ResearchGate, and Virtual Learning Resources Center. The first set of literature collected was checked for relevancy from their abstracts. A closer look into the papers' abstracts determined the relevancy of the papers. A preliminary study of research papers suggests that cybersecurity, interoperability, collaboration, Smart Contract (SC), and HLF are the main areas of emphasis. Extensive literature is studied that address these areas with respect to both BIM and BCT. The research suggests that BCT, BIM, and BCT, cybersecurity, HLF, and Smart Contract (SC) are the main aspects of the scope of this research. An extensive literature has been

studied that address these areas and is summarized in Tables 1.

Fig. 3 depicts the overall approach implemented in this research. The first phase of the research protocol focuses on the scope identification and the survey background on the current state of BCT and its applications. This phase covers the existing knowledge base, to provide background on the historical developments of prominent BCT, significant development of key features, market impact and uptake. Knowledge of ongoing research efforts could provide a fair sense of prediction of future developments. The second phase screens the literature review relevant to the goal of the research. This helped to ascertain the upper and lower limits of relevant fields with terms to current capabilities and limitations for BCT and BIM. This includes classifying the publications according to the main categories: BCT related only, BCT and the AEC, BCT, and BIM, Hyperledger Fabric, and SC. Thirdly, the collected literature is evaluated, and findings are formulated and presented. The third stage is a mixed study review since there has been minimal overlap between the fields of BCT and BIM (or between computational studies and AEC in general), it was necessary to develop a

cache of descriptive data and conceptual underpinnings pertaining to both fields. This review helped to strengthen the research question, clarify the scope and objectives, and validate the direction of the paper. Finally, conclusions about the potential applications of the emerging BC technology in the AEC industry are presented as well as proposing a new conceptualized framework resulting from integrating BCT and BIM that could facilitate the automation of design review processes.

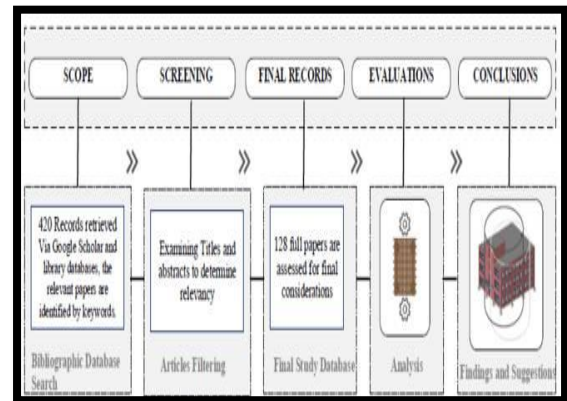


Figure 3: The General research approach

4. Blockchain Technology (BCT)

4.1 BCT Basics

Blockchain concepts, functionality, present implementation, mining, cybersecurity, and transaction protocols are discussed by many studies, such as [6,7,8,9,10,11,12,13,14,15,16,17,19,20,21,22,23, 24,25]. The advantages of using different types of BCT are studied by [26,27,28,29]. In a blockchain network, the ledger consists of a chain of sequentially arranged blocks of discretized, encrypted data, which is created and stored with cryptographic hashes upon validating a transaction. The two main parts that constitute an individual block are:

- Block header, consisting of the block version, a timestamp, Merkle tree root hash equivalent of the transactions, bits, Nonce, and a parent block. A Block version indicates the set of the block validation. Timestamp displays the current universal time. Nonce is a 4-byte field that generally starts from zero, and increases by one for every hash calculation, so acting somewhat as a

transaction counter. The parent block hash is the 256-bit hash value that references the parent block, i.e., the sequentially preceding block to the one in the discussion. The first block in the chain that does not have a precursor is called the genesis block.

- Block body, which contains the actual transaction data. This is the part of the block that effectively dictates the upper limit of the possible transactions, as well as the transaction time [30].

The digital infrastructure of the blockchain network can be divided into two layers of code:

- Fabric layer: consists of the actual blockchain code base, communication protocols, public key infrastructure, data structures for database maintenance, and smart contract capabilities. Since the blockchain network is owned and controlled by the developers, the fabric layer cannot be tampered with.
- Application layer: contains the application logic of smart contracts. It is collectively controlled by the participants who deploy the code onto the blockchain network when it is operational. Any participant that holds access and control of the deployed code can write the application layer.

The blockchain networks can be generated in several ways. These are typically organized according to the network's management and permissions, such as public (permissionless), private (permissioned), and federated [30,31,32,33]. It is worth mentioning that in a public blockchain network, any entity can join as a new user and perform operations, such as transactions or authentications.

4.2 Privacy in blockchain

A blockchain can address the accessibility and visibility of the data in a secure and efficient manner, since the ledger is distributed [34,35,36,37,38]. This ledger facilitates setting different levels of privacy, as every participant is essentially a stakeholder and no single participant has full administrative privileges. So, formulating and enforcing consensus is crucial to the blockchain operation, with respect to data updates, error-checking, and collective decision-making. The selection of which BCT to use depends much on the method of the agreement to reach consensus.

Based on the privacy, blockchains can be classified as:

- Permissioned blockchains: Permissioned Blockchains restrict the actors that can contribute to the consensus of the system state. Only a restricted set of users have the rights to validate transactions and may also restrict access to approved actors who can create smart contracts. HLF is an example of this permission type.
- Permission-less or public blockchains: Blockchain networks that are permission-less allow any participant to create consensus, as well as smart contracts, and uses the PoW mechanism to reach a consensus. They typically use a native cryptocurrency or none to validate transactions. Bitcoin and Ethereum blockchains are good examples of this type of permission.

5.Smart Contracts

Smart contracts are contracts programmed with the blockchain that automatically execute upon the fulfilment of certain conditions. This removes the requirement of a third-party intermediary for overseeing the transaction in real-time [35,36,38,39,40]. They are an extension of the blockchain that can independently enforce rules without requiring manual intervention.

Fig 4 illustrates the concept of a smart contract in a blockchain network.

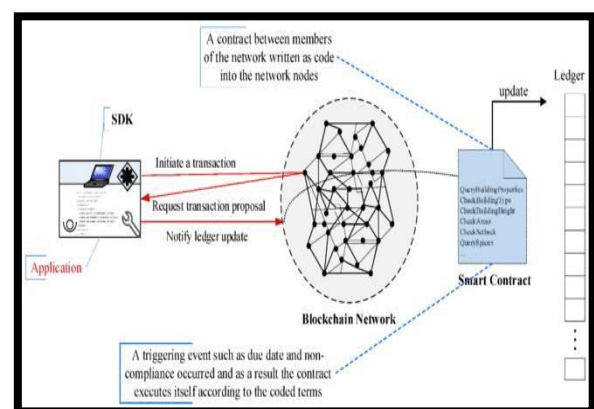


Figure 4: The concept of smart contract in a blockchain network.

The following is a definition for the concept of smart contracts [19]: “Smart contracts are digital contracts allowing terms contingent on the

decentralized consensus that is self-enforcing and tamper-proof through automated execution.” The introduction of smart contracts in blockchains has opened many new possibilities, such as complete lifecycle management of legal contracts, automated execution of contracts, and personalization of customizable contracts. In the context of the BCT taxonomy, two different definitions for the term ‘smart contracts’ are given, since the term is used interchangeably for the written code and the binding contracts [35,36]. Smart contracts codes: They are software agents fulfilling pre-set obligations and exercising certain rights and may take control of certain assets within a shared ledger. Smart legal contracts: This term focuses on the expression and implementation of the software and encompasses operational aspects and issues about the composition and interpretation of the contract. A high-level definition that combines both aspects of the smart contract and is based on automation and enforceability is given in [36]:

“A smart contract is an automatable and enforceable agreement, automatable by a computer, although some parts may require human input and control, enforceable either by the legal enforcement of rights and obligations or via tamper-proof execution of computer code.” Two widely used programming languages for writing Ethereum Smart Contract (SC) are Solidity and Serpent. Further, there are a number of emerging contract-oriented high-level languages under development, such as Viper, Lisk, and chain. In a Hyper ledger Fabric (HLF), SC is known as chaincode, which is executable code, deployed on the network, where it is invoked and validated by peers during the consensus process. The common programming languages used in developing chain code are Go, Ruby, Java, and Nodes [41].

In summary, the main characteristics of a smart contract generally include [36]:

Automation: Automation is accomplished by linking the legal prose to the smart contract code via parameters that generate instructions regarding the final operational details. **Enforceability:** The smart contract code must execute successfully, accurately, and within a reasonable timeframe. A smart legal contract must include legally enforceable obligations and rights that are expressed in complex, time-dependent, sequential, context-sensitive prose.

These may also include overriding obligations based on the fulfilment of certain conditions.

6. Limitations

On one hand, there are notable advantages of BCT that include: the trust system (consensus, mining and the public ledger), secure communication on open networks using cryptography, and encryption; transparency; removal of Intermediaries; decentralization; reduced costs; and increased transaction speed. On the other hand, there are also downsides and risks associated with the standard BCT that can be ignored at this time. These limitations may involve [7,30,16,21,24,25,34,43]:

6.1 Lack of Privacy

Decentralized public blockchains lack privacy, which will make full acceptance difficult. Not only is the information not private, but it is also readily accessible at any given moment to anyone using the system. This is also concerning considering that the computers running a large amount of the blockchain networks are in countries like Russia and China, where computer crime rates are high and personal information may be used against people living in or traveling to those countries. This is particularly an issue for Bitcoin and Ethereum systems.

6.2 Security concerns:

Blockchain-based assets are like cash. If the cash in your wallet is stolen or lost, then it is gone. Blockchain-based systems use advanced cryptography and encryption that are more secure than standard internet passwords or number access codes. However, more security can sometimes result in a system being less secure. There are countless examples of cryptocurrencies where someone has forgotten their private key and cannot access their money. With blockchain-based systems, transactions cannot be altered or reversed, and there is no intermediary to assist you if fraud occurs on your account. If you sent funds to the wrong account number (wallet) on the blockchain, then those funds are gone. If someone gains access to your private key, they can access other members’ data easily.

6.3 Lack of a centralized management entity:

The control is placed with most members of the network, creating issues with regards to control of the blockchain network. The decentralized nature of many blockchains means that the system must agree and decide the future direction of the blockchain system. With a traditional network and software, if an organization wants to make a change, they can make that change after approval from relevant departments within the organization. With a decentralized public blockchain system like Bitcoin, changes must be agreed to by a certain majority of the networks' participants. This may be over 50% but could be as high as 70% to 80% of the nodes of the network. No single entity has control over the changes or direction of a decentralized blockchain system, making them risky for businesses to use as they cannot manage any changes to the system.

6.4 Risk of a 51% attack:

If someone were able to control over 50% of the computers on a blockchain network, that person would control the transactions on the blockchain network. A malicious user controlling over 50% of the computers on a blockchain network is known as a 51% attack. Leveraging this control over a cryptocurrency network, they would theoretically be able to block new transactions from confirming, reverse transactions, and allow for moving assets freely in a Bitcoin network.

6.5 Cost:

The Proof-of-Work (PoW) algorithm that many blockchain networks use requires proof that computing power and resources contributed to the network before a block is added to the network. This proof is in the form of an answer to a puzzle that is attached to the block for the network to confirm it is correct. Solving this puzzle requires an enormous amount of computing power and electricity.

6.6 Lack of scalability:

At the current rate of energy consumption, the electricity costs of running certain public blockchain system, such as Bitcoin, and using the PoW algorithm make it unfeasible to handle the number of transactions (for example, by credit card companies like Visa and MasterCard). This is one of the factors that is presently affecting the scalability of blockchain networks.

7. Summary of BCT

Blockchain systems are generally comprised of four building blocks: (1) a shared ledger, (2) privacy, (3) trust, and (5) smart contracts (see [Figure 5](#)). These main blocks are briefly explained below:

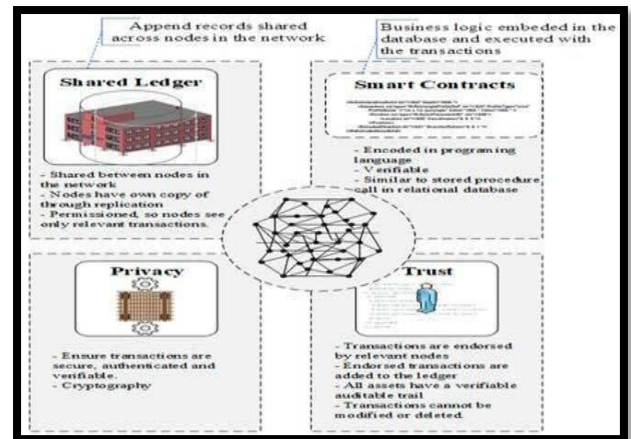


Figure 5: Main components of BCT.

7.1 Shared ledger

Shared ledger refers to the distributed transaction records in the network. With the bitcoin blockchain system, the intent was to publicize the visibility and transparency of data exchanges. However, enterprise blockchain systems requires a different approach due to the regulation of consumer data.

7.2 Privacy

Privacy is achieved through cryptographic encryption of data and ensures that transactions are authenticated and verified. Privacy is a crucial part of the BCT to strengthen security and make the distributed system on the network more difficult to breach.

7.3 Trust (consensus)

Trust means using the power of the network to verify data transaction. The trust model (consensus) is truly the heart of blockchain applications. Trust is what delivers the tenets of trust, exchanges, and ownership. Trust is what enables the blockchain to displace the transaction system, but this can only happen when trade and ownership are addressed by distributed/shared ledgers. The trust system is modified whenever new participants join the blockchain network and apply BCT to a new use

case or change. There is still much work needed to define an optimized trust system for various use cases.

8. Smart contracts

Smart contracts are business agreements embedded into the transaction database and executed automatically with transactions. Contracts consist of rules that are required in any commerce activities to define the flow of values and the state of transactions. A contract is smart because it uses a computerized protocol to execute the terms of the contract. Various contractual clauses (such as collateral, bonding, delineation of property rights, and so forth) can be transformed into machine language to enforce compliance with the terms of the contract and ensure a successful transaction. Smart contracts are intended to guarantee one party that the other will satisfy their promise. Part of the objective of such contracts is to reduce the costs of verification and enforcement due to the lack of an intermediary party to oversee transactions.

Smart contracts must be transparent (indicating that participants can see or prove each other's actions pertaining to the contract), confirmable (meaning that members can prove to other nodes in the network that a contract has been completed or breached), and private (implying that knowledge of the contents/performance of the contract should involve only the necessary members required to execute it). These advances made it possible for complex business contracts to be codified in a blockchain system.

9. APPLICATIONS OF BLOCKCHAIN TECHNOLOGY (BCT)

FIG 6 delineates the current and emerging areas of BCT applications. In the following sections, some of these areas are described.

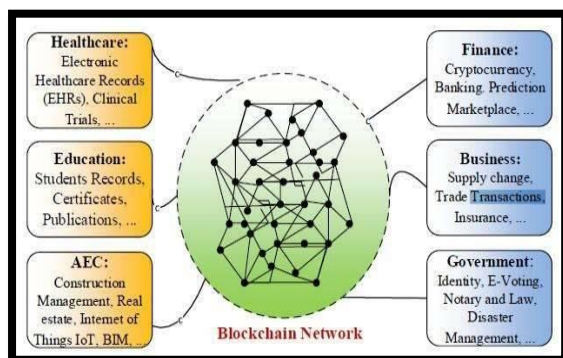


Figure 6: Classical and emergent areas of BCT applications.

9.1 AEC Industry

In the following sections, the application of blockchain technology in the AEC industry is explored, navigating the advantages and potential applications.

9.1.1 Blockchain in Construction Management

Blockchain technology, while still in its nascent developmental stages, has the potential to accelerate and streamline much of today's design and engineering practices with a multitude of benefits to the firm, individual, industry, clients, and society. The implementation of BCT could lead to the effective management and utilization of several tools that would drive efficiencies, transform industry culture, and advance futuristic advancements, such as [12]:

- Building information modeling software for intelligent and collaborative 3D design and modeling;
- cloud-based technology, allowing for real-time creation and coordination of a visualized database and serving as a platform for multi-disciplinary collaboration;
- smart contracts, a set of coded instructions that can automatically execute upon the fulfillment of certain conditions;
- reality capture technology, allowing verification and conversion of digital assets into real value;
- managing the Internet of Things (IoT);
- functionally permissioned blockchains that facilitate consensus-based collaboration.

BCT can considerably slash administrative costs, effectively protect intellectual property rights, and eliminate cumbersome paperwork, manual verifications, and contract execution. A potentially new stream of revenue for design professionals could be created by evaluating and selling designs and workflows. This, however, would also include addressing future problems that might arise, such as a possible drop in quality standards and continued liability [13].

Building a reputation is an essential asset to any organization, which is difficult to quantify and compare. BCT can facilitate the creation of a registry consisting of past achievements and

qualifications, with a goal to enable comparison of team constellations and so aiding in decision-making processes for clients and project managers to select a well-balanced team with varied skill sets, experience, and versatility [13].

10. Blockchain and BIM

This section addresses issues related to the potential capabilities of BCT in scaling and enriching the BIM process. It explores various aspects of existing BIM workflow that could benefit from the integration of blockchain technologies.

BIM is at the forefront of digital transformation in the AEC industry, encouraging collaboration and trust and simplifying data exchange. McGraw-Hill reports that BIM adoption increased to 71% in 2012 from 49% in 2009 [8,43]. BIM models present a comprehensive design model of the building that can include all aspects of the structure, like architecture, structural elements, and MEP design areas. Further, several built-in plug-ins in BIM platforms, like Autodesk Revit, enable the simulation of external site conditions, geography, weather, as well as carry out energy analysis, building energy modeling, structural analysis, etc. In the future, BIM development will eventually aim to unify all design and analysis tools in one platform.

In terms of the benefits incurred from the adoption of BIM in the AEC industry, Cannistrato [44] studied data from 408 projects over 6 years, totaling \$558,858,574, to quantify how much BIM contributed to saving money. The report indicated that BIM saved more money and the project team became more collaborative in the process. Another example is the study by [66], which indicated similar results. Their investigation covered a set of 35 case studies between 2008–2010, which all indicate cost savings due to BIM usage. The study has also noted reduced times in project schedules, improved communication, greater information exchange, and higher levels of coordination. The data clearly implies that initial costs, such as hardware upgrades, software implementation, and training of personnel, are offset on the long term upon BIM implementation. However, the BIM process still bears a number of shortcomings. These include some limitations in the schema, technical toolset, and managerial aspects of the current BIM process. More specifically, these deficiencies involve:

an insufficient toolset or methods that can efficiently comment or mark upon Requests For Information (RFIs) [45], no archive of BIM model changes and modification history, impracticality in the generated list of design errors [46], inapplicability of the integrated model for co-designing in real-time [68,69], a clear generation of comparative deviation reports contrast design changes between different file versions, detailed open model templates [47], insufficient communication standards and BIM model sharing that can lead to interoperability issues between different BIM tools [48,49,50], a lack of tools to map complex collaborative workflows and insufficient levels of interoperability [51], difficulties in assigning responsibilities and liabilities due to the overlap of roles and responsibilities, ensuring intellectual property protection, risk allocation, privacy, and third-party reliance and software agents [13,51], insufficient cyber-resilience of the software platform and consequent risks and liability to data theft, tampering, and other cyber-attacks, time-consuming re-modeling, conversions, and other repetitive tasks that could be automated during the project phases [51], the lack of a legal framework detailing model data ownership and legal/contractual issues [51].

11. Conclusions

A blockchain is defined as a decentralized database that records every transaction complete in the network, known as a ‘block’. Each block comprises encrypted data of the entire transaction history. The main concepts behind Blockchain Technology (BCT) are the creation of a digital distributed consensus, ensuring that data is decentralized among several nodes in the network that hold identical information and that no single node holds the complete authority of the network. The application of such decentralized technology in any industry would require augmented security, enforce accountability, and could potentially accelerate a shift in workflow dynamics from the current hierarchical structure to a decentralized, cooperative chain of command and effect a cultural and societal change by encouraging trust and transparency. This paper presents a comprehensive survey of BCT and its applications in various domains and examines the potential integration with building information modeling (BIM) workflow. The study examines how commissioning distributed ledger technology (DLT) such as the Hyperledger Fabric (HLF) could be advantageous in the BIM working

processes by reinforcing network security, providing more reliable data storage and management of permissions, ensuring change tracing and data ownership. The example presented indicates that the application of BCT in BIM workflow creates a system that is built on the principles of decentralization, open governance (or self-governance), and transparency, a system that rewards innovation and eradicates disintermediation. Moreover, such systems provide secure execution of BIM data exchanges and validation through privacy and trust mechanisms, in a secure process that facilitates speedy robust transactions. The cryptographically enforced interconnectivity in the blockchain applications fosters the stability and security of distributed ledgers. also presents a comprehensive survey of BCT and its applications in the built environment and examines BCT's potential integration with

Building Information Modeling (BIM) workflow. Sustainable which seeks to achieve sustainable development is now facing the challenges of energy consumption and economy in the building industry. The development of smart digital technologies such as BIM and Blockchain has many benefits for this industry. However, the main function of Blockchain + BIM in designing a sustainable building and construction process focuses on the use of intelligent energy and construction management. Considering the insufficient attention to the challenges of using BIM to propose strategies for sustainability goals, it is necessary to integrate blockchain and BIM for designing the sustainable building which requires considering the role of users who are the main actors of smart blockchain technology for managing construction projects.

Reference

1. Nawari, O., & Ravindran, S. BLOCKCHAIN TECHNOLOGY AND BIM PROCESS: REVIEW AND POTENTIAL APPLICATIONS. - *Journal of Information Technology in Construction*, 209-239 2019.
2. Zheng, R., Jiang, J., Hao, X., Ren, W., Xiong, F., & Ren, Y. bcBIM: A Blockchain-Based Big Data Model for BIM Modification Audit and Provenance in Mobile Cloud. *Mathematical Problems in Engineering* 2019.
3. Industry Training Group B. retrieved from <https://static1.squarespace.com/static/57390d2c8259b53089bcf066/t/57ec74e4b3db2bc3c7a0d5da/1475114316630/bim101+-+an+insight.pdf> 2020.
4. Erri Pradeep, A., Yiu, T., Amor, R., DeJong, M., Schooling, J., & Viggiani, G. . Leveraging Blockchain Technology in a BIM Workflow: A Literature Review. *International Conference on Smart Infrastructure and Construction 2019 (ICSIC) 2019*.
5. Nakamoto, S., (2008). Bitcoin: A peer-to-peer electronic cash system. <https://bitcoin.org/bitcoin.pdf> 2018.
6. Crosby, M.; Nachiappan, P.; Verma, S.; Kalyanaraman, V. Blockchain Technology: Beyond Bitcoin; Sutardja Center for Entrepreneurship & Technology Technical Report; University of California: Berkely, CA, USA, 2015.
7. Crosby, M.; Pattanayak, P.; Verma, S.; Kalyanaraman, V. Blockchain technology: Beyond bitcoin. *Appl. Innov.*, 2, 6–10 2016.
8. Tama, B.A.; Kweka, B.J.; Park, Y.; Rhee, K.H. A critical review of blockchain and its current applications. In *Proceedings of the ICECOS 2017, 2017 International Conference on Electrical Engineering and Computer Science: Sustaining the Cultural Heritage Toward the Smart Environment for Better Future*, Palembang, Indonesia, 22–23 August ; pp. 109–113. [CrossRef] 2017.
9. 18. Zheng, Z.; Xie, S.; Dai, H.; Chen, X.; Wang, H. An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In *Proceedings of the IEEE 6th International Congress on Big Data, BigData Congress*, Honolulu, HI, USA, 25–30 June 2017; pp. 557–564. [CrossRef] 2017.
10. Brandão, A.; São Mamede, H.; Gonçalves, R. Systematic review of the literature, research on Blockchain

11. technology as support to the trust model proposed applied to smart places. In World Conference on Information Systems and Technologies; Springer: Cham, Switzerland ; pp. 1163–1174 2018.
12. Mathews, M.; Robles, D.; Bowe, B. BIM+ Blockchain: A Solution to the Trust Problem in Collaboration In Proceedings of the CITA BIM Gathering, Dublin, Ireland, 23–24 November 2017; p. 11.
13. Turk, Ž.; Klinc, R. Potentials of Blockchain Technology for Construction Management. *Procedia Eng.* 2017, 196, 638–645. [CrossRef]
14. Atkins, B.J.B.; Mendelson, A.D. BIM Me Up, Scotty: Navigating Risk in Digital. White Paper. Available online: <https://www.theaiatrust.com/white-paper-bim-me-up-scotty-navigating-risk-in-digital-practice/> 2019.
15. Boyes, H. Cybersecurity and Cyber-Resilient Supply Chains. *Technol. Innov. Manag. Rev.* 5, 28–34.b [CrossRef] 2015.
16. Swan, M. Blockchain Temporality: Smart Contract Time Specifiability with Blocktime. In *Rule Technologies. Research, Tools, and Applications, 10th International Symposium, RuleML*, Stony Brook, NY, USA; Springer: Cham, Switzerland, ; pp. 399–404 2016.
17. Andersen, M.P.; Kolb, J.; Chen, K.; Fierro, G.; Culler, D.E.; Katz, R. Democratizing authority in the built environment. In Proceedings of the 4th ACM International Conference on Systems for Energy-Efficient Built Environments—BuildSys '17, Delft, The Netherlands, 8–9 November ; pp. 1–10 2017.
18. Wang, J.; Wu, P.; Wang, X.; Shou, W. The outlook of blockchain technology for construction engineering management. *Front. Eng. Manag.* , 4, 65–67 2017.
19. Cong, L.W.; He, Z. Blockchain Disruption and Smart Contracts. *Rev. Financ. Stud.* , 32, 1754–1797 2019.
20. Coyne, R.; Onabolu, T. Blockchain for architects: Challenges from the sharing economy. *Archit. Res. Q.* , 21, 369–374 2017.
21. Puthal, D.; Malik, N.; Mohanty, S.P.; Kougianos, E.; Yang, C. The Blockchain as a Decentralized Security Framework [Future Directions]. *IEEE Consum. Electron. Mag.*, 7, 18–21 2018.
22. Li, J.; Greenwood, D.J.; Kassem, M. Blockchain in the built environment: Analysing current applications and developing an emergent framework. In Proceedings of the Creative Construction Conference, Ljubljana, Slovenia, 2018; pp. 1–10.
23. Feig, E. A Framework for Blockchain-Based Applications. *arXiv*, arXiv:1803.00892v1 2018.
24. Hasan, H.R.; Salah, K.; Member, S. Blockchain-based Proof of Delivery of Physical Assets with Single and Multiple Transporters. *IEEE Access*, 6, 46781–46793 2018.
25. Mahamadu, A.M.; Mahdjoubi, L.; Booth, C. Challenges to bim-cloud integration: Implication of security issues on secure collaboration. In Proceedings of the International Conference on Cloud Computing Technology and Science, CloudCom, Bristol, UK, 2–5 December; Volume 2, pp. 209–214 2013.
26. Mason, J. Intelligent Contracts and the Construction Industry. *J. Leg. A. Disput. Resolut. Eng. Constr.*, 9, 04517012 2017.
27. Mason, J.; Escott, H. Smart Contracts in Construction: Views and Perceptions of Stakeholders. In Proceedings of the FIG Conference, Istanbul, Turkey, May; Available online: <http://eprints.uwe.ac.uk/35123/> 2019.
28. Hammi, A.; Bouras, A. Towards Safe-Bim Curricula Based on the Integration of Cybersecurity and Blockchains Features. In Proceedings of the INTED, Valencia, Spain,; pp. 2380–2388 2018.
29. Zheng, Z.; Xie, S.; Dai, H.; Chen, X.; Wang, H. An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends. In Proceedings of the 2017 IEEE 6th International Congress on Big Data, BigData Congress, Honolulu, HI, USA; pp. 557–564 2017.

30. Buterin, V. On public and private blockchains; Ethereum blog. Available online: <https://blog.ethereum.org/2015/08/07/on-public-and-private-blockchains> 2019.
31. Christidis, K.; Devetsikiotis, M. Blockchains and Smart Contracts for the Internet of Things. *IEEE Access*, 4, 2169–3536 2016.
32. Wood, D.G. Blockchains: What and Why.. Available online: <https://www.slideshare.net/gavofyork/blockchain-what-and-why> 2019.
33. Brakeville, S.; Perepa, B. Blockchain Basics: Introduction to Business Ledgers Get to Know This Game-Changing Technology and IBM's Contribution to It.. Available online: <https://scooblr.com/assets/uploads/2016/08/cl-blockchain-basics-intro-bluemix-trs-pdf.pdf> 2019.
34. Clack, C.D.; Bakshi, V.A.; Braine, L. Smart Contract Templates: Essential requirements and design options. *arXiv* 2016, arXiv:1612.04496.
35. Clack, C.D.; Bakshi, V.A.; Braine, L. Smart Contract Templates: Foundations, design landscape and research directions. *arXiv*, arXiv:1608.00771 2016.
36. Frantz, C.K.; Nowostawski, M. From Institutions to Code: Towards Automated Generation of Smart Contracts. In *Proceedings of the IEEE 1st International Workshops on Foundations and Applications of Self* Systems (FAS* W)*, Augsburg, Germany, 2016.
37. Seijas, P.L.; Thompson, S.; McAdams, D. Scripting smart contracts for distributed ledger technology. *IACR Cryptol. ePrint Arch.*, 1156 2016.
38. Bhargavan, K.; Delignat-Lavaud, A.; Fournet, C.; Gollamudi, A.; Gonthier, G.; Kobeissi, N.; Kulatova, N.; Rastogi, A.; Sibut-Pinote, T.; Swamy, N.; et al. Formal Verification of Smart Contracts. In *Proceedings of the 2016 ACM Workshop on Programming Languages and Analysis for Security—PLAS'16*, Vienna, Austria, pp. 91–96 2016.
39. Dhawan, M. Analyzing Safety of Smart Contracts. In *Proceedings of the Conference: Network and Distributed System Security Symposium*, San Diego, CA, USA, 16–17 February 2017.
40. Hyperledger. Hyperledger-Fabric Docs Master Documentation.. Available online: https://hyperledgerfabric.readthedocs.io/en/release-1.1/key_concepts.html 2018.
41. Kshetri, N. Blockchain's roles in strengthening cybersecurity and protecting privacy. *Telecommun. Policy*, 41, 1027–1038 2017.
42. Azhar, S. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *ASCE Lead. Manage. Eng.*, 11, 241–252 2011.
43. Cannistrato, M.P. Savings Through Collaboration: A case study on the value of BIM. *J. Build. Inf. Model.* Fall, 29–30 2010.
44. Shourangiz, E.; Mohamad, M.I.; Hassanabadi, M.S.; Banihashemi, S.S.; Bakhtiari, M.; Torabi, M. Flexibility of BIM towards Design Change. In *Proceedings of the 2nd International Conference on Construction and Project Management*, Singapore,; Volume 15, pp. 79–83 2011.
45. Kerosuo, H.; Miettinen, R.; Paavola, S.; Mäki, T.; Korpela, J. Challenges of the expansive use of Building Information Modeling (BIM) in construction projects. *Production*, 25, 289–297 2015.
46. Cerovsek, T. A review and outlook for a “Building Information Model” (BIM): A multi-standpoint framework for technological development. *Adv. Eng. Inform.*, 25, 224–244 2011.
47. Nawari, N.O. BIM Standard in O-Site Construction. *J. Archit. Eng.*, 18, 107–113 2012.
48. Nawari, N.O. BIM standards: Advancement and industry deployment. In *Proceedings of the 14th International Conference on Computing in Civil and Building, Engineering*, Moscow State University of Civil Engineering, Moscow, Russia, 27–29 June 2012.
49. Ahn, Y.H.; Kwak, Y.H.; Suk, S.J. Contractors' Transformation Strategies for Adopting Building Information Modeling. *J. Manag. Eng.*, 32, 05015005 2015.
50. Sherif, A.; Jinkook, L.; Chuck, E. Automated Cost Analysis of Concept Design BIM Models. In *Designing Together: Proceedings of the 14th International Conference on Computer Aided Architectural Design*; Les Éditions de l'Université de Liège: Liège, Belgium, ; pp. 403–418 2011.

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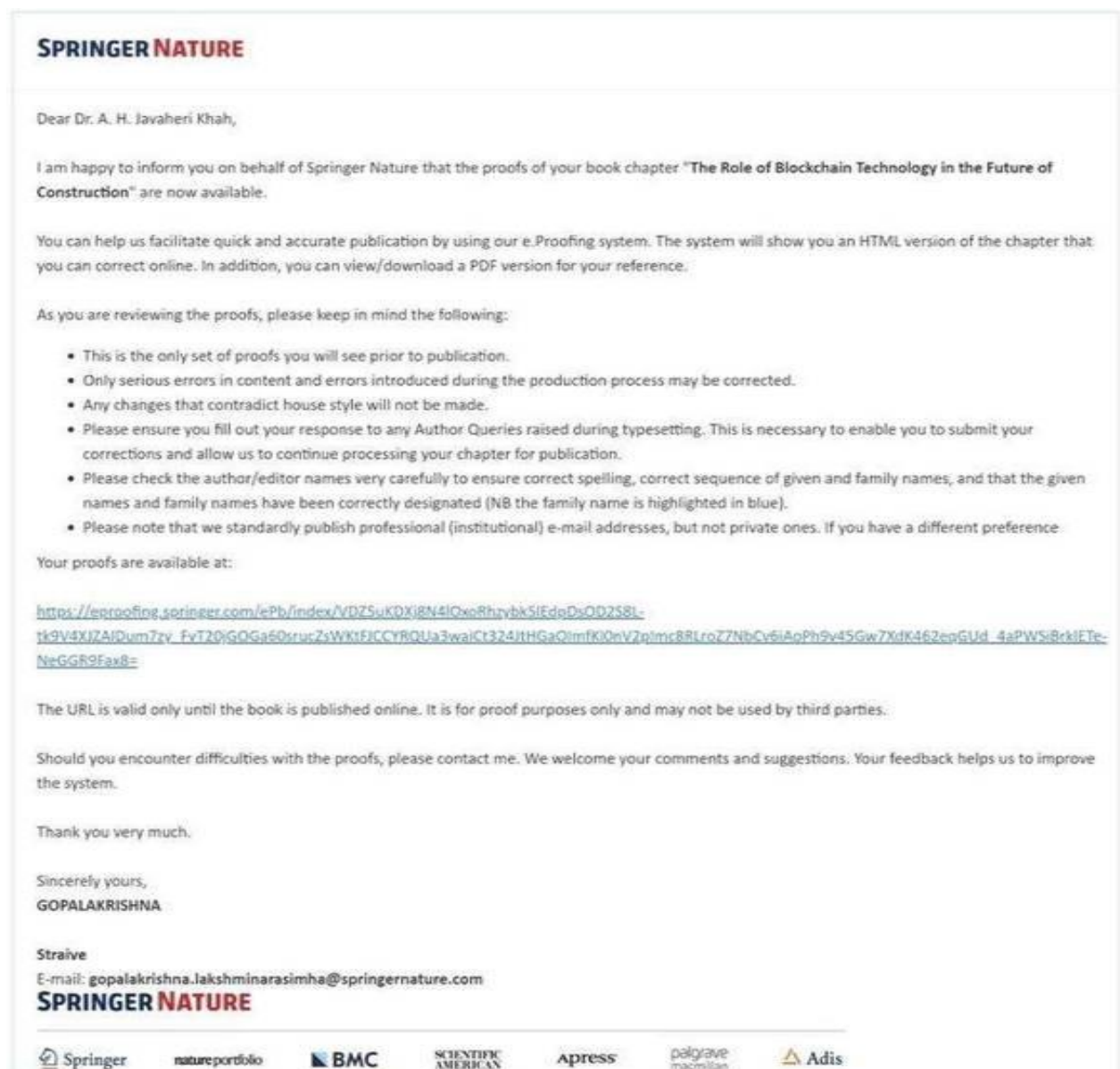
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Figure H.4: Article Certificate



Application of blockchain in BIM: a systematic review

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Abstract. Looking around, we see a change in all aspects of the digital industry, education, or the economy. The digital sector has witnessed a larger volume of transformation. Significant work and changes and improvements have been made in the field of design and manufacturing industry. The digital sector, as well as the construction sector, are witnessing digital transfers. Technology is evolving in solving various problems arising from all industries. The Blockchain is also moving towards the construction industry. Combining blockchain with BIM (building information modeling) is a great combination. Blockchain is really useful in the manufacturing industry. The blockchain is a chain of linked blocks in which each block relates to the block before it. The main characteristic of blockchain is to ensure information security. All the information is held in the blockchain in a codified and hashed form that has been encrypted. The blockchain is used for the accuracy of information transacted between two actors. The overall structure of blocks in the blockchain consists of two main parts. The first one includes the main information of the block in hashed form and the second part includes the address of the prior block in hashed form. In different construction projects, these data can include the smart contracts concluded between the employer, contractor, and consultant and also the correspondences done with different organizations, evaluation of workers' work hours. The structural information is the most significant data in the sensitive projects the accuracy of which should be assessed, since filtering such information leads to heavy casualties. The research method is descriptive with the Goal of getting acquainted with blockchain and combining it with the construction industry and building information modeling.

Keywords: blockchain, projects, BIM, construction, technology

1. Introduction

A blockchain is a digital, decentralized public document of data, assets, and all related transactions that is executed and shared among network participants. Although most associated with digital cryptocurrencies such as Bitcoin, blockchain is seen as an emerging technology that can transform the current digital operating landscape and business practices of finance, computing, government services, and almost any existing industry [1]. Transform. The main hypothesis behind blockchain is the creation of a digitally distributed agreement that ensures that data is decentralized across multiple nodes with the same information and that no user has full network authority. This provides transparency and increased data security. While initially designed only for financial transactions with the aim of creating a system that enables secure data transfer between the two parties without the

need for intermediaries, later with the exponential development of various cryptocurrencies in recent years, the extremely destructive capacity of blockchain is evident became. Emphasizing trust and collaboration between participants, the blockchain reorganizes existing workflow paths in each organization in which it is implemented, and includes many benefits, including shared learning, instant data exchange, and automated contract execution, Network security and improved collaboration. On the other hand, the emergence of new technologies can be the engine for the development of other technologies, especially space technology, which is dependent on a set of technologies. Blockchain technology is one of the emerging technologies. This technology in the space industry can be effective in the development of the space industry as one of the essential infrastructures in the digital transformation to provide a safe platform for the

transfer of any type of space data [2].

Figure 1 shows that there are 5 steps in blockchain, which include: 1- Transaction 2- Block 3- Confirmation 4- Hash 5- performance. On the other hand, from the beginning to the end of the blockchain transaction can be seen in Figure 1.

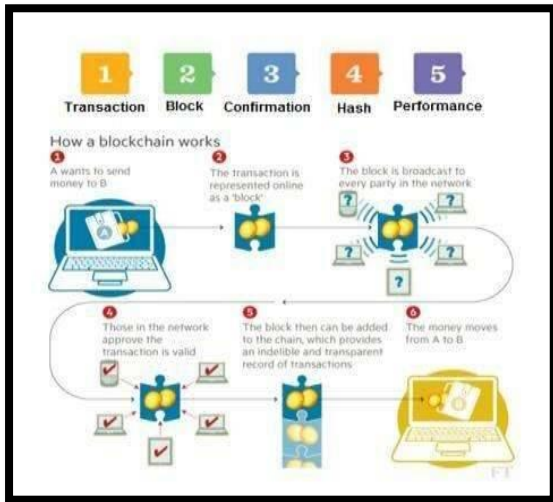


Fig1. General concept of BCT blockchain technology (Chris Linton 2017)

2. (BIM) Building Information Modeling

building information modeling has found wide applications from design and construction to operation and even demolition of buildings. This technology helps the project manager and stakeholders to make the right decision at each stage by digitally displaying the building specifications. Building information modeling All construction management activities according to the contract documents are related to two categories of drawings and specifications, so that with the help of drawings, the quantity of work and its quality are determined based on technical specification. In general, BIM adds 3D modeling components to specific drawings and related specifications. This feature is that each member of the design shown in BIM, in addition to its three-dimensional physical nature, provides a set of information about the various activities and tasks of construction management. This information relates to the entire project life cycle, from feasibility studies to conceptual design, first and second phase studies, preparation, construction and installation, commissioning, operation period and even its completion. So if we want to summarize BIM in a short sentence, the process of producing and managing building information will be throughout its life cycle. In

other words, the BIM model is a three-dimensional digital representation of the physical and functional characteristics of a building [3].

At present, the use of technology and the complete digitalization of the construction industry are still in the early stages. However, with the advent of technologies such as BIM + intelligent digital technology, all participants, and the entire management of the building design and construction process, can work together in a common platform. In the construction industry, the level of production, trade and management can also be effectively integrated, project data and management information are interconnected, and the era of designing and building sustainable buildings under BIM + smart digital technology will come.

3. State of the Art

According to the studies conducted in a certain period of time, about 12 articles, 21 conferences, 4 websites, 3 theses and 3 books have been registered in connection with blockchain. On the other hand, 4 articles, 3 conferences, 3 websites, and 2 theses have been registered in relation to Bakchin and Bim [4]. Now we will review these articles related to blockchain.

Due to the recording of all information in the blockchain and the understanding of the bulkiness of the block chain, we should include this in our work and store the necessary information in the block chain [5].

To recover data, there is no need to record all transactions, even -failed transactions. In this research, it is possible to speed up information retrieval by taking inspiration from this research [6].

Considering that in the -not-so-distant future, digital currency will replace regular currencies, it is -possible to look at the use of cryptocurrencies in the research [7].

the public-private blockchain will be used to prevent the significant growth of the block chain and to increase the speed of information recovery [3].

The basis of the contract work in the proposed model is the smart contract, which can be used sufficiently from the experiences of this research [8].

4. Methodology

This research is written using historical and prospective information to manage and combine building information modeling and blockchain. The information of this research has been used from books, magazines, articles, etc. related to blockchain and BIM.

5. Blockchain Technology

Block is a combination of the two words Block meaning block or piece and Chain meaning chain. Literally, blockchain means blockchain. A block is a space that can store a certain amount of information. By joining these blocks together, a chain of blocks is obtained that contains interconnected data. This connection is made with hashes. Hash is the same cryptographic code that is based on the information in a block. Hashes are a set of numbers and letters that contain the entire information of a block. When a block is written and its information is completed, a hash is assigned to it, and this hash will be placed in the next block to determine if the new block is a continuation of the previous block. Also, the production of these hashes continues and the previous block hash is placed in the next block, and by following the hashes, the first generated block can be reached. For example, this hash is the first bitcoin block known as the Genesis Block. Anything can be turned into a hash and encrypted. With the hashing algorithm, large data can be reduced to a few letters and numbers, and in this way, the information of a block can be converted into a multi-bit expression [9].

In the figure number 2 the components of a blockchain, which includes the genesis block, hash, previous block hash, etc ...

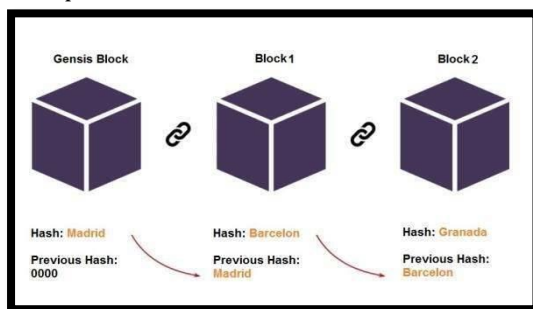


Fig 2. The structure of a blockchain (author)

The digital infrastructure of the blockchain network can be divided into two layers of code:

5.1. Fabric layer

A blockchain's data structure is expressed as a linked list of blocks in which transactions are ordered. The data structure of the blockchain consists of two fundamental elements: pointers and a linked list. A linked list is a list of chained blocks with data and pointers to the previous block. Pointers are variables that refer to the position of another variable, and a linked list is a list of chained blocks with data and pointers to the previous block. The Merkle tree is a binary tree of hashes. Each block contains the root hash of the Merkle tree and information like the preceding block's hash, timestamp, nonce, block version number and current difficulty goal. For blockchain systems, a Merkle tree provides security, integrity and irrefutability. The blockchain system is built on Merkle trees, cryptography and consensus algorithms. Because it is the first in the chain, the genesis block, i.e., the first block, does not contain the pointer. To protect the security and integrity of the data contained in blockchain, transactions are digitally signed. A private key is used to sign transactions, and anyone with the public key may verify the signer. The digital signature detects information manipulation. Because the data that is encrypted is also signed, digital signatures ensure unity. As a result, any manipulation will render the signature invalid. The data cannot be discovered because it is encrypted. It cannot be tampered with again, even if it is caught. The sender's or owner's identity is also protected by a digital signature. As a result, a signature is legally linked to its owner and cannot be disregarded [10].

5.2. Application layer

Smart contracts, chaincode and decentralized applications (DApps) make up the application layer. The application layer protocols are further subdivided into the application and the execution layers. The application layer comprises the programs that end-users utilize to communicate with the blockchain network. Scripts, application programming interfaces (APIs), user interfaces and frameworks are all part of it [11]. The blockchain network serves as the back-end technology for these applications, and they communicate with it via APIs. Smart contracts, underlying rules and chaincode are all part of the execution layer [12]. Although a transaction moves from the application layer to the execution layer, it is validated and executed at the semantic layer. Applications give instructions to the execution layer, which executes transactions and ensures the blockchain's deterministic nature [13].

5.3. Privacy in Blockchain

One of the main advantages of blockchain is its security. Blocks are always stored in chronological order, and it is very difficult to change a block after it has been added to the end of the blockchain. Each block has its own hash code, as well as the hash block that precedes it. If a hacker wants to edit a block, the hash of that block will change [14].

This means that the hacker will have to change the hash of the next block in the chain, and this process will continue. Therefore, to change a block, a hacker must change every other block after it, which requires a lot of computational power to do so. Although blockchain uses consensus algorithms, it is still vulnerable to a 51% attack. In these cases, the attacker controls more than 50% of the total blockchain computing power and gains the ability to overcome other participants in the network. However, this type of attack is unlikely to occur, because its implementation requires a lot of effort and computing power [15].

6. Smart contracts

With the advent of blockchain technology and the creation of the world's first digital currency (Bitcoin), the method of sending and receiving money, documents and documents has changed and intermediaries such as banks are gradually being phased out. The alternative to this system is smart contract technology. Simply put, smart contracts take on the task of trading. A process that is already performed by a third party. Like all contracts in our daily lives, like written contracts or software contracts, a smart contract has the same terms as a contract; However, unlike traditional contracts, the terms of the smart contract run as zero and 1 or code running on a blockchain network such as Atrium [16]. This is usually done by intermediaries for trading jobs. In fact, a smart contract is a program that can be stored on the blockchain and activated under certain pre-determined conditions. These contracts are used to automatically execute the agreement, so all contract participants can reach a final result very quickly, without interference and in a fraction of the time. These contracts also activate the workflow automatically, and when the conditions are right, the next activity begins [17].

Smart contracts are written in a variety of programming languages (including Solidity, Web Assembly, and Mickelson). In the Atrium network, each smart contract code is stored on the blockchain, allowing anyone interested to check the contract code and current status to confirm its performance. Figure 3 shows the

differences between smart contracts and traditional contracts [15].

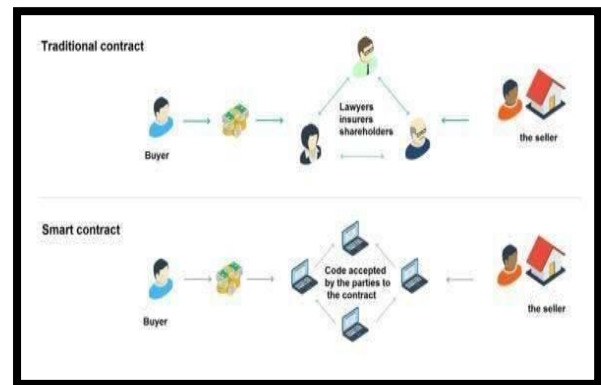


Fig3. The difference between smart contracts and traditional contracts (author)

6.1. Advantages of Smart Contract

Because smart contracts are based on Blockchain technology, they have high security and speed, are cost-effective, and at the same time offer a great variety to users.

- Security: The smart contract is intelligently distributed among all nodes in the network. This eliminates the possibility of losing or changing it illegally.
- Low cost and high speed: These contracts are executed automatically and eliminate the need for intermediaries and third parties.
- Variety: There is a wide variety of smart contracts that you can choose from and change some of the clauses according to your needs [10].

6.2. Disadvantages of smart contract

But smart contracts, just like any other technology, are not without flaws and have disadvantages.

- The human factor: Codes are written by humans in smart contracts, and humans can make mistakes. If the smart contract is on the block, it can no longer be changed. One of the most famous human errors about smart contracts happened to The DAO. The developers' mistake in writing this code cost user dearly, and some hackers were able to exploit the mistake and steal about \$ 60 million.
- Uncertain legal status: No country has yet enacted rules for smart contracts. As a result, it is possible that some countries will soon adopt a series of regulations in this area, which will change the legal status of this type of contract.
- Cost of writing: Smart contracts cannot be implemented without programming. It is necessary to use one or more expert programmers to write this type of contract, and

of course the internal structure of the contracting companies must be compatible with Blockchain technology [10].

7. Applications of Blockchain technology

Blockchain technology should be introduced as one of the greatest innovations of the 21st century due to its high upward impact in various industries and sectors. One can easily understand the impact of this technology on human life these days in one sentence, also Governments, businesses and other organizations are trying to explore and even implement blockchain technology in various fields, and many of these fields have nothing to do with digital currencies. Blockchain can bring security, immutability, traceability, and transparency across a distributed network. So, Blockchain, relying on these unique features, is a viable option for implementation in areas where traditional infrastructure is inefficient [18].

8. AEC

The full form of AEC is “Architectural Engineering and Construction.” The acronym describes the collaboration of architects, engineers, and construction professionals on residential, commercial, or industrial construction projects to ensure their smooth completion. These three disciplines are integral to the project from design to execution [19].

- Architecture: Architects design the concept for the construction, restoration, or refurbishment of buildings.
- Engineering: Engineers oversee the construction and maintenance projects necessary in the realization of that concept.
- Construction: Construction project managers and their skilled laborers execute the design.

8.1. Challenges AEC industry

The biggest challenge facing the AEC industry is workforce shortages. Between an aging workforce and a large skills gap, it can be very hard to find the talent the industry needs. Architecture, Engineering, and Construction positions require highly skilled leaders with safety awareness, technical expertise, and project management skills, a combination that can be hard to find [20].

“The ability to find talent for the AEC industry is changing. Younger people are entering the workforce, older workers are leaving the workforce, and more people are working remotely,” explains Stacia Norman, Director of Construction Recruitment at Orion Talent, “We have a shortage of experienced people to fill the needs of the AEC industry. It will be a challenge to recruit, hire and retain talent in 2022; but, it can be done with the right recruiting team in place [21].

8.2. Future for AEC

This has been a turbulent time for the AEC industry due to the loss of revenue during the pandemic. Companies looking to evolve need to think outside the box and adopt new technology. They should start by identifying new segments and even locations to target, and then move forward by embracing the time and cost savings that can be achieved by moving to the Cloud or leveraging tech like BIM Level 2 [20, 21].

9. Blockchain and Project Management

In the information compression process, the focus of information management is due to technology. The blockchain can provide a reliable infrastructure for managing information during the construction cycle. Even if used in a building information modeling (BIM) project, the role of the blockchain is essential to managing information about who did what and when. We conclude that the blockchain offers solutions to many of the problems in building information management [22].

10. Blockchain and BIM

This section addresses issues related to the potential capabilities of BCT in scaling and enriching the BIM process. It explores various aspects of existing BIM workflow that could benefit from the integration of blockchain technologies. BIM is at the forefront of digital transformation in the AEC industry, encouraging collaboration and trust and simplifying data exchange. McGraw-Hill reports that BIM adoption increased to 71% in 2012 from 49% in 2009. BIM models present a comprehensive design model of the building that can include all aspects of the structure, like architecture, structural elements, and MEP design areas. Further, several built-in plug-ins in BIM

platforms, like Autodesk Revit, enable the simulation of external site conditions, geography, weather, as well as carry out energy analysis, building energy modeling, structural analysis, etc. In the future, BIM development will eventually aim to unify all design and analysis tools in one platform. In terms of the benefits incurred from the adoption of BIM in the AEC industry, Cannistrato. studied data from 408 projects over 6 years, totaling \$558,858,574, to quantify how much BIM contributed to saving money. The report indicated that BIM saved more money and the project team became more collaborative in the process. Another example is the study by, which indicated similar results. Their investigation covered a set of 35 case studies between 2008–2010, which all indicate cost savings due to BIM usage. The study has also noted reduced times in project schedules, improved communication, greater information exchange, and higher levels of coordination. The data clearly implies that initial costs, such as hardware upgrades, software implementation, and training of personnel, are offset on the long term upon BIM implementation. However, the BIM process still bears a number of shortcomings. These include some limitations in the schema, technical toolset, and managerial aspects of the current BIM process. More specifically, these deficiencies involve: an insufficient toolset or methods that can efficiently comment or mark upon Requests For Information (RFIs), no archive of BIM model changes and modification history, impracticality in the generated list of design errors, inapplicability of the integrated model for co-designing in real-time, a clear generation of comparative deviation reports contrast design changes between different file versions, detailed open model templates, insufficient communication standards and BIM model sharing that can lead to interoperability issues between different BIM tools, a lack of tools to map complex collaborative workflows and insufficient levels of interoperability, difficulties in assigning responsibilities and liabilities due to the overlap of roles and responsibilities, ensuring intellectual property protection, risk allocation, privacy, and third-party reliance and software agents, insufficient cyber-resilience of the software platform and consequent risks and liability to data theft, tampering, and other cyber-attacks, time-consuming re-modeling, conversions, and other repetitive tasks that could be automated during the project phases, the lack

of a legal framework detailing model data ownership and legal/contractual issues [4].

11. Blockchain and Space

Blockchain technology, relying on its inherent capabilities, can be used not only as a technology but also as a tool. This technology can have a positive effect in reducing electrical and operational complications and increasing security. The following are examples of some of the features of blockchain, based on which the role of blockchain in the development of the space industry can be ascertained. These features include:

- Distributed database
- Peer-to-peer transactions
- Trust
- Transparency
- Immutability of records
- Implicit logic

Based on this, blockchain technology, per se, can be used in the space industry [2].

12. Protection of space information by Blockchain

Security in the blockchain platform in the space field can be mentioned in several cases. The blockchain distributed network removes the vulnerability of the omniscient and beyond that, it marks the spatial assets based on proprietary cryptography and protects them against disturbances and data manipulation to an appropriate extent. It also informs the companies and owners of this industry about all their existing assets in the space and their status and provides them with clear information. This technology detects any attack, manipulation or sabotage in systems or information in the form of a warning to the operators. In addition to the above, the encryption of transactions and the presence of smart contracts in this system increase its security, which is an example of a type of secure communication in the space domain. While none of the intermediaries have the possibility of decrypting it due to not having hash codes and private keys.

The presence of features such as block encryption is one of its security aspects. During the investigations on the platform of the blockchain (hash function is SHA-256), the probability of attacking the blocks (that is, placing an unrelated block in the chain) after about 20 correct blocks, is almost zero. The results are obtained based on the Poisson function and the Poisson process [23]. In figure number 4, after about 20 blocks, the probability of hacking the blockchain becomes zero.

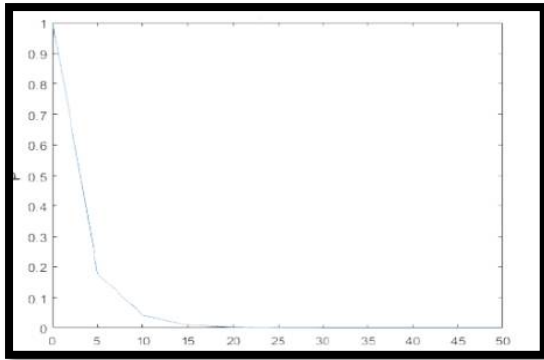


Fig 4. The probability of attacking the blockchain chain according to the number of trusted blocks (Yingyu Pan, 2018)

1.12 Conclusions

This article is an overview of blockchain and its applications in the construction industry, BIM and space industry. The construction industry is looking for sustainable development that faces the challenges of energy consumption and

economy in the construction industry. The development of smart technologies has many benefits for the construction industry. However, the main function of blockchain and BIM in building design and sustainable construction process is focused on intelligent energy use and construction management. The future of blockchain technology is somewhat unclear due to the way governments and businesses are looking to stimulate innovation and applications. It is quite clear that one day there will be a public blockchain that anyone can use. Blockchain proponents expect the technology to be embedded in the automation of specific tasks to help in all areas. The evolution of blockchain technology in recent years has increased the demand for blockchain professionals. Companies are also planning to use blockchain applications in their business areas to reap its benefits. With the entry of this technology into the space field, in addition to facilitating some matters or increasing safety and security, new capabilities and applications must be created.

References

1. Crosby M, Pattanayak P, Verma S, Kalyanaraman V (2016) Blockchain technology: Beyond bitcoin. *Applied Innovation* 2, 71. issn.
2. Jones KL (2019) Blockchain: Building consensus and trust across the space sector. *35th Space Symposium, Technical Track, Colorado Springs, Colorado*, p. 19.
3. Erri Pradeep A, Yiu T, Amor R (2019) Leveraging blockchain technology in a BIM workflow: A literature review. *International Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving data-informed decision-making*, pp. 371-380, ICE Publishing. doi: <https://doi.org/10.1680/icsic.64669.371>.
4. Nawari NO, Ravindran S (2019) Blockchain technology and BIM process: review and potential applications. *J. Inf. Technol. Constr.* 24, 209-238. issn. doi: <https://www.itcon.org/2019/12>.
5. Xue F, Lu W (2020) A semantic differential transaction approach to minimizing information redundancy for BIM and blockchain integration. *Automation in construction* 118, 103270. issn: 0926-5805. doi: <https://doi.org/10.1016/j.autcon.2020.103270>.
6. Dounas T, Jabi W, Lombardi D (2020) Smart contracts for decentralised building information modeling. issn: 2684-1843. doi: <http://10.13140/RG.2.2.34686.20809>.
7. Ye X, Sigalov K, König M (2020) Integrating BIM-and cost-included information container with Blockchain for construction automated payment using billing model and smart contracts. *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, pp. 1388-1395, IAARC Publications. doi: <https://www.proquest.com/conference-papers-proceedings/integrating-bim-cost-included-information/docview/2526369972/se-2?accountid=50247>.
8. Shojaei A, Flood I, Moud HI, Hatami M, Zhang X (2019) An implementation of smart contracts by integrating BIM and blockchain. *Proceedings of the Future Technologies Conference*, pp. 519-527, Springer. doi: https://doi.org/10.1007/978-3-030-32523-7_36.
9. Buterin V (2015) On public and private blockchains. *Ethereum blog*
10. Nawari NO, Ravindran S (2019) Blockchain and building information modeling (BIM): Review and applications in post-disaster recovery. *Buildings* 9, 149. issn: 2075-5309. doi: <https://doi.org/10.3390/buildings9060149>.
11. Clack CD, Bakshi VA, Braine L (2016) Smart contract templates: foundations, design landscape and research directions. *arXiv preprint arXiv:1608.00771*. issn. doi: <https://doi.org/10.48550/arXiv.1608.00771>.
12. Clack CD, Bakshi VA, Braine L (2016) Smart contract templates: essential requirements and design options. *arXiv preprint arXiv:1612.04496*. issn. doi: <https://doi.org/10.48550/arXiv.1612.04496>.
13. Christidis K, Devetsikiotis M (2016) Blockchains and smart contracts for the internet of things. *Ieee*

Access 4, 2292-2303. issn: 2169-3536. doi: 10.1109/ACCESS.2016.2566339.

14. Seijas PL, Thompson S, McAdams D (2016) Scripting smart contracts for distributed ledger technology. *Cryptology ePrint Archive*. issn. doi: <https://orcid.org/0000-0002-2350-301X>.
15. Frantz CK, Nowostawski M (2016) From institutions to code: Towards automated generation of smart contracts. *2016 IEEE 1st International Workshops on Foundations and Applications of Self* Systems (FAS* W)*, pp. 210-215, IEEE. doi: 10.1109/FAS-W.2016.53.
16. Bhargavan K, Delignat-Lavaud A, Fournet C, Gollamudi A, Gonthier G, Kobeissi N, Kulatova N, Rastogi A, Sibut-Pinote T, Swamy N (2016) Formal verification of smart contracts: Short paper. *Proceedings of the 2016 ACM workshop on programming languages and analysis for security*, pp. 91-96. doi: <https://doi.org/10.1145/2993600.2993611>.
17. Dhawan M (2017) Analyzing safety of smart contracts. *Proceedings of the Conference: Network and Distributed System Security Symposium, San Diego, CA, USA*, pp. 16-17.
18. Benisi NZ, Aminian M, Javadi B (2020) Blockchain-based decentralized storage networks: A survey. *Journal of Network and Computer Applications* 162, 102656. issn: 1084-8045. doi: <https://doi.org/10.1016/j.jnca.2020.102656>.
19. Ablyazov T, Petrov I (2019) Influence of blockchain on development of interaction system of investment and construction activity participants. *IOP conference series: materials science and engineering*, p. 012001, IOP Publishing.
20. Ahram T, Sargolzaei A, Sargolzaei S, Daniels J, Amaba B (2017) Blockchain technology innovations. *2017 IEEE technology & engineering management conference (TEMSCON)*, pp. 137-141, IEEE. doi: 10.1109/TEMSCON.2017.7998367.
21. Kshetri N (2017) Blockchain's roles in strengthening cybersecurity and protecting privacy. *Telecommunications policy* 41, 1027-1038. issn: 0308-5961. doi: <https://doi.org/10.1016/j.telpol.2017.09.003>.
22. Mathews M, Robles D, Bowe B (2017) BIM+ blockchain: A solution to the trust problem in collaboration. *CITA BIM Gathering 11*, 2017. issn. doi: <https://doi.org/10.21427/D73N5K>.
23. Pan Y (2018) Mathematical Derivation and Analysis of Success Probability of Bitcoin Attack. *2018 International Conference on Network, Communication, Computer Engineering (NCCE 2018)*, pp. 129-133, Atlantis Press. doi: <https://doi.org/10.2991/ncce-18.2018.22>.

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Figure I.5: Article Certificate



A REVIEW OF THE APPLICATION OF PREFABRICATED STRUCTURES USING BUILDING INFORMATION MODELING

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Abstract

Prefabricated construction technique is a reusable mold or "form" that is prepared in a controlled environment, transported to the construction site, and erected. Standardized and intended for the stability, longevity, and structural integrity of the structure, prefab construction technology comprises a variety of prefabricated parts such as walls, beams, slabs, columns, stairs, landings, and certain unique features. On the other hand, Building Information Modeling (BIM) is becoming increasingly accepted for prefabricated construction because it enables efficient design, construction, and construction through the production and management of virtual models that combine physical characteristics and functional behavior. Architects, civil engineers, and constructors have long been interested in new techniques of building construction that enhance quality, save time and cost, and raise their productivity. BIM is a multidimensional model that simulates building geometry, spatial connections, geographic data, the amount and qualities of all building components, and their intelligent interconnection. This technology is a novel approach to the design, development, and administration of buildings, characterized by very high quality and coordination. As a result of advancements in digital architecture, prefabrication, and all types of optimization in the design of structures, building information modeling technologies are increasingly used in construction industry projects. Building information modeling may have a considerable influence on prefabricated construction for this reason. In addition, it is intended to install prefabricated construction components and find operational interferences by examining the building model. This article analyzes the benefits and drawbacks of prefab construction. It also evaluates the global construction industry's requirement for insurance.

Keywords: *building, construction, technology, bim, country*

1. INTRODUCTION

Owing to the specific implementation problems and obstacles encountered by the majority of building projects, it is essential to apply modern technology to handle these issues in order to impact the two essential factors of time and cost. Avoid being affected by factors that have a negative effect on the success or failure of a project. Recent advances have been made in the field of providing alternative methods and techniques (1). A accurate virtual model of a structure, known as a BIM, simulates a building project in a virtual environment using BIM technology. The creation of a computerized building information model (2). Each component's parametric components have its own detail ideas and include the necessary information, including architectural and structural concepts, how to create and price them, and the installation date. It is applied on the model and evaluated from the design phase until the conclusion of the project's operational lifetime (3). Figure 1 depicts a building designed using building information modeling. Figure number two shows the premade components.



Figure 1: designing using building information modeling (18)



Figure 2: manufactured components (19)

2. LITERATURE REVIEW

Building information modeling has been the topic of a considerable variety of research, each of which has concentrated on different aspects and applications of the field. Each research, using a distinct technique, has discovered the need to analyze the status or effectiveness of the technology, improve it, appreciate its benefits, and advance its future development and wider deployment. The analyzed studies are often divided into three categories. The first category consists of research that have examined the degree of acceptance of building information modeling, as well as the obstacles and problems associated with its implementation. The third area is dedicated to research conducted to develop a model for enhancing and better understanding technology. The second category comprises research examining the applications, benefits, and usefulness of information modeling technology construction (4).

In a separate study, they identified barriers to the deployment of building information modeling. Via a questionnaire, this research determined that construction industry professionals are disinterested in and unfamiliar with building information modeling. It also found that a lack of support and a lack of desire to promote it are the greatest impediments to its adoption among policymakers. Additional obstacles to the application of this technology in Iran include the paucity of training materials and a lack of knowledge and comprehension. Additional challenges to the adoption of this technology include reluctance to adapt present methods, costs, Internet speed, a lack of vital infrastructure, and ignorance of potential benefits (5).

In contrast, based on studies conducted to the end of 2015, the United States is well ahead of other countries in terms of the production of scholarly articles in the field of building information modeling. The Nordic countries also rank 59 in the worldwide production of scientific articles in this field. This topic is based on a chart that was posted in 2012 and investigated through 2015. The ranking of the countries and their rating remain still in force after the competition has concluded. Notably, the significant difference depicted in the following diagram can be attributed to a number of factors, including the use of different operating systems, a preference for new technologies, the presence of universities

and other educational institutions, and particular trends in building information modeling and construction management (6). The amount of papers produced in developed countries is seen in chart 1.

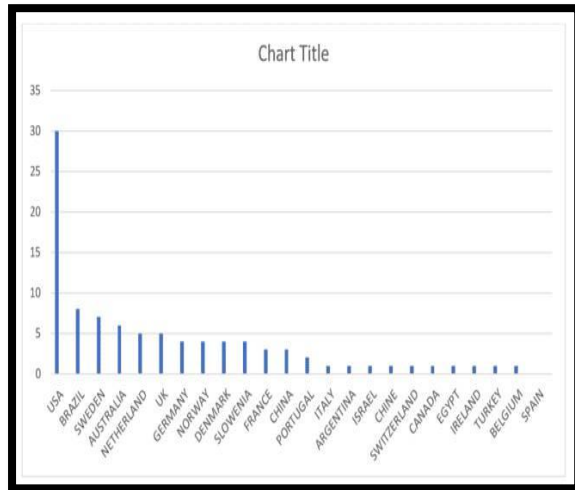


Figure 3: Articles published in the field of building information modeling by countries until 2015 (6)

3. BUILDING INFORMATION MODELING

The engineering, architectural, and construction sectors have a misunderstanding of the software component of building data modeling, despite its significance. Instead, data modeling is seen as a valuable tool. The generation of building information, which provides information on the whole structure as well as full, unified documents in a database, is a new advance in the design and documentation procedures employed in the construction industry. As these data are parametric, they are all interconnected. Each alteration to a model component affects all aspects of the project. Modeling of building data includes both actual building data and two-dimensional building maps, which are unusual in maps made using CAD software. (7,8)

3.1. Advantages of using building information modeling

- 3.1.1. Time-related issues: About time, BIM often reduces the amount of time required to produce construction drawings.
- 3.1.2. 4D models: By using 4D models, the construction planning chain may be analyzed and shared with the rest of the project team. The building model's components should be

arranged into groups depending on the stages of construction and linked to project planning activities.

- 3.1.3. Cost-related issues: A feature of BIM is that each component offers data on its length, width, and height, as well as any other information necessary for a quantitative project estimate.
- 3.1.4. Eliminating waste: The ability to rapidly develop alternative models, maintain information and coherence of the stated model (preventing interference), and provide automatic reports all contribute to reliable data that is typically discarded and reconstructed. Reduces the time and effort required to get information.
- 3.1.5. Quality: With BIM's many capabilities, it is straightforward to give the opportunity for quality verification and to attain the ultimate goal of higher-quality buildings. (9)

3.2. Disadvantages of using building information modeling

- 3.2.1. Conventional working practices and low acceptance of contemporary technologies in construction projects, especially in third-world countries.
- 3.2.2. The requirement for employee and operator training in consulting, employer, and contracting organizations.
- 3.2.3 According to several firms, one of the obstacles to the broad use of building information modeling is that it merely refers to 3D design. (9)

4. BUILDING INFORMATION MODELING IN SPAIN

Directive 2014/24/UE of the European Union has been implemented in the Spanish construction industry. Taking effect from 2016, the Directive Permits Member States to encourage, use, and even compel the use of Building Information Modeling (BIM) in EU-funded construction projects. Building Information Modeling is applied by Spanish AEC specialists to demonstrate that BIM technologies are currently utilized solely throughout the design phase of residential constructions. There are not many instances in which this technique is applied in other types of projects or in the construction, operation, and maintenance stages.

Nevertheless, experts estimate that it will take at least three to five years to completely use BIM in construction projects (10). Figure 4 shows building information modeling in Spain.

Particularly in the building and architectural industries, Building Information Modeling (BIM) is gaining popularity in Spain. In recent years, the Spanish government has supported the use of building information modeling (BIM) in public projects, which has helped increase awareness and promote its usage in the private sector as well. Many professional organisations, including the Spanish Association of Surveying and Mapping, the Spanish Association of Engineering and Architecture Firms, and the Spanish Association of Construction Companies, advocate the usage of BIM in Spain. These organizations offer training and assistance for professionals seeking to use BIM, as well as promote the advantages of BIM to clients and other stakeholders. There are also a rising number of BIM software vendors in Spain, such as CYPE and Tekla, as well as worldwide businesses like Autodesk and Trimble. These businesses provide a variety of BIM tools and solutions, including design and modeling software, project management and collaboration platforms, and more. The Spanish government has launched a variety of regulatory steps to encourage the use of BIM in public projects. For instance, from 2018, BIM has been compulsory for all public construction projects in Spain. In addition, the government has established a BIM Commission to monitor the deployment of BIM across many industries and to encourage software tool standardization and interoperability. (23)



Figure 4: Building information modeling in Spain (20,22)

5. PREFABRICATED PARTS

Many prefabricated building components are often used in the construction of structures, therefore decreasing waste formation and its negative environmental impacts. Moreover, the

examination into the possible use of prefabricated systems in construction projects indicates that non-standard building components and building foundations are better suited for conventional construction systems. For the construction of dry wall systems, concrete roofs, external coatings, and steel structural frames, prefabricated building components are also preferred. As many prefabricated building components are also load-bearing, it is important to consider upgrading lightweight prefabricated building components. According to data analysis, conventional construction methods have not delivered satisfactory results for the construction industry. Using prefab methods, however, may reduce construction waste by half. In this field, traditional and regular construction techniques will also be beneficial, and costs may be drastically reduced via the use of automated operations, recycled or recyclable materials, and industrial-style assembly of prefabricated building components. (11) Figure 5 depicts the prefabricated components of a house.



Figure 5: prefabricated parts (21)

5.1. Advantages of using prefabricated parts

Many researchers have highlighted the advantages of prefabrication. The top seven advantages of utilizing prefab for data collecting are as follows: Strong design in the early stages of design for better prefab use; better monitoring of the quality improvement of prefab products; reduction of overall construction costs; faster execution; improved environmental performance through waste reduction; integration of design and execution; and aesthetic aspects of the building. (12-13-14-15-16-17)

5.2. Disadvantages of using prefabricated parts

The disadvantages of prefabrication have also been taken into consideration. Ten of these disadvantages fall into the following categories: lack of adaptability to design changes, high initial cost, dearth of relevant research, time-consuming in the early stages of design, lack of consideration of the benefits of using common construction methods in the workshop, and limited space on the construction site. About the prefabricated component depot, the problems with sealing when connecting the prefabricated components, the incompetence of the contractors, the visual uniformity of the project, and the low demand for prefabricated construction components (12-13-14-15-16-17)

6. INTEGRATION OF BUILDING INFORMATION MODELING AND PREFABRICATION

Let's move on to the advantages of prefabricated and semi-prefabricated steel, concrete, and facility designs that particular BIM software may apply to accomplish building projects swiftly, effectively, and with high-quality outcomes. We will make and utilize them. Among the advantages of working in a controlled environment are: Work is performed in a controlled environment in which the construction procedure, workplace, and equipment are defined. As a result, the joinery stage project execution time may be reduced, and the prefabrication capacity can be increased to the point where even all joinery layers can be fully executed. With the aid of this feature, the construction site will be safer and more organized, allowing for assembly-line work and the limited use of equipment such as ladders and lifts. Preventing delays caused by inclement weather: The manufacturing and building sites for prefabricated components are commonly covered and enclosed, making it easier to finish the job in any adverse weather, which is one of the elements contributing to the popularity of this construction style in the areas. It has become cold. Raising the pace of component assembly on site: While the construction and processing of concrete are sped up by the fabrication and production of components using contemporary technology, it may be claimed that more time may be saved in the assembly of parts at the installation site. Before the introduction of BIM

and its associated software, prefabricated sections were coordinated and pieced together using CAD, which had limitations in imagining how to create these three-dimensional structures accurately. But, with the introduction of BIM and software. It is used similarly to Tekla Structures, which permits the configuration of manufacturing (carrying components), building designs, assembly, and even the CNC cutting program when the planned structure is of the steel variety. This process has changed significantly, and it can be claimed that it contributes a great deal of energy to the design and construction of these structures (6).

7. PREFABRICATION STAGES IN THE CONSTRUCTION INDUSTRY BASED ON BIM

- Like with other kinds of buildings, the building's overall design is generated by the design team, who then submits it to the prefabrication specialists for preparation.
- The components of the building are then divided into parts that may be assembled and, of course, transported in accordance with traffic restrictions.
- The design unit is then responsible for making the final selection and supplying the appropriate equipment and materials for the instruments that have been changed into prefabricated shapes.
- The assembly line is used to produce prefabricated components in accordance with instructions that are often developed depending on the implementation schedule of the project.
- The program describes how components are packed, counted, and identified prior to transmission to the site.
- Installation of components on-site (6)

8. CONCLUSION

Building information modeling is one of the construction industry's most promising innovations. This technology permits the development of very precise digital models of one or more buildings, which aids in the design process. The combination of BIM and prefabrication provides contractors with a unique opportunity to comprehend the process

prior to undertaking a project. Prefabrication covers the planning, production, and installation of equipment. To practice the implementation sequence (production and installation), select production locations, depots, towers, and elevators, manage the project site, and evaluate

the effects of their decisions prior to beginning implementation, the entire executive team, including main contractors, subcontractors, and builders in each production and installation department, can utilize virtual simulation facilities of the construction process.

Reference

- [1] S. Azhar, A. Nadeem, Mok, J. Y. N., and Leung, B. H. Y. "Building information modeling (BIM): A new paradigm for visual interactive modeling and simulation for construction projects." Proc., First International Conference on Construction in Developing Countries, Karachi, Pakistan, 435–446, 2008,
- [2] C. Eastman, P. Teicholz, R. Sacks, and K. Liston, BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors, Wiley, New York, 2008.
- [3] V. Bazjanac, "Virtual building environments (VBE)—Applying information modeling to buildings." (<http://repositories.cdlib.org/lbnl/LBNL-56072>), August 29, 2009.
- [4] S. Mamter, A. Abdolaziz, J. Zulkepli, Root causes occurrence of low BIM adoption in Malaysia: System dynamics modeling approach. The 3rd International Conference on Construction and Building Engineering. Palembang, Indonesia. 2017.
- [5] M. Hosseini Azari, E. Tivendale, L. Banihashemi, S. Chileshe, Building Information Modeling (BIM) in Iran: an exploratory study. Journal of engineering, project, and production management, 78-89(in Persian). 6(2) 2016.
- [6] A. Rezaei, review of the integration modeling of building information with the prefabricated industry in advanced countries and Iran, Research Quarterly in Science, Engineering and Technology, Volume 6, Number 1. 2019.
- [7] E. Krygiel, B. Nies, Green BIM: successful sustainable design with building information modeling. John Wiley & Sons. 2008.
- [8] M. Watankhah, H. Yazidi Muslim, Increasing the safety of works at height related to construction projects with bim in the collection of articles of the second international conference on architecture and the city of Byndsar, 2014.
- [9] E. Dunn, Building Information Modeling Specialist. Retrieved from: www.kcrevit.com/Job_Postings_Main.htm, 2007.
- [10] S. ANDRÉS, A. DE LA PEÑA, P. DEL SOLAR, M. DOLORES VIVAS, Implementation of BIM in Spanish construction industry, building and management, 2017.
- [11] A.Tasfiri, S. QanbarzadehQomi, advantages of prefabricated construction compared to conventional construction, Arman Shahr architecture and urban planning, No. 15. autumn and winter, 2013.
- [12] M. Golabchi, H. Mazaherian, New Architectural Technologies. Tehran: University of Tehran, 2012.
- [13] A. Sarja, Open and Industrialised Building. London: Taylor & Francis, 1998.
- [14] G. Staib, A. Dorrhofer, M. Rosenthal, *Components and Systems*. Munich: Birkhauser. 2008.
- [15] A. Sarja, *Predictive and Optimised Life Cycle Management*. London: Taylor & Francis, 2006.
- [16] M. Vafamehr, New Materials and Construction Methods. Tehran: Chapar, 2012.

- [17] A. Warszawski, Industrialized and Automated Building Systems. London: E&FN Spon, 1999.
- [18] <https://all3dp.com/2/cad-to-bim-export-files/>
- [19] <https://www.zingapp.ir/content/?id=21570>
- [20] <https://biblus.accasoftware.com/en/bim-in-europe-national-strategy-developments-in-spain/>
- [21] <https://ostovarsazan.com/%D8%B3%DB%8C%D8%B3%D %AA%D9%85-%D9%BE%DB%8C%D8%B4 %D8%B3%D8%A7%D8%AE%D8%AA%D9%87%D8%A8%D8%AA%D9%86%DB%8C/>
- [22] <https://www.pinterest.es/pin/558939003735362943/>
- [23] S. Andrés, A. de-la-Peña, P. del-Solar and M.D. Vivas, "Implementation of BIM in Spanish construction industry". Building & Management, vol. 1, pp. 01-08, 2017.

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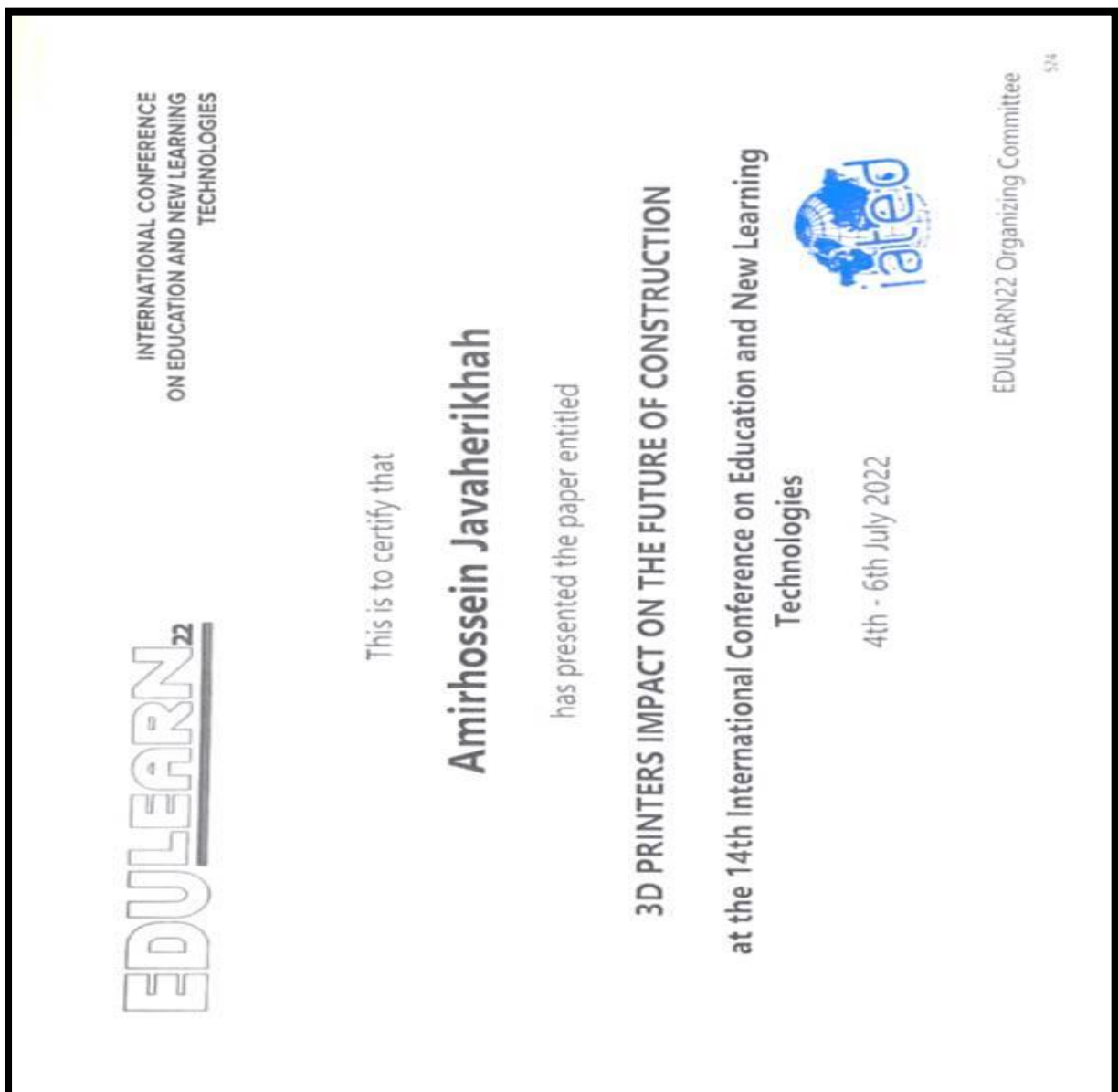
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Figure I.6: Article Certificate



3D Printers' Impact on the Future of Construction

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Abstract

One of the most comprehensive technologies in the world is a three-dimensional printing technology used in different areas. The three-dimensional print can become one of the buildings of the building. With this method, the cost of building materials will be dramatically reduced, because, in this method, fewer materials are used and even wasted, it is also likely that human mistakes are almost zero. By replacing these giant robots instead of manpower, as well as the replacement of recycled materials and waste, instead of new materials, it can be claimed that the construction industry has taken a major step toward achieving its goals. The purpose of this research is to investigate the role and performance of 3D printers in the construction industry and review the benefits and disadvantages of this technology. This research has been relying on a descriptive method and refers to many valid articles and library studies.

Keywords: 3D printer, Construction, Technology, Building, Material

1. INTRODUCTION

The construction industry has an annual revenue of nearly 10 trillion USD, which represents around 6% of the global GDP. Indeed, the engineering and construction industry is a cornerstone of the world's economy [1]. Construction companies are always seeking new means to increase productivity while reducing costs [2]. Studies have shown that over the years, labor productivity in the construction industry has been declining [3]. The lack of implementation of new technology is one of the reasons for this decline [4]. Additive Manufacturing (AM), or more commonly 3D printing, is one of the newest systems of technology that has been introduced in the construction industry. Some drivers are pushing construction towards automation: lowering labor for safety reasons; reducing construction time on-site; reducing production costs; and/or increasing architectural freedom [5]. In Figure 1, construction is done using 3D printers without the need for a worker and only with an operator and a robot.



Figure 1. Construction with 3D printers (Source : www.edelplast.com/3Dprinter)

Additionally, 3D printing helps address sustainability issues. The construction industry has been recognized as one industry that consumes a considerable amount of resources and poses significant environmental stresses [6]. 3D printing of buildings is a new technology for building sustainable buildings and houses of the future. A new construction method began with the invention of the 3D printer. The first 3D printer was invented by Charles Hall in 1984, and 3D printing became one of the fastest systems. It was very complicated and expensive at first, but over time, 3D printing became part of everyday life, and printers entered all industries. In 2014, the real revolution in the construction

industry began with the printing of the first house and a new chapter in construction technology began. This paper investigates briefly the different 3D printing systems in construction, their benefits, and the challenges associated with their use in construction projects. The use of 3D printing technology offers several advantages over traditional methods. However, additional challenges and risks are faced due to the introduction of this new technology in construction projects.

2. 3D Concrete Printing Method

In order for a structure to be printed in 3D, a model using special modeling software such as SAP, Rhino, Maya, Zbrush and etc. Design or scan a prefabricated model. In 3D printing of buildings, printers are a kind of robot and are driven by a computer [8]. In some cases, due to the high cost or unavailability of a special type of 3D scanner, the Kinect device made by Microsoft will be used in the initial stage. Then we have a digital model that we divide into 2D sections and do the printing process layer by layer [9]. This technology reduces construction costs by 40 to 50 percent for the production of more complex structures without the need for structures. Carbon production can be significantly reduced during mass production by 3D printers [10]. In Figure 2, the 3D printer is making the desired design using concrete materials.



Figure 2. Construction with 3D printers with concrete (Source: Austin, Lim & Le, 2012)

3. 3D Printing Features

3.1 Reduction of construction waste and its impact on the environment;

3.2 Its ability to create free form shapes reduces costs;

3.3 The cost of a house built with this technology mainly depends on the items used and the

working time of the machine. Innovative structures may cost even less than rectangular structures because they require less support.

3.4 Gives architects more flexibility in design because it eliminates many design constraints

4. types of 3D Printing

There are different types of 3D printing technology that process different materials in different ways.

Now for Prototyping and industrial production:

Functional plastics, Metals (gold, bronze, platinum ...), ceramic, Sand

Used to create the final object. Different types of 3D printers each use different materials. Some of these technologies used in construction are:

4.1 SLS

One of the techniques for 3D printing is selecting a laser spray (SLS), which involves using a laser to melt material particles together to create an object, and a laser is used to bake a liquid resin and turn it into hard plastic. Used in SLS technology, they usually have high strength and flexibility, the most popular of which are nylon and polystyrene [11]. Figure 3 shows the process of using a 3D printer with the SLS method.

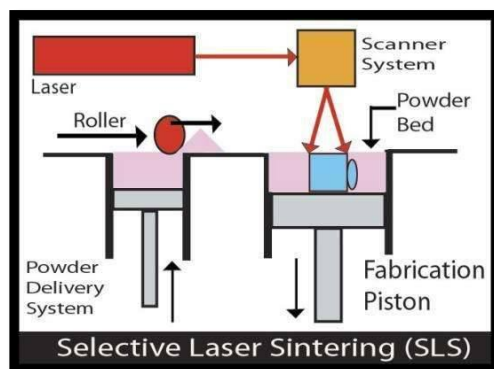


Figure 3. 3D printer SLS (Source: Avanish Kumar Srivastava, 2021)

4.2 FDM

Sediment modeling is a technology that was invented in 1988 by Scott Crump. Flexible materials that harden themselves during the cooling process are extruded through a double-sided nozzle. Modeling and materials are stored based on cross-sections, produced from a digital

model supported by a printer. The nozzle consists of resistive vapors that hold the filament at a suitable melting point that can easily flow through the nozzle to form layers. Like other technologies, after creating one layer, one platform is reduced and the next layer is created. This process is repeated until the whole process is complete. [12]. In Figure 4, that the device is making a design using spool material.

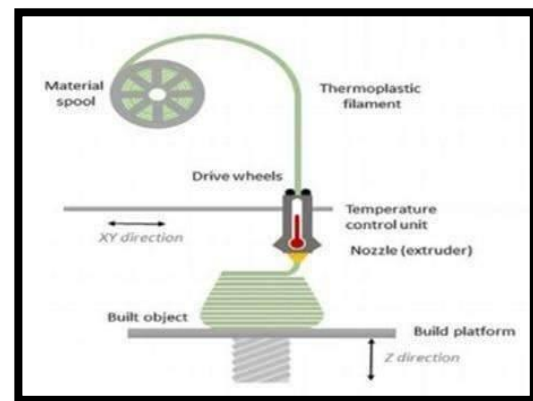


Figure 4. 3D printer FDM (Source: Avanish Kumar Srivastava, 2021)

4.3 Contour Crafting

It is a construction technology used in 2006 by Behrokh Khoshnouis of the University of California, Science Information Institute, which uses a crane or computer crane to produce buildings quickly, efficiently, and with little manual labor. Contour crafting technology reduces the additive manufacturing process from the manufacture of small industrial parts to the construction of buildings. It is an add-on technology that uses computer control to exploit it. Contour crafting gives the ability to make thick layers using different materials without compromising the quality of the surface. The inventor's idea is to create a printer that has one or more nozzles mounted in two parallel lines at the construction site. The next part of the process is similar to the previous processes and the materials are extruded through the nozzle and placed in the form of empty blocks [13.] The purpose of contour crafting is to build custom houses in a short time of one day. Craft contouring differs from other methods in dimensions, projects made with craft contouring have larger dimensions and implementation restrictions are less than SLS and FDM methods. In Figure 5, using the contour crafting method, which is one of the most common methods, you can build a house without the need for workers

and reduce construction time and construction hazards.



Figure 5. Construction of the Building by contour crafting (Source: Enzo Vergara, 2014)

4.3.1 Application of contour crafting

Since contour crafting has the potential to significantly reduce costs and is environmentally friendly, it can be used effectively to build homes for the low-income class and shelter for victims of disasters and even colonies in remote areas or on other planets. Complex structures can also be constructed. The main advantages provided by the calligrapher are that the process, which is mainly done by the machine, will be safer and its cost and time will be reduced by using suitable materials and with good printer parameters. In addition, 3D printing can create large components with unlimited architectural flexibility and the highest accuracy [13]

5. Benefits of 3D printing

Based on the literature review, the main benefits are time, cost, geometric freedom, sustainability, and safety. 3D printing allows to reduce the construction time considerably. Faster construction is the most cited benefit of 3D printing. Reduction of construction costs is also cited as the main benefit. The labor cost of this office, in Dubai, was 60% lower than traditional buildings of the same size. 3D printing also improves productivity which results in cost savings. AM is seen as a way of addressing construction productivity challenges. Using 3D printing technology allows more geometric freedom to design structures that are not otherwise possible. Geometric freedom is often cited as one of the main benefits. Sustainability is the main benefit of 3D printing. 3D printing allows for the design and construction of eco-friendly structures. Using 3D printing reduces

waste produced during construction and also reduces formwork. The printing process will eliminate unnecessary waste of materials, so reducing the environmental impacts of the production/construction process. Reducing the use of formwork reduces the amount of wood and therefore trees. The new technology also improves safety on construction sites. 3D printing results in safer sites. 3D printing reduces the number of injuries and fatalities on site as the printers will be able to do most of the hazardous and dangerous work. [14], [15], [16], [17], [18], [16], [18], [19], [21], [23].

6. Limitations

Despite the many advantages of 3D printing, this technology has its limitations and disadvantages. Labor use is minimized and employment conditions are reduced. It is difficult to imagine that 3D printing will replace traditional construction, and it is more likely that the two will be present together in the industry. 3D printing may be associated with and support traditional techniques. In this method, the use of the software is essential. 3D printing can only do up to a certain size and has limitations in dimensions and size. All of this limits the building's 3D printing technology.

7. Prototype testing and validation for performance standards

In this section, a study of structures made by printers is performed to evaluate cycle by cycle. The production of additives by printers is different from conventional methods because the performance of objects is based on the direction of the layer and their size. This means testing the required properties of structures with building standards and codes. Load-bearing capacity is the most important and obvious factor that guarantees structural performance and is one of the key criteria [24]. Free structures and figure made to measure density, tensile strength, and compressive strength in different directions are examined [25]. They tested the strength and stress capacity of concrete under different conditions. Apart from load-bearing, other features such as durability, resistance to water vapor emission, thermal properties, and fire resistance are important aspects for use in the construction industry. [26.] The challenges of using 3D printing are:

- Structural performance and the need for steel to improve tensile strength and mobility

- Matters related to micrometry and fluidity of cement mixture (pumping problem)
- Hardening and connection of concrete layers and bonding between layers [27]

Table 1. performance standards

substance	The ratio of mixtures (kg/m ³)				
	Mix d1	Mix d2	Mix d3	Mix d4	Mix ed
Sand	1612	1485	1362	1241	1123
Cement	376	446	513	579	643
Fly ash	107	127	147	165	184
Silica fume	54	64	73	83	92
water	150	178	205	232	257

8. 3D printing cost analysis and life cycle evaluation

Large-scale production of additives is a very expensive process due to initial adjustment costs and required materials. But with this technology, about 50% of costs such as scaffolding, etc. Several studies have compared the cost of traditional manufacturing methods with printers. These studies show that the cost of building a 5 by 3-meter wall with the help of a printer is almost half that of traditional construction. There are various costs associated with the manufacture of concrete, mainly the labor force and the materials and equipment required by this department to analyze. Formatting alone accounts for 28 to 50 percent of the cost. The table below shows the amount of labor, raw materials, and equipment required for different types of walls [28].

Table 2. cost analysis and life cycle evaluation

Construction method	Types of costs		
	workforce	Raw material	Equipment
Straight wall / conventional method	56%	23%	21%
Straight wall / printer	36%	45%	18%
Curved wall / conventional method	22%	75%	3%
Curved wall / printer	38%	44%	18%

9 Conclusion

The advent of 3D printing in the construction industry has transformed many new projects. 3D printers are coming together to make significant strides in building and developing the right materials. Studies show that 3D printing is effectively regarded as one with lower costs and environmental benefits. Although we are currently at the beginning of this new technology, with the passage of time and optimization of performance and cost of initial construction, we can use this method as one of the conventional methods in the construction industry in the Later years. Finally, despite the many advances in 3D printing of buildings and the construction of suitable materials, this method alone is able to meet all needs. It is not construction, so it is difficult to imagine that 3D printing will replace traditional construction, and it is more likely that the two will be present in the industry together. 3D printing may be like strong backing with and supporting traditional techniques. Also, for construction 3Dp methods to be successful in the future there must be an ability for all the processes involved to be able to be performed on site with little to no effect of the everyday outdoor conditions of building sites. An additional issue is that with equipment involving robotic workers, the technology should be easy to use and have intuitive user interfaces and be able to share work spaces with workers as well as encompass a high level of safety (Vähä, 2013). Without such functionality, it seems likely to present day observers that automated construction 3Dp will not be in widespread use for many years to come.

REFERENCES

- [1] P. Gerbert, S. Castagnino, C. Rothballer, A. Renz, R. Filitz. (2016). The transformative power of building information modeling, March 08, 2016, Boston Consulting Group, [Online]. Available: <https://www.bcgperspectives.com/content/articles/engineered-products-project-business-digital-engineering-construction/>, [Accessed 28 Jan. 2019].
- [2] S. El-Sayegh, L. Romdhane, and S. Manjikian, (2020). A critical review of 3D printing in construction: benefits, challenges, and risks. *Archiv.Civ. Mech.Eng* 20, 34. [Online]. Available: <https://doi.org/10.1007/s43452-020-00038-w>
- [3] T. Bock, "The future of construction automation: Technological disruption and the upcoming ubiquity of robotics," *Automation in Construction*, vol. 59, pp. 113-121, 2015.
- [4] B. García de Soto, I. Agustí-Juan, J. Hunhevicz, S. Joss, K. Graser, G. Habert, B. Adey, "Productivity of digital fabrication in construction: Cost and time analysis of a robotically built wall," *Automation in Construction*, vol. 92, pp. 297-311, 2018.
- [5] S. Lim, R. A. Buswell, R. A. Le, Austin, A. G. F. Gibb, T. Thorpe, "Developments in construction-scale additive manufacturing processes," *Automation in Construction*, vol. 21, pp. 172-268, 2011.
- [6] P. Wu, J. Wang, and X. Wang, "A critical review of the use of 3D printing in the construction industry," *Automation in Construction*, vol. 68, pp. 21-31, 2016.
- [7] Hager A et al. 3D printing of buildings and building components as the future of sustainable construction? , *Procedia Engineering*; 151: 292-299, 2016.
- [8] Gosselin, C, Duballet, R, Roux, P, Gaudilliere, N, Dirrenberger, J, Morel, P 2016,
- [9] Large-scale 3D printing of ultra-high performance concrete – a new processing route for architects and builders', *Materials & Design*, Vol 100, June 2016.
- [10] Karyne, L 2014, A Chinese Company 3D Printed 10 Houses in A Day, *Business Insider*, viewed 27th September 2018,>.
- [11] Sakin M, Caner Kiroglu Y. 3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM, *Procedia Engineering*; 134: 702-711, 2017.
- [12] Xia M, Sanjayan J. Method of formulating geopolymer for 3D printing for construction applications, material, and design; 110: 382-390, 2016.
- [13] Zhang J. Contour Crafting process planning and optimization, 2009.
- [14] S. El-Sayegh, L. Romdhane, and S. Manjikian, (2020). A critical review of 3D printing in construction: benefits, challenges, and risks. *Archiv.Civ. Mech.Eng* 20, 34. [Online]. Available: <https://doi.org/10.1007/s43452-020-00038-w>
- [15] I. Hager, A. Golonka, and R. Putanowicz, "3D printing of buildings and building components as the future of sustainable construction?" *Procedia Engineering*, vol. 151, pp. 292-299, 2016.
- [16] O. Davtalab, A. Kazemian, and B. Khoshnevis, "Perspectives on a bim-integrated software platform for robotic construction through contour crafting," *Automation in Construction*, vol. 89, pp. 13-23, 2018.
- [17] S. Lim, R. A. Buswell, R. A. Le, Austin, A. G. F. Gibb, T. Thorpe, "Developments in construction-scale additive manufacturing processes," *Automation in Construction*, vol. 21, pp. 262-268, 2011.
- [18] P. Wu, J. Wang, and X. Wang, "A critical review of the use of 3D printing in the construction industry," *Automation in Construction*, vol. 68, pp. 21-31, 2016.
- [19] S. Ghaffar, J. Corker, M. Fan, "Additive manufacturing technology and its implementation in construction as an eco-innovative solution," *Automation in Construction*, vol. 93, pp. 1-11, 2018.
- [20] Apis Cor. We Print Buildings, Retrieved from: [APIs-cor.com/en/](https://apis-cor.com/en/).
- [21] I. Kothman and N. Faber, "How 3D printing technology changes the rules of the game," *Journal of Manufacturing Technology Management*, vol. 27, no. 7, pp. 932-943, 2016.
- [22] M. A. Kreiger, B. A. MacAllister, J. M. Wilhoit, M. P. Case, "The current state of 3D printing for use in construction," in *Proc. the 2015 Conference on Autonomous and Robotic Construction of Infrastructure*, Ames, Iowa, pp. 149-158, 2015
- [23] L. Robichaud and V. S. Anantmula, "Greening project management practices for sustainable construction," *Journal of Management in Engineering*, vol. 27, no. 1, pp. 48-57, 2011.
- [24] De Schutter, G, Lesage, K, Mechtcherine, V, Naidu Neralla, V, Habert, G, Agusti-Juan, I 2018, 'Vision of 3D printing with concrete – Technical, economic and environmental potentials', *Cement and Concrete Research*, Vol. 112, October 2018, Pg. 25 – 36.

- [25] Buchanan, A, Honey, B 1994, Energy and carbon dioxide implications of building construction, *Energy and Buildings*, Vol. 20, November 2013, Pg. 205 – 217, viewed 10th September 2018.
- [26] Nassen, J, Holmberg, J, Wadeskog, A, Nyman, M 2007, 'Direct and indirect energy use and carbon emissions in the production phase of buildings: An input-output analysis', *Energy*, Vol. 32, Issue 9, September 2007, Pg. 1593 – 1602, viewed 10th September 2018,
- [27] Berndt, M 2009, 'Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate', *Construction and Building Materials*, Vol. 23, Issue 7, July 2009, Pg. 2606 – 2613.
- [28] Labonnote, N, Rønnquist, A, Manum, B & Rüther, P 2016, "Additive construction: State-of-the-art, challenges and opportunities", *Automation in Construction*, vol. 72, pp. 347-366.

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Abstract:

Industrialization and the use of modular components in buildings are two of the best methods of mass production in the construction of housing and urban residential spaces. This method has always been used by humans for thousands of years in primitive housing, so that the age of industrialization in the building can be equated with the antiquity of architecture and the beginning of early construction by humans. This method has reached the best possible shape and quality with the advancement of science and technology in the present age and has caused many advances in the mass production of buildings. Increasing demand for housing due to population growth, migration to cities, and finally the development of urbanization on the one hand, and the lack of adequate supply of housing due to the inefficiency of traditional construction methods on the other hand, has made the use of building industrialization in different societies impossible. Today, the development of science and technology has led to the emergence of new technologies in the field of construction. In fact, for the production of quality, cheap, and mass housing, other traditional methods of construction do not meet the current demand of society, so improving the quality of materials, design and implementation methods, speeding up the construction process, competition in technological progress, optimal use of the labor force, and the use of new manufacturing technologies are among the influential components in this industry.

Keywords: 3D printer, Construction, Technology, Building, Material

Figure I.7: Article Certificate



Figure I.8: Poster

A Brief Review at Industrial Construction



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Introduction

Industrialization and the use of modular components in buildings is one of the best methods of mass production in the construction of housing and urban residential spaces. This method has always been used by humans for thousands of years in primitive housing. So that the age of industrialization in the building can be equated with the antiquity of architecture and the beginning of early construction by humans. This method has reached the best possible shape and quality with the advancement of science and technology in the present age and has caused many advances in mass production of buildings (Gholabchi 2012). Increasing demand for housing due to population growth, migration to cities and finally the development of urbanization on the one hand and the lack of adequate supply of housing due to the inefficiency of traditional construction methods on the other hand, has made the use of building industrialization in different societies impossible (HosseinAlipour 2010). Today, the development of science and technology has led to the emergence of new technologies in the field of construction (Tagdiri 2013). In fact, for the production of quality, cheap and mass housing, other traditional methods of construction do not meet the current demand of society; so improving the quality of materials, design and implementation methods, speeding up the construction process, competition in technological progress, optimal use Labor force and the use of new manufacturing technologies are among the influential components in this industry (Zahrani 2015).



Key words: Housing, building industrialization, new construction technologies, industrialization strategy, construction.

Disadvantages of Building industrialization

In addition to the advantages of prefabricated, the disadvantages of using prefabricated have also been considered. Inflexible to changes in design, high initial cost, lack of related research, time in the early stages of design, little attention to the advantages of using conventional construction methods in the workshop, limited construction workshop space for storage of prefabricated components, sealing problems. When connecting prefabricated components, contractors have little experience, aesthetic uniformity in the building, and low demand for prefabricated components (Gholabchi 2012, Sarja 1998, sarja 2006, stieb 2008, vafamehr 2010, warszawski 1999).



Advantages of Building industrialization



Many researchers have pointed out the benefits of using prefabricated. The seven main advantages of using prefabricated to collect data are as follows: Strong design in the early stages of design to better use prefabricated, better monitor the quality of prefabricated products, reduce overall manufacturing costs, Reduction of execution time, better environmental function through reduction of waste, integration of design and execution and aesthetic aspects of the building (Gholabchi 2012, Sarja 1998, sarja 2006, stieb 2008, vafamehr 2010, warszawski 1999).

Conclusions

Prefabrication provides suitable solutions to the problem of large-scale waste generation in construction workshops. The use of prefabricated has had many capabilities, including better monitoring of the quality of prefabricated products in the construction industry. However, there are many obstacles to its development and application. Nevertheless, it is possible to achieve environmental and quality standards and reduce construction time costs. To make better use of prefabrication, it is necessary to pay attention to the execution methods from the initial stages of design. Development of effective prefabrication methods for large projects, mass housing, construction of residential and private commercial projects are effective in reducing waste production and the use of prefabrication methods and modular construction should be expanded with awareness of environmental aspects. Prefabrication will only be successful if contractors and stakeholders are aware of the cost reduction. In the following cases, prefabrication will lead to cost savings: the use of mechanized construction process and heavy machinery, the use of standard construction designs, the conversion of manufacturer construction in the construction workshop to the construction components assembly industry. The use of recycled and recyclable materials in prefabricated building components. However, three motivating factors are required to use prefabrication:

- Environmental aspects: When strict environmental laws and regulations are in place, prefabrication will be one of the ways to reduce waste production.
- Construction costs: Providing more effective and alternative construction methods dramatically reduces construction costs and reduces the need for heavy initial capital.
- Incentive facilities: Incentive facilities for large infrastructure built with prefabricated elements will make the use of prefabricated popular.

References

- ✓ Gholabchi, M., Masraherian, H. (2012). New Architectural Technologies, Tehran: University of Tehran.
- ✓ Sarja, A. (1998). Open and Industrialized Building. London: Taylor & Francis.
- ✓ Sarja, A. (2006). Predictive and Optimised Life Cycle Management. London: Taylor & Francis.
- ✓ Stieb, G., Dierhölter, A., Rosenthal, M. (2008). Components and Systems. Munich: Birkhäuser.
- ✓ Vafamehr, M. (2012). New Materials and Construction Methods. Tehran: Chapar.
- ✓ Warszawski, A. (1999). Industrialized and Automated Building Systems. London: E&FN Spon.



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TECHNOLOGY AND NANOTECHNOLOGY IN SMART BUILDINGS

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Abstract

In the category of nanotechnology, what in the first place seems to be a friendly environment and energy saving, which is among the excellent human progress. The use of modern technologies, including nanotechnology in construction, can be effective in functional characteristics of architecture, including sustainability and safety issues. Nanotechnology has more durability due to the ability to transform the fundamental characteristics of materials and solving structural problems. Most importantly, most environmental sustainability, intelligent materials and structures and multi-functional materials and materials are allowed through this new technology. Nanotechnology is very effective in constructing and improving the quality of buildings, and its benefits can increase the quality of materials, saving energy consumption and, consequently, sustainable architecture and environmental sustainability. The purpose of this study was to investigate the position of nanotechnology in the building to enhance the quality of building materials and achieve sustainable architecture using a descriptive analytical approach. The achievements of this research can be introduced and examine the solutions of energy conservation in the building and achieving sustainable architecture in intelligent buildings using nanoscale materials and technology.

Keywords: Nanotechnology, Nano materials, sustainable architecture, environmental sustainability, energy.

1.introduction

Nanotechnology is a name that refers to a type of manufacturing technology. Homework is achieved when it comes to its name, which is the ability to build objects from atoms, and then the ability to reinstate materials with atomic precision (Fazeli et al, 2005).

Nanotechnology is not a new string, but it means a new approach in all disciplines. Nanotechnology provides a new perspective of the production of materials on a nanoscale with different nuclear properties and layout. The goal of nanotechnology is actually making objects, atoms. With an approach from the bottom to top, the approach that nature is millions of years (Bagheri and Kovanlu, 2012).

In the current world, it is time when the alarm is completed by the completion of oil and fossil reserves, finding new sources of low-cost energy and maintaining reserves and resources for future generations is the success of the nations in the lack of dependence on others. On the other hand, reducing environmental pollution, preventing manpower and reduced costs is one of the features that are defined for each project or successful and sustainable activity; By supplying the resources required for each activity to maintain natural and renewal resources for the next generation and reduce pollution and maintain biomass. (vejdanzadeh 2014).

The application of nanotechnology in architecture includes a wide range of materials and equipment, which aims to objective and implement the theories. Nanotechnology can improve construction conditions. Reduce the need to maintain and reduce the cost of maintenance. The result of this improvement will be: reducing the consumption of raw materials and energy, as well as reduced carbon dioxide emissions, maintain natural resources, dynamic economic resources, and as a result of further comfort (Hagh panah 2013).

Based on the purpose of technology and nanotechnology in the intelligent cities of the research method used in this paper, the applied research method and based on the properties of the subject of descriptive method have been selected. Since this, with a comprehensive definition of Nano, refer to the use of this technology in the fields of smart buildings and emphasizes the construction and sustainable architecture and mention examples of the

application of nanotechnology in the architectural and building industry as a case and Expressing the benefits and disadvantages of using this technology are presented and the results are presented.

2. Introduction of nanotechnology

The term Nano is derived from the Greek word of Nanos and the dwarf means. The phrasal phrase is like other proofers that are at the beginning of measurement units such as seconds, sooths, etc. A nanometer means a billion meters or 10 angstroms (equal to the dimensions of the five atoms). (Golabchi, 2011, p. 23) Nanotechnology is not a new string, but it means a new approach in all disciplines. Nanotechnology provides a new perspective of the production of materials on a nanoscale with different nuclear properties and layout. The goal of nanotechnology is actually making objects, atoms. With an approach from the bottom to top, the approach that nature is millions of years (Bagheri and Kovanlu, 2014). Nanotechnology reduces human need for scarce materials and, by reducing the aluminum, provides a healthier environment. For example, studies show that over the next 10 to 15 years, the brightness of the progress of nanotechnology reduces global energy consumption by up to 10%, saving \$ 100 billion annually, as well as reducing air pollution by 200 million tons of carbon. (Majidi, Hashemi 2018).

3. Nanotechnology history in building construction

About 400 BC, Democritus Greek philosopher, for the first time, the atomic word that means divisible in Greek means to describe the material particles. Hence, maybe he can be considered the father of technology and nanoscience. Greek Nano roots' 'nan' means dwarf (Majidi, Hashemi 2018). Among the many achievements of this technology, its application in the production, transfer, consumption and storage of energy is high performance, which creates a tremendous transformation in this area. (keramat azar Azar 2015). Especially in consumption of energy resources and ultimately achieve sustainable development (Majidi, Hashemi 2018).

4. Nanotechnology in architecture

The application of nanotechnology in architecture includes a wide range of materials and equipment, which aims to objective and implement theories that did not go to the practical arena. Nanotechnology makes us a step

closer to having the desired features of our desires. Materials that have unique features and engineers separate from old aggregates, with numerous problems when using them in construction processes. Perhaps the most important help of nanotechnology in the field of materials and materials materials helped the consumption of raw materials and energy meters (Golabchi 2013).

We can divide nanotechnology in architecture to 2 groups.

4.1 Sponge architecture, which is the use of geometry and structural structure in different biodegradable architecture. Livetick architecture is such a way to design and build clear buildings. That design and construction of the building is clear that their plans and lines are inspired by natural forms.

4.2 Calculus and nano use in the fields of production and manufacturing materials and materials that can be placed in this group. Also, it should be considered a large amount of pancel architecture, which is about 3 billion years old from the planet's life and during this period he introduced its industry as creative and capable architecture (Leydecker, 2008, p. 85).

5. Nanotechnology and environmental sustainability

Environmental sustainability has defined this: "utilization and exploitation of natural resources, as the current need of the world is fulfilled energy and does not endanger the needs of subsequent generations." Not only does an effective use of energy sources, but rising the life of the useful period of materials and materials, are important criteria for maintaining environmental sustainability. Appropriate exploitation of energy sources, while maintaining and protecting these resources, has always been a matter of many environmental and building engineers. (Dezfuli 2011). Still, most of the energy needed in the world is based on coal and oil. Two energy sources that cause the highest emission of greenhouse gas emissions. Of course, for decades, replacement sources such as wind energy, sun energy, biomass energy, nuclear energy, geothermic energy and energy of ocean waves, but to date, have not been able to succeed all and perfection for traditional resources and fueled Fossils out of the energy generation cycle. Hence, expectations of nanotechnology are high

for nodding of environmental issues. Undoubtedly, nanotechnology, although it is at the beginning of the road, has caused positive changes in environmental sustainability in different areas. (Majidi, Hashemi 2018).

6. Nanotechnology in building

Nanotechnology is a dramatic advancement in various scientific and industrial areas, including the construction industry. This technology provides many opportunities to strengthen competition in the construction industry such as construction faster, more reliable, more sustainable and more cost-effective. Nanotechnology is used in almost all parts of the building including skeleton, facade, construction systems and interior design. The use of this technology in the building industry has produced high performance multi-purpose building materials and, while creating value added, has increased the durability and quality of building materials. This technology helps two directions to the building industry: first, optimization and improvement of existing technologies. Second, the presentation of a new group of technologies and practices that was not before the advent of nanotechnology (Hosseini, dehkordi 2015). Therefore, the benefits of using nanotechnology in the building industry include increasing the quality of materials, saving energy and, consequently, economic savings. Based on the results of the studies, in the 10 applications of nanotechnology in the development of the world, the building industry is in the eighth place. Therefore, the use of nanotechnology in the building industry is small in terms of the extent of the industry. Although today we are witnessing limited use of nano materials in the building, according to the capabilities of this emerging technology, it is expected that in the near future, we can see a significant increase in the use of nano materials in the building industry. Nanotechnology activities at the world are highly expanding, and nanotechnology has very important aspects that are difficult to coordinate without a strategy for research and development. The possibility of preparing suitable building materials to control energy in the building is possible by this technology. Other applications of these materials are also studied in building materials and building materials by the Institute of National Research Council for research on some construction materials including cement and glass (Majidi, Hashemi 2018).

- Use of nanoparticles, nanoparticles and carbon nanotubes to improve the quality and sustainability of building materials as well as minimize pollution
- Build cheaper steel without corrosion
- Production of thermal insulation materials with very high performance
- Production of ultra-thin layers of self-cleaning and color change to reduce pollution and energy consumption
- Production of nano sensors and nano materials
- The ability to repair for more reliable buildings



Figure 1. Building with Nano structure(Wiki Pedia)

7. Appropriate achievement of civil engineers using nano materials

If we want to summarize the impact of nanotechnology on building materials and products, it can be said that nanotechnology allows us to upgrade the characteristics of materials. Engineers and civil engineers have turned to building building nanoparticles in order to increase the strength of the building and the performance of materials. Adding nanoparticles to materials such as metal, cement and concrete reinforces features such as heat resistance, tensile strength, cyclewrigance and self-esteem. On the other hand, the architectural profession and construction industry are faced with a huge range of materials and materials.

In fact, materials make up the core of the building and their impact on the environment cannot be ignored. Nano achievements in this field can be mentioned that reduces energy consumption and increases life. In general, nanotechnology with the efficiency of tools and materials used in different sectors, as well as reducing the consumption of raw and energy, has provided

effective measures to protect natural and environmental resources, all of these steps effective in The truth is the realization of sustainable design (Tanazian and sariangholi, 2013).

8.Achieve smart homes using Nano materials

Materials make up the central core of buildings and is huge in human strength. By investigating the processes of conventional materials and their performance in the long run, we conclude that materials and materials are gradually eroded and invasive agents of the external environment), such as sunlight and moisture (them to the abyss The deterioration can only be used by applying appropriate methods to increase the life of materials, which typically continues care procedures as long as they are worn out and replace new materials. This The method is still dominant on the construction process. If we want to summarize the effects of technology in a sentence, it can be said: " nanotechnology, technology that allows us and enabled us. It makes upgrade features or even create new features (Ashby 2009). Today, the combination of steels and resistive concrete in design of structures is widely used. These materials can improve the design and construction methods of buildings. For example, in the attitude of the design of the structures, they should satisfy a high level of environmental standards with emphasis on the cost of useful life period, often used for such materials, because these materials have a better nature with the environment. And also have recycling capabilities (Golabchi 2011).

9.explain Nano material in construction

9.1 Automatic coverage

This style of coatings into two groups

- hydrophobic
- Hydrophilicity

is divided into two types of coating due to the presence of water. Today, the maintenance of the building and its components, especially in the surfaces, are of great importance in the building view. Cleaning coatings are created in two forms of color on the surfaces, with the advantage of these colors, clean and significant reduction in maintenance, meaning that the number of cleaning per year and reducing the consumption of detergents and the cost of manpower, as well as reducing the amount of The depreciation of surfaces in the wash during the year decreases (Kolahdoz 2018).

Table 1: Automatic coverage

Nano materials	Application	Property
Anti-bacterial	Bath wall, kitchen, restaurant and bathroom	Eliminate microbial contamination in the environment
Antismoke	Restaurant, kitchen, corridors and ...	Lack of dust and dust in a closed space
Scratch resistant	Parking, Places	High wear resistance and friction
Waterproof	Kitchen, pool, bathroom	Prevent water penetration.
thermal resistance	The kitchen wall, near the flame and ...	Prevent the destruction of color film against heat
Self-cleaning	Wall halls, rooms and corridors	Failure to influence contamination inside the film of ease in cleaning

9.2 Insulation

Insulation and coating such as foam in the building plays a significant role in spending energy, and also creates comfort and relaxation of people living in a residential unit. (golkohi 2022). Types of Insulation:

Sound, thermal, moisture is divided.

9.2.1 Sound insulation

The sound insulation in the building is used to reduce and cope with the face and transfer of audio contamination from the environment to another environment, which also reduces the velocity of sound waves in the sound of sound waves in this regard. Advantages that are as follows: High quality and higher ability to proportion to conventional insulations and requires less thickness. (Tabrizi 2021)



Figure 2. Sound insulation (Wikipedia)

An important factor in choosing these insulators is their thermal resistance. As much as this resistance is higher, the insulation passes the heat and saves itself, so instead of insulating thickness, their thermal resistance is better

compared. The basis for insulating materials is based on a large number of cavities in the structure, which can hold the air as much as possible. Nano materials are more capable of trapping air in substance due to smaller and more nanoparticles. Thermal insulators are very resistant, lightweight and quality, and more than traditional insulators, more capable of reducing energy loss and have 2 to 6 times higher returns (Tabrizi 2021).

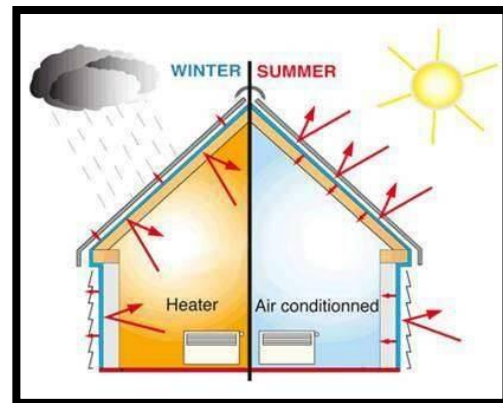


Figure 3. thermal Insulation (Wikipedia)

9.2.3 Moisture insulation

Moisture insulators are referred to in materials that can prevent water penetration. Moisture causes decay of materials and producing pathogens and harmful. Increased against the growth of bacteria, mushrooms, mildew and the influence of ultraviolet radiation (Tabrizi 2021).

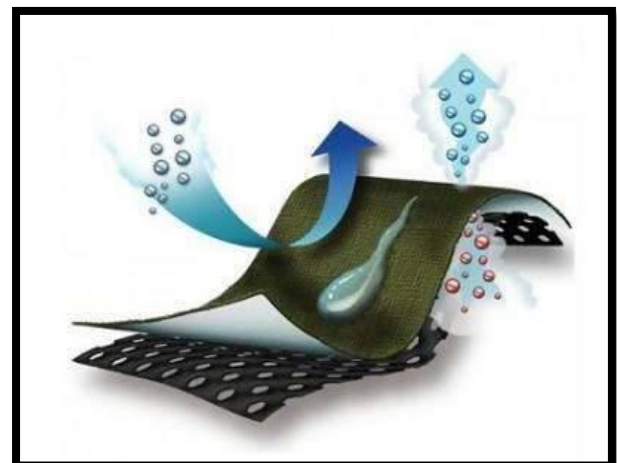


Figure 4. Moisture insulation (Wikipedia)

9.3 Concrete

Annual production of concrete among other materials is the most, and probably why this material is with serious advances using

nanotechnology. One of the most important aspects of the use of nanotechnology in concrete is probably cement hydration control, which can lead to the production of a new generation of products that can be more consistent. By adding SiO₂ nanoparticles (silica), cement-based materials can improve the durability and resistance of refined materials. In the case of corrosion problems in concrete products, nanotechnology can provide clever solutions and covers that respond to external influences and repair or prevent damage. The current research on the use of multi-purpose materials, nanoparticles and carbon nanotubes indicate that these materials increase the compressive strength of cement mortar samples significantly, but also changes their electrical properties that can be used to monitor the health and diagnosis of injury. (Ghorbani 2022).

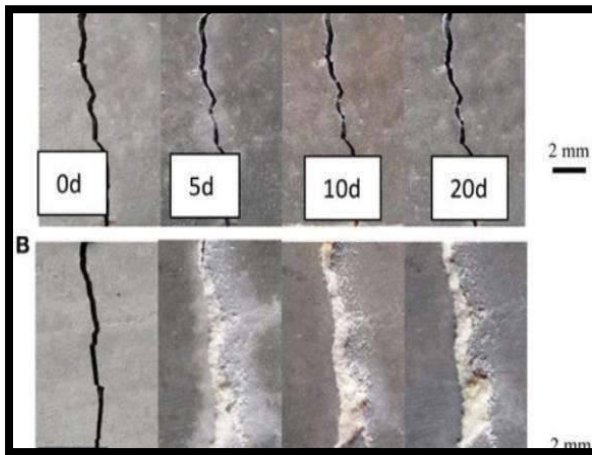


Figure 5. concrete (Wikipedia)

9.4 Glasses

9.4.1 Smart glass

From Smart Glass capabilities, it is possible to change the amount of transparency and color of the glass, which can play an effective role in controlling the intensity of light and reducing energy losses, and so reduces the intravenous entry into the environment and its destructive complications on the skin. Body and home appliances prevent the need for curtains and accessories in the building. (Mohsenipour, Ranjbar 2018).

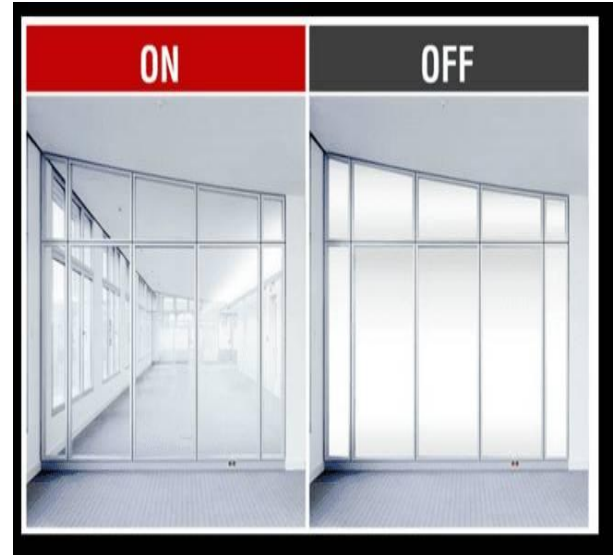


Figure 6. Smart Glass (Wikipedia)

9.4.2 Anti-reflective glass

These glasses can be used for applications that need low light reflection and high passage. Museums, valuable objects, machines, glasses, mobile and These glasses are made up of nanotechnology in the construction industry. (Mohsenipour, Ranjbar 2018).

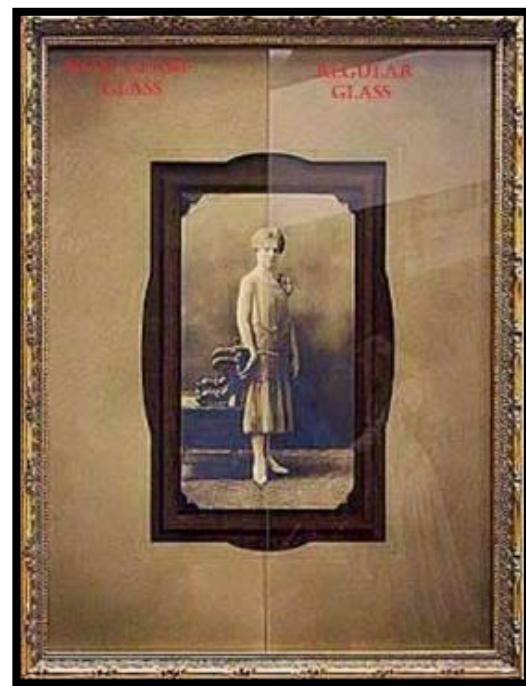


Figure 7. Anti-reflective glass (Wikipedia)

9.4.3 Anti-dust glass (self-cleaning)

In this glass, in addition to self-cleaning, there are materials that cause bacteria and infections. Also, using these glasses, it can always be clear and clean. (Mohsenipour, Ranjbar 2018)



Figure 8. Anti-dust glass self-cleaning (Wikipedia)

9.4.4 Anti-fire glass

Using anti-phase glass nanoparticles, which form a sponge coating, and prevent the glass breakthrough. These glasses versus typical glass 50% lighter and their anti-fire effect is 2 times more. (Mohsenipour, Ranjbar 2018).



Figure 9. Anti-fire glass (Wikipedia)

10. conclusion

The use of nano technology is used in almost all parts of the building, including skeleton, facade, construction systems and interior design. The use of nano technology in the building industry produces high quality building materials, as well as the durability and quality of construction materials. The expansion and development of nano technologies in the construction industry can lead to the production of high-function and functional products, therefore, is waiting for the progress of nanotechnology in Iran construction industry as one of the The largest platform of the country is converted to massive market production of nanoscale products. Informing the architects and building engineers, and the placement of units in universities and understanding the students of relevant disciplines can be useful programs for recognition and use of these materials in smart building

References

- [1] A. Fazeli, M. Zarei, A. Akhavan, M. Moradi, M. Darab, A. Salimi, S. Seyedmostafavi, S.Alikhani, M. Farazkish, F. Moaied, F. Eslamipour, S. Noroozi . Nanotechnology Mirror of Creation, (2005).
- [2] F. Bagheriand, S. Kiwanolo. Proposal of an inventive panel with concrete Ekliki in line with Buildings Buildings Second Internal Architectural Conference and Decoration of the High School Research Institute (2012).
- [3] L. Vejdanzadeh. Application of Nanotechnology in Architecture, Architecture and Urban Design Architecture and Winter No. 13. (2011).

- [4] M. Hagh panah, F. Dehghani. New structures in intelligent buildings with sustainable architectural approach. National Conference on Sustainable Architecture and Urban Development.(2013)
- [5] M. Golabchi, K. Taghizade, E. Sorooshnia. Nanotechnology in Architecture & Construction Engineering, Tehran: University of Tehran, (2011).
- [6] F. Majidi, M. Hashemi,, A review of the position of technology and technology in achieving sustainable architecture, (2018).
- [7] S. Leydecker, Nano Materials in Architecture, Interior Architecture and Design, BirkhauserVerlag AG. (2008)
- [8] S. Keramat azar, A. Feyzollah Beigi, examining the status of intelligent materials and self-restoration in sustainable architecture. First National Conference on Architecture, Restoration, Urban Development and Sustainable. (2015)
- [9] A. Gorji, Sustainable Architecture Solutions, along with Japan's architecture. Journal of Fine Arts, No. 41. (2010).
- [10] M. Golabichi, Nanotechnology in Architecture and Building Engineering. Published University of Tehran, (2011).
- [11] A. Dezfuli, Investigating the role of nanotechnology in the realization of sustainable architecture and energy saving. Proceedings of the second national architectural conference. (2011).
- [12] L. Hosseini, M. Dehkordi, S. Hosseini, Sustainability in National Conference On New Theories in Architecture and Urbanism. (2015).
- [13] SH.Tanazian, H. Sarbani, the effect of nanotechnology in sustainable architecture. Sustainable architectural conference and urban development. (2013)
- [14] M.F. Ashby, P.J. Ferreira, D.L. Schodeck, Nanomaterials, Nanotechnologies & Design (an introduction for engineers & architects), 1st edition,Oxford ,UK, (2009).
- [15] Z. Kolahdozan, Intelligent Structures and Nano-Technologies in the building, the second international conference on new research findings in civil engineering, architecture and urbanity. (2018).
- [16] N. Golkohi, Impact of Nanotechnology in the Building Industry and Multifunctional and Multifunctional Design, 6 TH. National Congress on Civil Engineering, Architecture and Urban. (2022).
- [17] A. Tabrizi, Application of Nanotechnology Materials in the Building Industry, International Conference on Civil, Architecture, Development and Reconstruction of Urban Infrastructure. (2021)
- [18] S. GHorbani, the effect of nanotechnology and nano materials in improving the strength of concrete (with a specific look at nano silica), the 7th International Conference on Civil Engineering, Architecture and Urban Development. (2022).
- [19] GH. Mohsenipour, M. Ranjbar, Nanotechnology Place in the preparation of self-cleaning glass for application in the building, 2nd International Conference of Civil Engineering, Architecture and Crisis Management. (2018).

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The effect of building information modeling on project planning, control and management

ESCUELA TÉCNICA SUPERIOR DE EDIFICACIÓN DE MADRID

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ABSTRACT

Today, in the industries of architecture, engineering, and construction (AEC), it is essential to implement management techniques and tools, especially with increasing project scale. While the search for better techniques and tools continues, BIM building information modeling is one of the most promising developments in the industry, reflecting a digital picture of the physical and functional characteristics of a structure in order to create a reliable basis for decision making. During the life cycle of the structure and presents the project in multidimensional. Geometric data is modeled and, most importantly, project-related data such as element performance, material specifications, execution details, program, cost, etc. are also stored with the model. The BIM also incorporates many of the functions needed to model a building's life cycle, paving the way for new designs and capabilities, and changing roles and relationships between project teams. The goal is to provide a single model for all stakeholders at all stages of the project. In this paper, the main challenges in the current method of project management and control are analysed and how BIM-based project management overcomes these challenges. It explored how to use BIM to manage and gather information to build a BIM model. The benefits of planning, cost estimation, sustainability, and facilities management of BIM-based multiple-dimensional in the areas of planning, control, project management and construction were explored. At the end, a brief explanation was given about the BIM software platforms and how to work with them.

Keywords: *project planning, control and management, BIM, IFC, nD, BEP.*

1. Introduction

In industry, it has become a requirement for effective project management and control. The rate of BIM deployment has been growing in recent years. A McGrawille study conducted in North America during the five years between 2007 and 2012 shows that BIM utilization increased from 28% in 2007 to 71% in 2012 (Shakeri, Dadgar, Rashidi Nasab and Taheri Jebeli, 2107) Traditional management systems / routines do not have the ability to manage at the moment and simultaneously with the project, one of the new methods of project management and control is the method of control during the project. On-time project management means real-time and real-time control and monitoring of

all execution processes, including elements, method of execution, time and costs of a project, and the ability to update the schedule and closely monitor it (Qasim, Zamani Nouri and Fallahi, 2017) The use of new methods due to the integration in planning time, cost, failure structure and monitoring the progress of the project in the project control process prevents the project managers from misunderstanding the existing problems and making decisions with low impact (Sabat and Dadashi Haji. 2016) The advent of IT has taken a fundamental form in project construction and management technologies and plays a crucial role in the execution of executive processes (Ebrahimi, Golabchi and Shaeafi, 2018) . BIM is able to provide a digital image of the project in three

dimensions, But more importantly, in addition to geometric data, BIM systems have all the necessary conceptual data such as element performance, material specifications, execution details, program, costs, etc. in the model for exchanging and updating information. In this way, a single model of the project is created for the common understanding of the stakeholders in all stages of the work (Gol Nahali and Ravanshadnia, 2018) The technological benefits of BIM start from the conceptual design stage and cover the entire project life cycle (Ebrahimi, Golabchi and Shaeafi, 2018.) 21. BIM creates a collaborative design and implementation process between project members and manages and It integrates project control into a model and, depending on the built-in security systems, provides different access levels for different users (Rezazadeh, Rostami Nikoo, Khanzadi, 2018) . This information in different parts of the manufacturing industry The instrument has effective applications such as project planning, various analyzes, value mining, construction design and integration, optimization, risk assessment, cost estimation, risk management, project management and construction management (Gol Nahali and Ravanshadnia, 2018). BIM building information modeling has successfully addressed many of the problems of traditional approaches in the AEC, such as poor communication, repetitive repetition, and misinformation of information, and can be said to lead to effective use of building information modeling. High quality of buildings and reduction of project costs (Ebrahimi, Golabchi and Shaeafi, 2018). In this paper, the existing and effective structures of BIM for planning, control and project management are reviewed and the different phases of project management are discussed with the aim of clarifying the effects of building information modeling.

Information modeling of construction projects is a process based on the integration of a three-dimensional model of the project with A comprehensive database, which helps all project stakeholders, from designers to project operators, to better and more effectively perform their tasks throughout their life cycle, as shown in Figure 1. (Sotoudeh Beidakhti 2015)

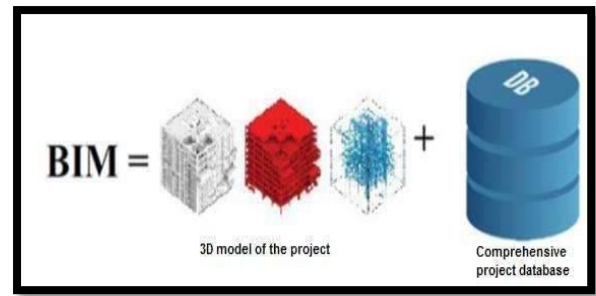


Figure 1: Information modeling of BIM construction projects. (Sotoudeh Beidakhti 2015)

2. Background

The basic concepts of BIM were first introduced by Eastman in the mid-1970s with a prototype building description system. However, due to the high cost of the required hardware, its widespread use was limited until in 2002 Autodesk introduced BIM for the first time in an article. (Wikipedia and BIM Handbook, 2010). In his book *The BIM Guide*, Eastman defines it as a modeling technology and related set of processes for producing, communicating, and analyzing building models. The Pennsylvania State Research Group also defines BIM as the process of designing, analyzing, integrating, and documenting the life cycle of a building by creating a smart virtual prototype of the building using a database of information (Shakeri, Dadgar, Rashidi Nasab and Taheri Jebeli, 2017). The New York City Building Information Modeling Guide defines BIM as: Building information modeling is a technology that enables digital exchange of information and collaborative collaboration between designers by establishing digital communication between different applications, and by increasing the accuracy and integrity of designs. Significantly reduces. (Adibfar, Maghrebi, Hosseini and Bagheri, 2015). In the PMBOK definition, a project is a temporary effort to create a unique product, service or result. Project management The application of knowledge, skills, tools, and techniques related to activities / activities is done through five interrelated process groups: 1 Initial process 2 Planning process 3 Execution process 4 Monitoring and control process 5 Termination of Pmbok 2013 project And project management knowledge areas include domain management, time management, management, cost, quality management, human resource management, communications management, risk management,

and logistics management and integration management. Each project in accordance with these management areas has levels of uncertainty and the main challenge is managing uncertainties taking into account all cases. At each stage, the project manager and other experts have tasks and many uncertainties ahead. For this reason, the use of computer-assisted systems helps professionals to perform their assigned tasks. To build a successful project management system, it is important to have access to information at the right time. This helps project experts make better decisions when needed. This information includes items such as material specifications, installation and assembly guide, product warranty services, maintenance, price information and construction and installation steps, and acts as a common reference between the employer, the designer and the manufacturer to increase coordination, reduce errors. And waste reduces costs and increases quality (Abedini and Shakeri 2014).

3.The phases of information building modeling

The phases of the project are planning, design, implementation, operation and maintenance, which we briefly review here with the BIM approach. The planning phase in which these letters and rules are collected and the project is analyzed and feasible. Examining the concept of feasibility and design method, increasing the performance and quality of the building, better cooperation with the help of IPD are some of the pre-construction benefits for the owners. (Ebrahimi, Golabchi and Shaeafi, 2018). The most important point in contractors' use of BIM capabilities is to communicate with employers before starting construction. Integrated project delivery requires a joint collaboration agreement rather than architects; Designers and general contractors work together from the start of the project and make the best use of BIM.) Shakeri, Dadgar, Rashidi Nasab and Taheri Jebeli 2017). The design phase includes project analysis, faster and more accurate visualization of the design, 3D model presentation, design coordination between units, automatic corrections when design changes are made, interference detection, cost estimation, energy consumption simulation, etc. .. with the help of BIM models (Ebrahimi, Golabchi and Shaeafi, 2018). Three detailed sections are divided into schematic design in

which options are analyzed. Detailed design of three-dimensional models of structures, electricity and mechanics and specification of construction details, 4D planning and 5D execution cost estimation is done and horizontal for the execution stage is provided. Tender design limits the contractor's ability to apply his knowledge in the design phase, when they can have a significant impact. (Shakeri, Dadgar, Rashidi Nasab and Taheri Jebeli 2017). The construction phase includes designing the implementation method, adapting to the schedule, specifying values, managing resources, and performing planned activities. The project manager determines the optimal location for the workshop equipment by simulating the project space and the movement routes of manpower and machinery. (Qasim, Zamani Nouri and Fallahi, 2017) Advantages of construction with the help of BIM models, Adaptation of design and construction planning, better application of construction techniques, coordination of logistics with design and construction. (Ebrahimi, Golabchi and Shaeafi, 2018.). Operation and maintenance phase includes site management after project implementation, and the benefits of using BIM in this phase include improved commissioning and delivery of facility information, better facility management and performance, model integration with facility performance, and management system (Ebrahimi, Golabchi and Shaeafi 2018).

4. Bim benefits

Modified information flow Because the building information pattern provides a single description of a building, you can modify and improve the information flow at any stage of a building's design, construction, and life cycle. Architects, MEPs, contractors and building owners can change or extract information to support their role at different stages of the building life cycle. A clear view of the project is obtained to improve decisions to reduce errors and improve production. Better Design Drawing The ability to predict how residents, visitors, and neighbors will react to or influence how they treat the building is an important part of the design process for architects and engineers. The ability to virtualize the HVAC system and test it virtually in a 3D environment, just as it does in a real building, can provide added assurance to the components when they start building. Advanced cost estimation Due to the depth and accuracy of

the information provided by BIM, it is obvious that it can improve the accuracy of cost estimation. A simple method for extracting the amount and number of materials required can increase the speed and accuracy of the estimate and provide a better measure of the impact of design changes so that budget issues can be actively addressed. Advanced energy analysis Here, too, BIM accuracy can be simplified and help improve accuracy in energy analysis. While calculating energy use requires other software tools, the data for which such analysis is required is available in BIM (Lagüela, 2014).

Bim benefits for employers, executives, contractors, manufacturers (Taheri Borun et al., 2017).

Facilities management in the period of operation, financial forecasting and financial management, increasing the quality of projects, accurate project estimation, reducing energy consumption costs through energy optimization, increasing building efficiency	Bim benefits for employers
Investigation of pre-execution interference, better execution quality, optimization of project implementation process, safety management in execution, optimal planning and equipping of the workshop, minimum errors and mistakes and repairs in the execution stages	BIM benefits for executives
Document the project implementation stages and facilitate the process of final meetings and situations, use the designed model to build parts, identify and investigate design errors, investigate possible interferences and collisions before construction and provide solutions, material meters and cost estimates of various fronts and use in contracts	BIM Benefits for Contractors

Use of manufacturers 'products in the design and implementation stage, standard coding of manufacturers' products, complete knowledge of consumers about products before purchase	Benefits (BIM) for material producers

Table 1: Bim benefits for employers, executives, contractors, manufacturers (Taheri Borun et al., 2017).

BIM Dimensions One of the basic and important concepts in BIM technology is building information modeling. When we talk about information dimensions, these information dimensions enter the information model, so we can produce a more complete model by adding a series of information at each stage. BIM Dimensions, like information puzzles, evolve a beam model and guide the project in achieving information integration from design to construction and operation. BIM Dimensions in each dimension or stage has its own software solutions and workflow that each stage needs special attention. (Taheri Borun ., 2017).

5.Challenges of using BIM

Ownership of Model Rights One of the primary challenges of BIM is to determine how the owner of the BIM data and information manages how to copy it (Darby, 2006). Database of Construction Objects and Components Using BIM, companies and manufacturers of construction equipment will be able to easily provide modeled product information to professionals and designers. Prevent manufacturers and manufacturers from copying their product information accurately and pass it on to others, which can lead to abuse. Lack of integrated software for full execution BIM The software used in all parts of the design, implementation and management must work crackslessly, otherwise the information in each part is generated separately and the ability to analyze and read for other parts involved in the project Will not exist. Data Entry Control It is crucial to know who and by what mechanism can provide information to the BIM model, as inaccuracies in data entry require a lengthy data review and refinement process (Darby, 2006).

6. Dimensions of building information modeling

6.1 2D Dimension Two-dimensional drawings

The first dimension in Beam technology is the 2D dimension, which is CAD or Computer Aided Design. Documents produced to date by tools such as AutoCAD can be considered as a traditional method in Beam technology. This two-dimensional method has no information and this model can not be known as a beam model. The first stage of the Beam model is a three-dimensional model that, in addition to geometry, also produces information, such as the number of walls, the length of the walls, the area or materials used. 2D Dimension is one of the details of Level 0 Beam. (Abedi Moghadam, 2016).

6.2 3D Dimension:

It is the third dimension and is the first dimension that is referred to as information dimension in Beam technology, because in this dimension, in addition to geometry, there is also information. Information is an integral part of Beam technology. (Abedi Moghadam, 2016).

6.3 4D Dimension

The fourth dimension is Time or the Time dimension. After producing the 3D model, by adding the time model, a construction simulation can be performed according to time, which helps to manage and control the project comprehensively. (Abedi Moghadam, 2016).

6.4 5D Dimension

The fifth dimension is the cost or cost dimension, in which by adding the daily price to buy materials and wages and other costs in the project, we can have the output of a price analysis. (Abedi Moghadam, 2016).

6.5 6D Dimension

The sixth dimension includes two concepts in Beam technology

- Supply of goods
- Manpower

Carbon Footprint Or the amount of emissions that are under the discussion of energy and green buildings and Sustainability or we try to produce buildings with the lowest carbon emissions. Also in this dimension it is possible to create a coordination between sustainability issues and

energy analysis for optimal construction. (Abedi Moghadam, 2016).

6.6 7D Dimension

The seventh dimension is called FM or Facility Management. It means the operation and maintenance of the building, especially for projects that have general use, such as hospitals, subways, schools, universities, etc., such projects are used for years and eventually are maintained, so check this The dimension is very important. (Abedi Moghadam, 2016). The information generated in the previous six dimensions, when entered into the seventh dimension, forms a very comprehensive model that can be used as a criterion for project maintenance.

7. Software used in building information modeling

The following table lists the software used in building information modeling in the architectural and structural and development management departments (Sotoudeh Beidakhti, 2016).

Application in sustainable development management	Application in structures	Application in architecture
Autodesk Ecoteet Analysis	Autodesk Revit Structure	Autodesk Revit Architecture
Autodesk Green Building Studio	Bentley Structural Modeler	Graphisoft ArchiCad
Graphisoft EcoDesigner	Bentley RAM, STAAD and ProSteel	Nemetschek Allplan Architecture
IES Solutions Virtual Environment VE-Pro	Tekla Structures	RinboBIM
Bentley Tas Simulator	StructureSoft Metal Wood Framer	Softtech spirit
Bentley Hevacomp	MSA Strad and Steel	CADsoft Envisioneer
Design Builder	Autodesk Robot Structural Analysis	Bentley Architecture

Table 2: Software used for building information modeling (Sotoudeh Beidakhti, 2016).

8. Bim substrates

They can be used in a variety of construction methods. Architects for modeling, design and production, engineers for structural calculation or energy management, contractors for a coordinated model, specification of construction details or facility management. Each of these platforms includes different capabilities and some of them are offered for multiple uses. Different marketing strategies lead to packages with different sets of performance, the applications and limitations of which are considered according to different types of BIM

users. The choice of a software platform is based on current capabilities, future development, support network and user community that provide a collaborative environment. Most BIM design programs have interfaces with other programs for interpretation, energy analysis, cost estimation, and more. Some of them also provide opportunities for multiple users to coordinate their work with each other. BIM in most organizations includes different programs for different applications, and large companies usually support 10 to 50 different programs for the use of their employees. These platforms have enough information to support design, editing and modification, as well as parametric rules to maintain the accuracy of a building model. They may have several built-in tools for 3D modeling, estimating values, rendering, and generating maps. Here is an overview of the Revit platform from the perspective of Revit Architecture as the most widely used construction platform. (Sotoudeh Beidakhti, 2016).

9.Revit

The most famous market-leading software platform for BIM is in architectural design. Revit was introduced in 2002 by Autodesk. And a completely different context of code, with a different file structure and programming base. Revit is a family of integrated products, including Revit Architecture, Revit Structures and Revit Facilities. The program lets its users design a building and its components in 3D, interpret the model with 2D text elements, and access building information from the building model database. Revit The software is capable of 4D BIM with tools for mapping and tracking various stages in the life cycle of a building, from the initial concept to construction and then demolition. Three Revit products (architecture, structure) use RVT file extensions to store BIM models. A building is usually built using 3D objects to create walls, floors, roofs, windows, doors, electrical systems and other needed objects. These parametric objects are called three-dimensional building objects (such as doors and windows) and two-dimensional objects (such as fasteners) of the family and are stored in RFA files and entered into the RVT database when needed. In this section, Revit focuses on architectural vision. (BIM Handbook, 2010)

9.1 Revit Benefits:

- Vision as a design tool is powerful and sensitive.
- Learning to see is simple.
- Has a wide range of objects designed by software developers and manufacturers in the market.
- Due to the position of this software in the market, Revit is usually preferred when you need to exchange information with other software.
- Multi-dimensional map support in these applications, the ability to update and manage maps from different parts of the environment, such as views or schedules.

Simplicity and speed of learning, increasing the speed and accuracy of drawing as well as changing drawings, simultaneous drawing of three-dimensional and two-dimensional drawings of structural and installation drawings and simultaneous application of changes between these drawings, elimination of compliance errors with structural drawings and installations and simultaneous application Changes between these plans, elimination of errors in the adaptation of views and plans and sections, the possibility of conducting climatic studies (light and shadow) on the building, the possibility of defining construction standards in building equipment, calculating the building meter and changing it quickly if plans change, capability Communication with other BIM software through IFC as well as AtuoCAD (input and output), the possibility of volume design and its conversion into executable drawings are other benefits of this software. (BIM Handbook, 2010)

9.2 Disadvantages of Revit

This software, when working on projects with a size of more than 300 MB, is faced with a significant reduction in speed. It has limitations in the design of complex curved surfaces. Software related to visibility in different parts of construction is placed in the table (BIM Handbook, 2010).

Structural	Revit Structure (Dir), ROBOT (Dir), and RISA structural analyses (IFC), BIM ME S.A.R.L. ETABS Link, SismiCAD for FEA analysis, Graitec's Advance and ARCHE, Fastrak Building Designer, StruSoft FEM-Design, SOFTEK S-Frame, STAADPRO via SFXchange, SOFISTIK
Mechanical	Revit MEP (Dir), HydraCAD (fire sprinklers), MagiCAD (mechanical design), QuantaCAD (mechanical laser scanning for as-builts), TOKMO (COBie facility operators handover)
Energy and environmental	Ecotect, EnergyPlus, IES all indirect, Green Building Studio via gbXML
Visualization	Mental Ray (Dir), 3D Max (Dir), Piranasi
Facility management	Autodesk FMDesktop (Dwf), Archibus (IFC)
Site analysis	Interface with AutoCAD Civil 3D
Manufacturing components	Interface with Autodesk Inventor
Site planning	Interface with LANDCADD
Quantity takeoff for cost estimation	Interface with US Cost, Cost OS by Nomitech, Innovaya, Sage Timberline, Tocoman iLink
4D simulation	Primavera, MS Project
Scheduling and quantity takeoffs	Autodesk Navisworks
Specifications	e-SPECS, BSD SpecLink
Import models	SketchUp, AutoDesSys form, McNeel Rhinoceros, Google Earth

Table 3: sets of programs related to different work areas in Revit

Revit A powerful visual and design tool with high performance map generation tools that is user-friendly and organized and supports multitasking. This collection has a very large library of objects developed by Autodesk and third parties. Its two-way design support allows you to update and manage information from design and model views, and model views, including applications. Due to its dominant position in the market, this platform is more suitable for communication with other BIM tools. (BIM Handbook, 2010)

11 Reference

- [1] PMBOK, A. Guide to the project Management body of knowledge. Project Management Institute, Pennsylvania USA. BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors / Chuck Eastman . . . [et al.]. — 0nd ed 2013.
- [2] Sharifpour. Ahmad, Basic, Intermediate and Advanced Levels of REVIT Software Training 2015.
- [3] Ziaee. Ali, Autodesk Navisworks Applied Training based on BIM- level one 2015.
- [4] Ziaee. Ali, Autodesk Navisworks Applied Training based on BIM- Advanced level 2016.
- [5] Abdullah Badawy Mohammed: Applying BIM to achieve sustainability throughout a building life cycle towards a sustainable BIM model, International Journal of Construction Management 2019.

10 Conclusion

This study, while defining construction projects based on BIN, identified its cases and communication sections with project planning, control and management. For this purpose, the working method was stated and it was stated how the three-dimensional model was upgraded to load the required data more completely in the model and this data in the form of a creative model, how to more fully define and master all project elements in planning, control And creates project management.

However, it should be noted that using the model will be a challenge for non-professional users. What can be explicitly said that can be produced automatically by the model is the plan and cutting of floors and meters and estimates. It also displays interventions that are notified in a timely manner before the implementation phase to avoid unnecessary costs.

The advantage of using BIM technology in the early stages of design is to cover the needs of the project throughout its life cycle. BIM facilitates the design and implementation of construction projects and provides a platform for collaboration between different groups. Numerous studies show that BIM-based models are time-saving and cost-effective compared to conventional manufacturing methods. This study provides insight into how BIM technology is used and exploited.

It is expected that by using BIM in projects, both small and large, we will be able to achieve the desired result for consultants and employers in the shortest time and at the lowest cost, which is always the case.

- [6] Abedini, Behzad and Iqbal Shakeri, Control costs in construction projects using BIM, International Conference on Management in the 01st Century, Tehran-persian 2014.
- [7] Adibfar, Alireza; Mojtaba Maghrebi · Mohammad Reza Hosseini and Seyed Ramtin Bagheri, , Examining the legal aspects and providing a contractual framework for using building information modeling (BIM), 11th International Project Management Conference, Tehran-persian 2015.
- [8] Ebrahimi, Hamidreza; Mahmoud Golabchi and Farhang Shaeafi, The role of building information modeling (BIM) in preventing cost diversion in project management, 0rd International Conference on Civil Engineering, Architecture and Urban Design, Tabriz-persian.2018.
- [9] Farzamfar, Alahyar and Ali Ghorbani, Investigating the effect of building information modeling on labor productivity of construction projects using fuzzy logic, Civil & Project Journal (CPJ)-persian 2019.
- [10] Farzin Khanghah, Omid · Mehdi Ravanshadnia and Abbas Taj Al-Dini, implement a building information model (BIM) in industrial projects to reduce work interference Increase productivity through integrated project information management methods, project, 10th International Project Management 2018.
- [11] Gol Nahali, Yousef and Mehdi Ravanshadnia, provide an automated production schedule for construction projects using BIM, 10th International Project Management Conference, Tehran-persian 2018.
- [12] Maria Angeliki Zanni, Robby Soetanto & Kirti Ruikar Towards a BIMenabled sustainable building design process: roles, responsibilities, and requirements, Architectural Engineering and Design Managemen 2017.
- [13] Mirzaei, Ali; Majid Parchami Jalal · Farnad Nasirzadeh and Elnaz Aghaei Asl, identify temporal-spatial interference in construction projects and quantitatively evaluate their impact using the 0D-BIM four-dimensional building information model, 11th International Project Management Conference, Tehran-persian 2015.
- [14] Naghash Tusi, Hossein · Reza Mahmoudi Hassan Khanlou and Akbar Maerefat, Evaluate the impact of BIM on the design phase to reduce claims in the construction phase, 10th International Project Management Conference, Tehran-persian 2017.
- [15] Qasim, Reza; Alireza Zamani Nouri and Mohammad Amin Fallahi, provide a model for Timely managing construction projects using building information modeling, National Conference on Research and Development in Modern Civil Engineering, Architecture and Urban Planning, Tehran-persian 2017.
- [16] Rana Ayman, Zaid Alwan & Lesley McIntyre: BIM for sustainable project delivery: review paper and future development areas, Architectural Science Review-persian 2019.
- [17] Rezazadeh, Mohammad · Reza Rostami Nikoo and Mostafa Khanzadi, provide a comprehensive project control system by establishing a link between scheduling, 0D model and database, First International Conference on Building Information Modeling, Tehran-persian 2018.
- [18] Sabat, Mohammad Hassan and Mostafa Dadashi Haji, Four-dimensional simulation of Beam to improve the project control process by the last decision maker system, The first international conference and the third national conference on construction and project management, Tehran-persian 2019.
- [19] Salman Azhar Ph.D & Justin Brown MBC BIM for Sustainability Analyses, International Journal of Construction Education and Research 2009.
- [20] Shakeri, Iqbal; Ebrahim Dadgar · Armin Rashidi Nasab and Sajjad Taheri Jebeli, Investigate BIM applications for each stakeholder and analyze it at different stages of the project, 0nd International Conference on Civil Engineering, Architecture and Urban Design, Bangkok-persian 2017.
- [21] Shakeri, Iqbal; Hossein Taghados · Amir Hossein Babaei Ravandi and Vahid Abbasianfar, a framework for automatic control of construction criteria in Iran in the context of BIM building information modeling,

0nd International Conference on Building Information Modeling, Tehran - Niroo Research Institute - Persian Gulf Hall-persian 2017.

[22] S. Lagüela, L. D.-V. J. Armesto, P. Arias. Non-destructive approach for the generation and thermal characterization of an as-built BIM. *Construction and Building Materials*, 51, 55-61 2014.

[23] S. Lagüela, L. D.-V. J. Martínez, J. Armesto. Automatic thermographic and RGB texture of as-built BIM for energy rehabilitation purposes. *Automation in Construction*, 31, 230-240 2013.

[24] Darby, S. The Effectiveness of Feedback on Energy Consumption. A Review for Defra of the Literature on Metering, Billing and Direct Displays. University of Oxford, Oxford, UK: Environmental Change Institute 2006.

[25] Amir Hossein Sotoudeh Beidakhti, Introduction to the use of BIM building information modeling in the operation and maintenance management of buildings, First National Conference on Urban Planning, Urban Management and Sustainable Development, Tehran, Iranian Institute, Iranian Architectural Association, 2014.

[26] Amir Hossein Sotoudeh Beidakhti, Performance Survey of Building Information Modeling (BIM), Reinforcement and Improvement Industry Quarterly, No. 10 New Series (No. 30 in a row), Winter '93 and Spring '94, page 82, 2014

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Figure I.11: Article Certificate



THE ARCHITECTURE OF IDEAL LEARNING ENVIRONMENTS

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Abstract

Educational spaces and their design are one of the most influential factors in learning. The classroom is considered as the most important learning environment in the educational space and is responsible for responding to people and their changing needs. Therefore, the educational space should be adapted to the age and educational level of the students because educational spaces have the greatest influence on the mentality and civilization of the society. In some developed countries, great importance is given to the education of the next generation. Therefore, the design of spaces with the help of appropriate models and standards takes into account not only technical and architectural aspects, but also pedagogy and psychology. In order to create an ideal and flexible classroom, descriptive and analytical methods as well as library documentation techniques were used in this study. We will provide an overview of environmental factors through architectural themes to facilitate student learning and better implement the curriculum as they have a significant impact on student learning and also on the quality, health and attractiveness of the learning environment.

Key word: Psychology environment, interior design, education spaces

1. Introduction

In modern life, as we know, man spends most of his time in man-made environments. Humans live at home, learn in schools, work in offices, drive cars, and are in constant contact with the physical environment (Nourmusavi, 2020). Research has shown that many behavioral disorders in urban communities, such as violence, aggression, violation of the rights of others, and disobedience to the law, have historical, cultural, and economic roots in the quality of living, educational, and working spaces; this is evidence of the importance of spatial quality. The physical environment with its components such as color, texture, light shadows, light, sound, form, etc. influences the human body and mind (Anbari, 2015). Therefore, proper design of these spaces and adherence to standards and quality indicators are important and effective factors to increase the quality level of educational spaces (Zaeghami, 2013). An effective learning environment is an environment that has an important impact on children's education along with other influential components such as curriculum, teachers, etc. However, the physical environment of the school is only one of the influential components of learning; however, it can be said that the most important component is an active learning

environment (De Gregori, 2007). The need for educational reform is to create spaces that are connected to students' activities. Spaces that provide suitable conditions for the physical, mental, emotional and social development of children, which can be achieved by designing the details of the spaces according to the behavioral patterns of students (Torkaman 2016). Functional indicators and esthetic principles and fundamentals in the design of physical educational spaces will not only meet the mental and physical needs of students, but also enhance their talents and develop their creativity (Tohidi 2018).

2. Rationale

Space with all its characteristics plays an effective role in shaping the personality of man. This space is especially important for the growth of students, a factor that should have a positive impact on their physical and mental development (Serfat, 2017). Nowadays, most of the buildings used as academic or cultural centers for students do not meet their real needs, neither in terms of their architecture nor in the type of activities they offer (Nasr, 2017). Students need spaces for play and learning that are controllable but do not restrict them, that are attractive, and that are more of a movement than a break. Students are more interested in experimentation than

anything else. Spaces designed for students, especially educational spaces, should be able to influence their mental and emotional powers to engage in their education and create a happy and energetic environment for them (Azmodeh, 2012, p. 5).

The main objectives of this research are to:

1. describe an appropriate educational space with the necessary standards, and
2. describe the principles and criteria of design.

The main areas of this research include the design of educational spaces, the developmental psychology of children, and the educational psychology of children. The purpose of this paper is to explain how to design educational spaces in the best interest of children while being efficient in education. We explore the topic of the different abilities of spaces to meet the behavioral patterns and needs of children in schools, including (1) the ability of spaces to meet the moods of children for their physical, mental, social, and emotional development, (2) the ability of these spaces to influence the child's mental and emotional strengths, (3) the ability of these spaces to participate in the child's education while creating a happy and energetic environment, and (4) the ability of these spaces to create a desire in children to participate in the educational environment, which is the main part of this article. In this phase of the research, the results were analyzed and presented using qualitative methods and logical conclusions from studies in related fields.

3. Literature Review

In this part of the research, a summary of the results of studies on the articles by researchers and scholars in the field related to the topic of this paper is presented in Table 1, which shows the factors that influence children's learning.

Table1. Results of researchers(Torkaman,2016)

Key results	Article / Project / Report Title	Researcher
1. Determining the effective criteria in choosing the type of school space organization 2. Appropriate model for designing educational space 3. Possibility of creating a space for comprehensive communication	Strategies for optimizing educational spaces	Halim bordi hagh nia, Rahim bordi hagh nia (2016)
1. color 2. light 3. ceiling 4. sound 5. furniture	Application of environmental psychology in the design of educational spaces	Farzaneh kian abri, marzie tabaeian (2016)
1. Observance of standard 2. Partitioning 3. arrangement of school 4. furniture 5. doors and windows	How to design educational spaces from a psychological point of view with the aim of achieving a standard classroom	Mahbobe tohidi, ahmad mirza kochak khoshnevis (2018),
1. Technology Classes 2. Teaching Strategies	Environment-Behaviour Studies in the Classroom	Sandra Horne Martin, (2009)
1. play, Playgrounds and Nature 2. Aesthetics and Unusual Spaces 3. Flexible Spaces and Furnishings	ENVIRONMENTAL PSYCHOLOGY IN CLASSROOM DESIGN	KATIE HUNTER (2005)
4. Sex of the subjects 5. Age of the subjects 6. Creating spaces based on children's age and releasing energy 7. Using architectural forms appropriate to children	Child-oriented architecture from the perspective of environmental psychology	Maral Anbari, Hossein Soltanzadeh, (2015)
1. Educational space Smart 2. physical environment 3. Air quality	Factors of interior design of education spaces by emphasis on Environment psychology principles	Sara Davarpanah (2017)
1. Prioritize furniture 2. Recognize the factors affecting success 3. Diagnose student academic failure	The effect of satisfaction with the quality of educational space architecture on academic success	Vahid vaziri (2017)
1. learning level 2. quality of learning 3. learning environments	The role of architecture and physical factors of educational environment on facilitating learning	Mozghan torkaman (2016)
1. School design 2. Teaching place analysis	Designing Sustainable Schools as Three Dimensional Textbooks	Ester Ehrlich Schwartz (2013)
1. Comfortable chairs and work spaces 2. Classroom layout is changeable 3. From Use attractive colors, textures and patterns to cover floors and walls	School facilities	Henri (2001)

The pedagogical method that focuses on the development of outdoor education leads to a variety of curricula, so that different ideas are presented on how to use nature for education in different conditions and according to the culture and situation of each class and teacher. What all these ideas have in common is that they motivate teachers and students to achieve learning outcomes that go beyond the classroom. This shows that this method of education does not assume that out-of-school instruction is better than classroom instruction. Rather, it simply points out that some lessons are better presented outside the classroom and, more generally, that classroom instruction should be combined with instruction outside the classroom (Robbie 2002).

4. The effect of environmental factors on learning and behavior in educational environments

Environmental psychology is a subfield of the behavioral sciences. This debate dates back to the early 1960s. Looking at the history of this field, one finds that in the 1960s and 1970s, the field of environmental psychology and research in general that examined the effects of the environment on various human behaviors was an important topic (Kamelnia, 2010). However, since the 1980s, the role of humans in the environment has also been studied. This field of psychology is an interdisciplinary branch that is closely related to architecture, landscape architecture, and urban design (Tabaian, 2016). The field of environmental psychology emphasizes how the physical environment influences emotions and behavior (Ata, 2012).

Numerous studies show that the quality of the environment in which a person works, i.e., factors such as space, color, light, sounds and the extent to which they enjoy the space, influences their perception. For this reason, the relationship between architecture and psychology is necessary for the better design of spaces (Tabaian, 2016). A beautiful school facilitates learning, brings vitality and enjoyment of life for children and young people. An inadequate school that is cramped and dark is soulless, leads to boredom and depression among students, and is detrimental to active learning and school presence and vibrancy (Roghani, 2016). To achieve the desired educational environment, one must first identify the needs of the age groups. Meanwhile, the study of behavioral patterns in educational environments will

facilitate the identification of needs an ecological psychologist, agrees that there is a special relationship between the physical dimensions of architecture and behavior (physical behavioral places). In this regard, the benches in the classroom, how they are arranged, affect students' behavior and learning (Ghafari, 2000).

5. Features of a safe and ideal school

School is a familiar environment where you feel relaxed, know where everything is and can concentrate without anyone interrupting. A safe space is also necessary for a group of several people. Without such an atmosphere, social communication with others would be impossible. Because if you do not have the space to say it's yours, you cannot understand your situation. This is why it is so important that children can keep the items they make, such as crafts, in the classroom in places that are safe for them and where they do not have to worry about them being damaged (Hertzberger, 2008). Functional and appropriate spaces are needed to achieve the goals of ideal learning. One of the problems in designing a classroom is to create an area in the classroom that is dedicated to the general activities and general education of the children but can also become a space for their activities. During the lesson, it should be possible for the teacher to control and monitor the students' activities. Classrooms should be flexible, for example, with removable partitions to create the desired spaces (Kamelnia, 2007). According to the projections, 1.5 square meters of space and 5.5 cubic meters of air are needed for each student. In other words, for a class of 30 students, the room should be 8 meters long, 6 to 7 meters wide and 4 meters high. The space required for each student should not exceed 4.5 cubic meters and the height should be less than 3 meters. So, when choosing a room for the class, the size of the class and the number of students should be considered (Haghnia, 2016).

6. Five Recommended Factors for Classroom Design

In school architecture, it is necessary to pay attention to the wants and needs of users, The architecture or physical space of the school is also considered as a living and dynamic factor in the quality of students' educational activities. From a systemic point of view, how the school architecture, its principles and constituent elements such as:

1. An efficient classroom is the center for a variety of activities. Furniture and materials are directly determined by the type of

activity. Shelves and furniture are used to delineate different areas because children are better able to concentrate on their activities when they are not distracted by other visible activities in the classroom.

2. Use areas that relate to the learning topics, divide them and put each piece of equipment in its place.
3. Furniture can be changed depending on the type of activity.
4. Involve the children in the design of the furniture and the classroom.
5. Set up an area to show daily activities and activity charts, etc. to reinforce a sense of safety and control (Kamelnia, 2007).

7. The role of architecture following the spirits of children for their physical, mental, social, and emotional development

7.1 Stairs

Perhaps for a long time there was a notion that height differences should not be created in indoor spaces (especially for children), but today in the interior design of schools going up and down stairs is an effective indicator of the quality of learning. is. Therefore. the use of stairs and surface differences can be considered in this regard (Hertzberger 2008).

7.2 Roof variety

In the interior design of learning environments, paying attention to the roof as one of the space-creating components can be effective in defining the different qualities of interior spaces. The use of sloped roofs not only creates spatial diversity, but also contains themes of spatial semiotics for children (Cottage Memory). (Turkman 2016)

7.3 Corridors

In architecture for children, the design of connecting spaces and break rooms is as important as the space itself. Communication spaces are just a place for adults to communicate between spaces, but for children they are a place where they can have different experiences freely without the shackles of space. Also, by creating break spaces in the hallways, they seem less cramped, dark, and long, and it is more attractive to continue on the path. On the other hand, by creating one-way corridors that allow communication with the outside space, the child no longer feels trapped in the space. However, since one-way corridors are not economical and energy efficient, this problem can be alleviated by combining one-way and two-way corridors (Azmoodeh, 2012)

7.4 Light

The psychological effect of light in educational spaces for children Light is the first condition for any kind of visual perception. In absolute darkness we can see neither space nor shape nor color. But light is not only a physical necessity, but its psychological value is one of the most important factors in human life in all areas (Groter, 2007). Natural light means the same as daylight from the sun. Environmentalists place great emphasis on the use of daylight in educational spaces. Research shows that the use of natural light not only plays an important role in learning, but can also affect students' health and attention (Hawes, 2012).

Due to the importance of lighting for the environment, there are points that are as follows

1. The reflection of light in water and the light elements in water produce pleasant sensations.
2. The use of stained-glass windows and skylights is recommended to vary the spaces.
3. The source of light should not be in the students' field of vision as it is dazzling.
4. It is better to locate classrooms in the north and south and east and west of the building so that direct sunlight does not enter the room.
5. High and large windows let more light into the classroom and make it brighter. This allows more air into the classroom and students need more air. High and large windows give a feeling of freedom and informality (Mahmoodi 2011).
6. The intensity of light coming in depends on the design and size of the window. Generally, windows with an area of 30 to 60 percent of the facade area or about 15 to 30 percent of the classroom area are suitable for classrooms.
7. Classroom windows should not be less than 4.5 to 4.9 degrees.
8. The minimum illuminance in the classroom is 200 lux and the maximum illuminance is 500 lux (Shojaei. 2009).

8. The predominance of color and form

Most school-age children, between 3 and 6, show a strong interest in colors, but between 7 and 9 they pay attention to shapes, and this interest is greatest at age 9. As children get older, they become more interested in nature and shapes. However, in a survey, about 10 percent of preschoolers showed that they tend to dominate shapes over colors. Children who dominate shapes more than colors (IQ) are smarter than supposed color groups. However, some theorists believe that ingenuity and creativity are stronger

in putative color groups. Studies of children's documents related to colors have shown that the color orange, then red and pink are the favorite colors of children ages 3 to 6. According to Ashley, it is concluded that the color red is a superior color for children when colors are used consciously and with the knowledge of their relationship to the emotions in the child's life, because children act on their feelings. As they grow older and are able to control their emotions, they become interested in cool colors as well. Research has shown that the color red has two opposing properties:

First, the feeling of affection and love, and second, the feeling of being attacked and suppressed, as red colors are closely associated with very intense feelings. Blue is associated with emotional control. Researchers have found that children are also interested in brown. However, researchers have found that in some cases, children who have a tendency toward blue have very strong emotions that change them or change their direction.

Table 2: Psychology of colors and how to use them in spaces (Anbari 2015)

	How to use it in spaces	Specifications	Color
1	Using it in the environments of game, show and sport	warm color and stimulating Passion and love, sincerity	Red
2	For Educational spaces in elementary school – due to the prevention of drowsiness and lethargy in children ... lively, invigorating, warm peace of the children	Energizing and stimulating color	Orange
3	Its combination with other colors and use it in the space of rest	indicating Love and romance	Pink
4	It is better to use the color with combination with other colors in classes	Expresses the sense of relief – represents peace, security and order-	Blue

	and educational spaces	expresses the feeling of sorrow, introspection and isolation in some people	
5	To make interior decoration happy and bright	Warm and happy color-stimulating thought-making eyes bored more than other colors	Yellow
6	For decorating studying rooms, educational spaces and a place needs concentration.	Cool color and a symbol of nature represents peace, happiness, health and jealousy, gaining the ability to read	Green
7	Pale violet spectrum in space and educational environment, gives peace and happiness. as a result it can be used practical and craft classes .	The most spiritual color represents harmony between reason and emotion and border between spirituality and materialism	Purple

Table 3: Psychology of forms and how to use them in spaces (Anbari 2015)

1	The place of use	Excited emotions	Form
2	Child's play space	Imaginary-creative imagination	Irregular forms
3	Entrance	Caller	Concave form
4	emphasis points and pausing space	Innovation and complexity	Static form
5		Suggests the status of rejecting	Convex form
6	Children love the spaces	Softness and comfort	Soft and arched form
7	Passage	Comfort and mobility	horizontally Expanded form
8		Hard	Angular and broken forms

Researchers have found that there is a strong correlation between color choice and gender. For

example, between the ages of 6 and 17, girls tend to perceive warm colors and boys tend to perceive cool colors, but when they become adults, this correlation reverses. In the field of physiology, certain colors are associated with various diseases. For example, Table 2 can be used to use the right colors for all rooms in terms of their psychological properties, and Table 3 to use appropriate shapes when designing children's rooms. (Anbari, 2015).



Figure 1. Woodland school / HMFH Architects

9. The role of architecture in participating in the education of children at the same time creating a happy and full of energy environment

9.1 Noise

Constant and unpredictable noise causes physical fatigue and limits students' field of vision and color recognition, which ultimately reduces their work efficiency. Alburg College research by scientists on the echo of sound in the classroom shows that in classrooms where there are no carpets or curtains and the chairs are made of wood or metal and no fabric is used, the sound stays in the room longer. So, the classroom is full of unnecessary noises like whispering, rustling of paper etc. And sometimes the teacher speaks loudly to drown out the sounds, which is undesirable for the students (Shahbazi, 2015). Unfortunately, the wrong location of many schools in our country can also cause noise pollution. Conversely, noise pollution in some schools prevents communication between students and teachers. In this case, slow children and those with hearing problems are the most affected. School should be for everyone (Tawhidi, 2016).

9.2 Heat and cold

Turkman (2016) investigates the effect of classroom temperature, wind and rainy weather on students' behavior and shows the impact of such physical factors of the environment on behavior. In the study, which was conducted for two consecutive years in the first and second grades of elementary school through field observation, 48 teachers completed questionnaires. These questionnaires were used to determine two factors: the level of effort (the amount of effort and cooperation with the teacher) and the number of class activities and mobility. Then, the relationship between these two behavioral aspects with air temperature and other air characteristics (humidity, wind, and rain) was re-examined in the morning and afternoon. This study shows that student behavior is significantly affected by temperature and air quality. For example, a temperature of more than 2 degrees Celsius decreases students' mobility and lethargy (Moinpour, 2004)



Figure 2. Woodland school / HMFH Architects

9.2 The organization and design of the classroom

The most important change in the classroom is to break the line of sight between teachers and students and to create space for students to interact with each other. To this end, linear rows are at odds with the mood of the students. In traditional classrooms where students' chairs are arranged in regular rows and the teacher's desk is at the front of the classroom, all attention is focused on the teacher and little communication takes place between students (Jalalian, 2016).

This order may be very desirable when the teacher is giving a lesson to the whole class, but it makes learning from classmates and group work impossible. Students in the back row of the class are far away from the teacher and can easily cause disciplinary problems and disruptions (Dejdar, 2016). In some classes, the chairs are arranged around the desks and the teacher's desk is on the sidewalk. This type of arrangement is practiced in experimental science classes. The students work with each other. If the classroom is arranged in such a way that the students are arranged in a circle or can interact with the teacher, then the teacher is a part of the students and can lead and guide the students' group discussions in addition to teaching. However, when designing classrooms, it is important to consider all students. One of the basic needs of children is to be noticed by teachers. If the physical space of the classroom fosters this feeling in students, the number of disciplinary problems will undoubtedly decrease significantly (Siarni, 2001).

9.3 Interior design patterns in learning environments

All components of interior design should be attuned to the development of children's various learning abilities and play an effective role in this regard. For example, flooring that teaches children subjects (such as multiplication tables, the alphabet, etc.) or a tool that children can play with and have fun with can be attractive (Jalalian, 2016). There are different design patterns for a learning environment. These patterns can be considered in different areas. From the way the school is organized and how it fits into the context, to the design of the smallest furnishings (such as door handles), all of these elements can be very important (Turkman, 2016).

9.3 Learning streets

School corridors become learning streets with a variety of activities, including conversation and discussion spaces, seating areas, small workstations, individual changing rooms for children, work shows, and workshops. Corridors

are the expandable spaces of classrooms and their extensions (Dezhdar, 2016).

9.4 Inviting entries

For a child, the most important motivating factor for going to school is to see his friends. If the entrance of the room is designed in such a way that before the child enters the room, he is shown a picture of the presence of other children, this is the best kind of invitation. Setting up a separate entrance and cue for children also increases the desire to enter the room (Jalalian, 2016).

9.5 Water and trees

the presence of elements that are mostly found in the natural environment, such as water and trees, can add a sense of liveliness to the educational space. Therefore, this can be considered not only in terms of the quality of the space created, but also as an effective factor in children's sense of belonging to the environment and nature, as well as in providing knowledge about natural life and related skills (Jalalian, 2016).

9.6 Internal and external communication (role of nature in education)

Louis Kahn (1924) defines the word school so: All places which man uses to satisfy his desire for learning are called schools, and these places serve not only for learning and the acquisition of ideas and theories, but also for understanding the reasons for the existence of everything and the mutual possibilities and relations between man and nature. The presence of nature in educational spaces is often very limited, and this limited presence takes place without taking into account the specific needs of children and the high capacity of natural environments to meet these needs. There is a need to design natural environments in schools to meet the diverse developmental and educational needs of children and to enhance their abilities. The importance of the presence of nature and outdoor areas in schools has been considered by child researchers from different aspects. The study of educational theories shows that educators are paying attention to outdoor education in addition to school education, and the use of nature as an educational tool is receiving much attention today. It is also a very suitable platform to enhance various aspects of a child's development. Moreover, the existence of natural spaces creates peace, freshness and a sense of belonging for more children than the school room. The way outdoor spaces are designed and the quality of nature present there vary

according to the aspects mentioned for children and should be considered by designers. How (the presence of nature and the right design methods for it can influence the quality of children's education (Muzaffar 2009).

10. Conclusion

As noted in the psychology of child development and education and in research, several factors affect a child's learning, one of which is the learning environment. A school with appropriate and child-friendly premises can have an impact on children, the development of their talents, the formation of their personality and moral and social values, and finally on their learning speed and lay a good foundation for their future education. Be fruitful for the next generation. Your buildings must be creative, not imitative. Be a stimulating environment for free thinking and creative expression. In this case, the child in this type of school shows a great desire to attend it, and it even influences the child to become dependent on it. Finally, attending the school and the educational environment lays the foundation for the student's interest in learning. This leads the child to reject and detest similar environments and even has lasting negative effects on his personality.

This model consists of two parts

1. Factors affecting the level of learning
2. Factors influencing the recipient of

In general, the design of spaces based on children's behavioral patterns and mental characteristics should be able to meet three specific categories of children's needs. These needs include educational needs, nutritional needs (social growth and physical growth), and spiritual and emotional needs. Meeting these needs makes the physical environment of schools an effective environment for the educational purposes of children. Designed spaces should be a good platform for children's physical and social development. Social spaces designed in educational environments allow children to interact, communicate and confront each other, and group and individual play spaces promote children's physical and social development. Finally, from the examination of the studies conducted, it can be concluded that the educational environmental factors studied influence student learning. This influence is such that the combination of these factors together creates conditions that make it easier for the student to concentrate on the subject matter. On the other hand, it creates better conditions for the teacher so that he or she can also communicate the subject matter to the students more effectively; in this way, learning is made easier for the students.

References

1. Nourmusavi, S., Karimi, A., Azeri, S. (2020), Ideal physical features of environmental design in children's hospital: Using children's perspectives
2. Anbari, M., Soltanzadeh, H., (2015). Child-oriented Architecture from the Perspective of Environmental Psychology
3. Zarghami, A., nasiri, M. (2013). the effect of environmental quality factors on reducing behavioral disorders in children
4. De Gregori, A (2007). Learning environments: redefining the discourse on school architecture, thesis for master of science in architecture, New Jersey school of architecture.
5. Torkaman, M. (2016). The role of architecture and physical factors of educational environment on facilitating children's learning
6. Tohidi, M., khoshnevis, A. (2018), How to design educational spaces from a psychological point of view with the aim of achieving a standard classroom.
7. Azmoodeh, M. (2012). Architecture and design for children, Tehran Science and Knowledge Publishing
8. Bordihaghnia, H., bordihaghnia, R., (2016). Strategies for optimizing the educational spaces of the country's schools
9. Kian abri, F., tabaeian, M. (2016). Application of environmental psychology in designing children's educational spaces
10. SandraHorne, Martin, (2009). Environment-Behaviour Studies in the Classroom
11. HUNTER, K. (2005). ENVIRONMENTAL PSYCHOLOGY IN CLASSROOM DESIGN.
12. Davarpanah, S. (2017). Factors of interior design of education spaces by emphasis on Environment psychology principles.
13. Vaziri, V. (2017). The effect of satisfaction with the quality of educational space architecture on academic success

14. Schwartz, E. (2013). Designing Sustainable Schools as Three-Dimensional Textbooks.
15. Taher, N. (2017). Living room design in character formation
16. Robbie, N. (2002). Authentic Learning in the context of Landscapes, Outdoor Education, Vol. 2, p 2-14.
17. Kamelnia, H. (2010). A New Approach to Designing Learning Environments, Journal of Architecture and Culture, No. 41, Page 6-13
18. Ata S, Deniz A, Akman B. (2012). The physical environment factors in preschools in terms of Environmental Psychology: A Review. Journal of Social and Behavioral Sciences, 46:2034 -2039.
19. Kamelnia, H. (2007).principals of designing learning environments, Tehran: Subhan Noor
20. Ghafari, A. (2000) Systems of use of spaces and the relations between them in school design, School Magazine, No. 14
21. Hertzberger, H. (2008). space and Learning, Publisher: Rotterdam
22. Dezhdar, O. (2016). Architecture and physical factors of educational environment on facilitating learning.
23. Groter, M. (2007) Aesthetics in architecture 624 pages
24. Hawes, T. (2012). Effects of four workplace lighting technologies on perception, cognition. International Journal of Industrial Ergonomics,42: 122-128.
25. Mahmodi, A. (2011). Design of educational spaces with a flexible approach. Tehran University Press Tehran 214 page
26. Shojaei, M. (2010). Design and architecture of educational spaces. Tehran Simaye Danesh, 256 pages
27. Shahbazi, M. (2015). The effect of interior design of educational environments on increasing students' learning.
28. Moeinpor, A. (2004). The effect of physical factors on students' academic achievement, educational and psychological research
29. Jalalian, S. (2016). The role of architecture and physical factors of the educational environment.
30. Siami, SH. (2001). Teacher, Classroom Management, Barriers and Strategies. Tehran Tiran Activities Association
31. Mozafar, F. (2009). Recognizing the role of nature in educational spaces. Scientific Journal of Education Technology, Fourth Year page 37-46
32. Kahn, L. (1924) The New Approach in School Design
33. Parkash, N., Randall, F. (2005), The Language of School Design, NCEF.
34. Roghani, M. (2016). Investigating the environmental components of the educational space and its effect on students' behavior
35. Serafat, SH. (2017) The impact of how to design a living environment on the mood and the process of shaping people's personality
36. Tanner C.K, (2000), The Influence of School Architecture On Academic Achievement, Journa of Educational Administration, Vol. 38 No. 4, pp. 309-30.
37. Henry, T, (2001). Creating a place where people want to be. Middle Ground, vol 3, p10-16.
38. Earthman, G. I. (2002). School facility conditions and student academic achievement, California: UCLA's Institute for Democracy.

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Figure I.12: Article Certificate



EXPLORING THE GEOGRAPHICAL, STRUCTURAL MATERIALS, AND CONSTRUCTION TECHNIQUES ON MARS

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ABSTRACT

Due to the limited resources available on Mars, careful consideration of the location of each building and the use of materials readily available on the planet is essential. One possible building material is the ice found on Mars, which could provide both structural support and radiation protection. Another option is to use Martian soil known as shillite, which can be pressed into a solid building material. In addition to choosing the right materials, it is important to use construction technology that can withstand the harsh environment of Mars. This may include 3D printing technology that can quickly and efficiently construct buildings using local materials. It is also important to consider the location of any buildings on Mars. Factors such as proximity to resources, terrain, and weather patterns must be considered when choosing a building site to ensure the safety and sustainability of any structure built on the planet. In addition, any building on Mars must be designed to withstand the planet's extreme temperatures and dust storms. One potential solution to achieving long-term sustainability on Mars is to design buildings that can be easily expanded or renovated. In this article, we examine these important factors using library sources and previous research.

Keywords: Material, Technology, Construction, Resource, Location

Highlights: In a pioneering Paper, we navigate the complexities of Mars, dissecting its geography, dissecting its geography, and unveiling revolutionary insights. Our focus extends to groundbreaking structural materials and avant-garde construction methods, envisioning a Mars transformed into a habitable realm. This exploration not only expands our cosmic comprehension but also charts a course towards the development of resilient, sustainable infrastructure capable of sustaining human life amidst the challenges of the Martian frontier.

1. Introduction

Mars is the fourth planet from the Sun in our solar system, and it is often referred to as the "Red Planet" due to its reddish appearance in the night sky. It is a terrestrial planet, meaning that it is primarily composed of rocks or metals, and it has a thin atmosphere. (1) Mars has a diameter of about half that of Earth and a surface area of around 28% that of Earth's. It has a rocky surface with craters, volcanoes, valleys, and polar ice caps. The largest volcano on Mars, Olympus Mons, is about three times the height of Mount Everest, making it the largest volcano in the solar system. (2) Mars has a day and night cycle similar to Earth, with a day lasting 24.6 hours. However, Mars has a longer year, taking approximately 687 Earth days to complete one orbit around the Sun. (3) Mars is a focus of intense study and exploration by scientists and space agencies around the world. It has been the subject of

numerous missions, including flybys, orbiters, landers, and rovers. These missions have revealed a wealth of information about Mars, including evidence that liquid water once flowed on its surface and the possibility that it could support microbial life (4).

2. Methodology

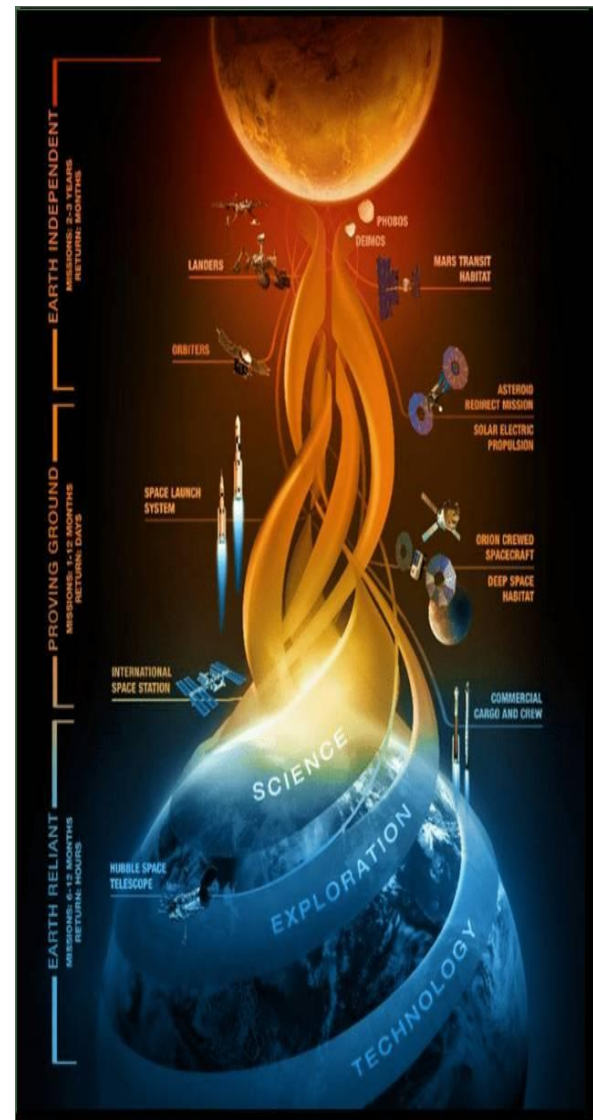
The research paper in question relies primarily on library resources and a comprehensive review of prior research as its principal research methodology for information gathering. This approach entails an in-depth examination of existing literature and scholarly works to establish a robust foundation for the study, offering a rich and well-informed perspective on the subject matter.

3. History of Mars exploration

Mars has been a subject of human curiosity and observation for thousands of years. Ancient civilizations, including the Egyptians and the Chinese, recorded observations of the planet as early as 1500 BC. However, it was not until the scientific revolution of the 16th and 17th centuries that humans began to study Mars systematically. (5) The first telescopic observations of Mars were made by Galileo Galilei in the early 17th century. Later, in the 19th century, astronomer Giovanni Schiaparelli made detailed observations of Mars, describing features on the planet's surface that he called "canali," which were interpreted by some as evidence of artificial canals built by intelligent beings. (6) In the early 20th century, interest in Mars increased with the development of space technology. In 1960, the Soviet Union launched the first mission to Mars, Marsnik 1, but it failed to leave Earth's orbit. The United States followed with the launch of Mariner 4 in 1964, which successfully flew by Mars and sent back the first close-up images of the planet's surface. (7) Subsequent missions by both the US and Soviet Union, including the Viking missions in the 1970s, provided additional information about the planet's atmosphere, geology, and potential for supporting life. In 1996, NASA's Mars Pathfinder mission landed a rover, Sojourner, on the surface of Mars, marking the first time a vehicle had moved on another planet. (8) In 2015, NASA issued its official plan for human exploration and colonization of Mars, which was named as "Journey to Mars", as shown in (Fig. 1. The plan operates through three distinct phases including Earth Reliant, Proving Ground and Earth Independent). Since then, numerous missions by various space agencies have continued to explore Mars, including the Mars Exploration Rovers (Spirit and Opportunity), the Mars Reconnaissance Orbiter, and the Mars Curiosity Rover. These missions have provided valuable information about the planet's history, geology, and potential for supporting life. (9) In recent years, interest in Mars exploration has continued to grow, with the goal of eventually sending humans to Mars. NASA's Mars 2020 mission, which included the Perseverance Rover and the Ingenuity Helicopter, successfully landed on Mars in February 2021. The mission is designed to study the planet's geology and search for signs of past microbial life, as well as pave the way for future human exploration of the planet. (10) In addition to NASA, other space agencies and private companies, such as SpaceX, are also planning missions to Mars. The ultimate goal is to establish a sustainable human presence on the planet, which could serve as a stepping stone for further exploration of our solar system and

beyond (10). Figure 1 shows the technologies sent to Mars.

Figure 1: Journey to Mars by NASA (NASA).



4. Spacecraft used to travel to Mars

Name Space craft	lau nc h da te	Manuf acturi ng Countr y	Loc atio n	oper ation al	explo ratio n
Mars 2	19 71	Soviet Union	cras hed	Faile d	Faile d
Vikin g 1	19 75	Nasa	Chry se Pla niti a	micro bial life	succe ssful
Vikin g 2	19 75	Nasa	Uto pia Pla	The existe nce of a	succe ssful

			niti a	micro bial yard	
Pathfinder	19 96	Nasa	Are s Vall is	Geolo gy, weat her	succe ssful
Global Surveyor	19 96	Nasa	In orbi t	clima te, geolo gy, and atmo sphere	succe ssful
Odyssey	20 01	Nasa	In orbi t	Wate r	succe ssful
Exploration Rovers	20 03	Nasa	Gus ev Crat er	Wate r, geolo gy	succe ssful
Science Laboratory	20 11	Nasa	Gale Crat er	geolo gy and habit abilit y	succe ssful
Atmosphere and Volatile Evolution	20 13	Nasa	In orbi t	atmo sphere	succe ssful
Mars 2020	20 20	Nasa	Jeze ro Crat er	micro bial life	succe ssful

Tabla 1: Spacecraft History

In Table 1, the information about the probes sent to Mars. of September 2021, a total of 49 spacecraft have been sent to Mars by various space agencies and organizations around the world since the first mission in 1960. Of these, 26 have been successful in reaching Mars and completing their mission objectives, while the remaining missions either failed or were only partially successful. several more spacecraft have been sent to Mars, including NASA's Perseverance rover and China's Tianwen-1 mission, which both successfully arrived at Mars in February 2021. As of March 2023, there have been a total of 15 successful Mars missions by

various space agencies since the start of the 21st century (11) .

Figure 2: Parts of Mars (Nasa)



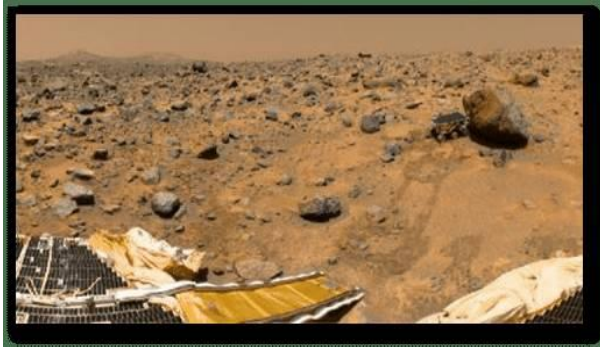
5. Goals for exploring and living on Mars

Exploring and living on Mars have several goals that are both scientific and technological in nature. Some of the key goals include:

- Scientific exploration: Mars is a fascinating planet that can provide answers to some of the most important questions about our solar system and the universe. The exploration of Mars aims to study its geology, atmosphere, climate, and other factors to understand the planet's history and potential for life. (12)
- Search for life: One of the primary goals of exploring Mars is to search for signs of past or present life. Scientists believe that Mars may have had conditions suitable for life in the past, and the exploration of the planet can help determine if life ever existed on Mars. (13)
- Technological advancement: The exploration of Mars requires the development of advanced technologies and systems that can function in the harsh and unforgiving environment of space. The development of these technologies can have numerous benefits for space exploration and Earth-based applications. (14)
- Colonization: Some scientists and visionaries see Mars as a potential site for human colonization in the future. The establishment of a human settlement on Mars would require the development of sustainable habitats, infrastructure, and transportation systems, which could have significant implications for human civilization. (15)

Preparation for future exploration: The exploration of Mars can serve as a stepping stone for future space exploration missions. The technologies and systems developed for Mars missions can be adapted for other destinations,

Figure 4: The Geology of Mars (86)



such as the moons of Jupiter and Saturn or even interstellar travel. Figure 3 shows an imaginary picture of astronauts on Mars.

Figure 3: Colonize Mars (85)



6. Geology of Mars

Mars is a terrestrial planet with a geology that has many similarities with Earth. The surface of Mars is dominated by impact craters, many of which are billions of years old. The planet's lack of tectonic activity means that these craters have remained relatively unchanged since their formation. The largest impact crater on Mars is the Hellas Basin, which is about 2,300 kilometers (1,400 miles) wide and over 8 kilometers (5 miles) deep. Mars also has several large volcanoes, including Olympus Mons, which is the largest volcano in the solar system and stands at over 22 kilometers (14 miles) tall. The planet's volcanoes are much larger than those on Earth, and are thought to have formed from hotspots in

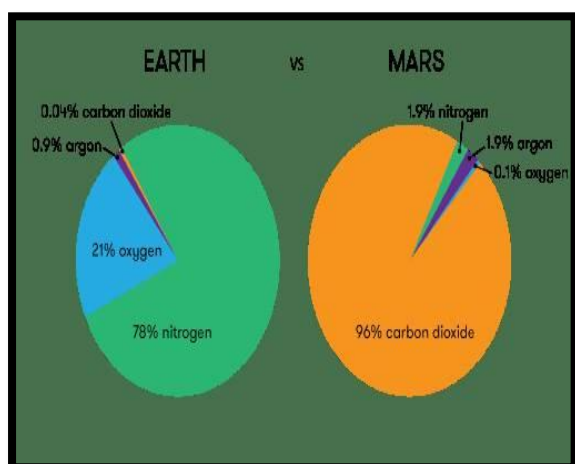
the planet's mantle. The surface of Mars also has vast plains and canyons, including Valles Marineris, which is over 4,000 kilometers (2,500 miles) long and up to 7 kilometers (4.3 miles) deep. These features are believed to have formed from tectonic and volcanic activity, and some may have been shaped by the flow of water on the planet's surface in the distant past. Mars' geology is still being studied by NASA's rovers, orbiters, and landers. These missions have revealed that Mars was once much more similar to Earth in its geology, atmosphere, and potential for supporting life. The planet's ancient geological features suggest that liquid water may have once existed on the planet's surface, and there are indications that subsurface water may still exist today. Understanding Mars' geology is critical to understanding the planet's potential for past or present life and for future human exploration and colonization. (16-17). Figure 4 shows the real image of Mars.

7. The atmosphere of Mars

Mars has a thin and cold atmosphere composed mainly of carbon dioxide (95.3%) with small amounts of nitrogen (2.7%), argon (1.6%), and trace amounts of oxygen and water vapor. The surface pressure on Mars is about 1% of Earth's, meaning that the atmosphere is too thin to support human life without protective equipment. The Martian atmosphere is also subject to intense seasonal changes, with the planet's axial tilt causing dramatic shifts in temperature and atmospheric pressure. During the Martian winter, the planet's atmosphere cools and condenses into dry ice (frozen carbon dioxide) at the poles, causing a significant drop in atmospheric pressure. This dry ice sublimates back into the atmosphere during the Martian spring, causing a temporary increase in atmospheric pressure. Mars' thin atmosphere has significant implications for the planet's potential for supporting life. Without a thick atmosphere to shield the surface from harmful radiation and without enough atmospheric pressure to keep liquid water from evaporating, Mars' environment is extremely hostile to life as we know it. However, here are still possibilities for microbial life in the subsurface where conditions may be more hospitable (16-17).

The atmospheres of Earth and Mars differ significantly. Earth has a thick and oxygen-rich atmosphere composed mainly of nitrogen (78%) and oxygen (21%), with small amounts of argon, carbon dioxide, and other trace gases. In contrast, Mars has a thin and carbon dioxide-rich atmosphere, with much lower atmospheric

Figure 5: Comparison of atmospheres of Earth and Mars
(87)



pressure than Earth. These differences have significant implications for the potential for life and the habitability of each planet. Earth's atmosphere is conducive to supporting a wide range of life forms, while Mars' atmosphere is too thin and cold to support life as we know it without protective equipment (18). Figure 5 shows the difference between the atmosphere of Earth and Mars.

8. Mars climate

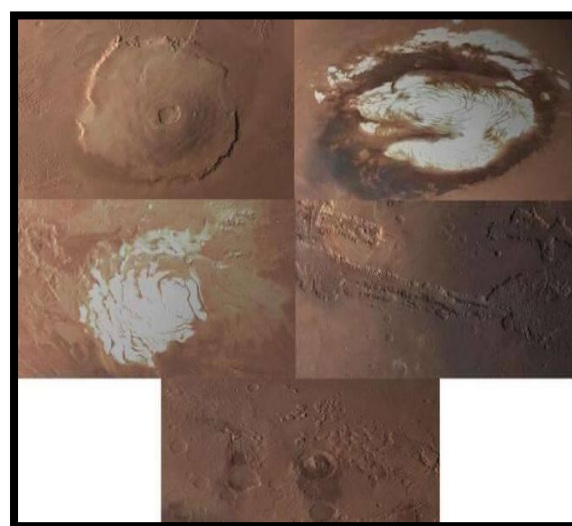
Mars' climate is defined by its thin, cold, and arid atmosphere, which is composed mainly of carbon dioxide. The planet's climate is characterized by large temperature fluctuations, ranging from an average surface temperature of around -60 degrees Celsius (-76 degrees Fahrenheit) to extreme lows of -153 degrees Celsius (-243 degrees Fahrenheit) at the poles at night. Mars' axial tilt also causes seasonal variations in temperature and atmospheric pressure, with the atmosphere cooling and condensing into dry ice (frozen carbon dioxide) at the poles during the winter and sublimating back into the atmosphere during the spring. The planet's climate has significant implications for its potential for supporting life, with the thin atmosphere and lack of protection from radiation making the surface environment extremely inhospitable. However, there are still possibilities for microbial life existing in the subsurface or near thermal vents, where conditions may be more hospitable. Understanding Mars' climate is critical to understanding its potential for habitability and for planning future missions to explore the planet. (16-17-19)

9. Locations on Mars that have ice and human-usable resources

There are several places on Mars where water ice and other resources usable by humans have been identified:

- North and South Poles: The polar regions of Mars are known to contain large quantities of water ice. (21)
- Utopia Planitia: This is a large plain in the northern hemisphere of Mars where a large underground reservoir of water ice has been detected. (22)
- Olympus Mons: This is the largest volcano in the solar system and has been found to contain large quantities of water in its subsurface. (23)
- Valles Marineris: This is a massive canyon system on Mars that may contain subsurface water. (24)
- Gale Crater: This is a large impact crater on Mars where the Curiosity rover discovered evidence of ancient lakes and streams, suggesting the presence of liquid water in the past. (25)

Figure 6 shows parts of Mars.



These locations are of great interest to scientists and explorers who are interested in establishing human settlements on Mars. By utilizing these resources, it may be possible to create sustainable habitats on the planet.

Figure 7: Mars soil (NASA)



Figure 8: A sample of soil similar to Mars soil in the laboratory (NASA)



10. Mars soil

Mars soil, also known as Martian soil, is the top layer of the planet's surface. It is composed of various materials such as iron oxide, silicon

dioxide, aluminum oxide, calcium oxide, and magnesium oxide, among others. Mars soil is reddish-brown in color, which is due to the high concentration of iron oxide (20-26-27).

The soil is very dry and dusty, with a low percentage of water content. The atmosphere on Mars is thin, and the planet has a weak magnetic field, which means that the soil is exposed to a higher amount of radiation from space. The soil is also affected by the harsh weather conditions on Mars, including strong winds, extreme temperatures, and frequent dust storms. Scientists are interested in studying Mars soil because it can provide clues about the planet's history, geology, and potential for life. Some studies suggest that the soil may contain traces of microbial life, which could be a significant discovery in the search for extraterrestrial life. Mars soil is an essential resource for future manned missions to Mars, as it could be used for various purposes such as growing plants, producing water, and creating building materials. However, it is essential to understand the soil's composition and properties to determine its suitability for different applications (28). Figure 7-8 shows a sample of Martian soil.

11. Energy sources on Mars

Mars is a planet with vast potential for energy sources, which can support human exploration and settlement. The energy sources on Mars include solar, nuclear, wind, geothermal, and In-situ Resource Utilization (ISRU). (32). Each energy source has its unique benefits and challenges. Here are some examples of each energy source:

- **Solar Energy:** Mars is an excellent location for solar energy due to its thin atmosphere and lack of cloud cover. Solar panels can be used to generate electricity during the day, and batteries can store excess energy for use at night. NASA's Mars Exploration Rover Opportunity used solar panels to generate electricity during its mission from 2004 to 2018. The Mars 2020 Perseverance rover is also equipped with solar panels to power its instruments and equipment. (33-35). Figure 9 shows the solar system on Mars.

Figure 10: Nuclear Reactor to Power Lunar and Martian Exploration (90)



- **Nuclear Energy:** Small modular reactors (SMRs) can be used to provide electricity and heat for settlements and rovers on Mars. NASA's Kilopower project is developing a nuclear reactor that can provide up to 10 kilowatts of electrical power continuously for at least ten years. Nuclear energy can also be used to extract water and oxygen from Martian regolith. For example, NASA's Mars Oxygen ISRU Experiment (MOXIE) is a

small instrument on the Perseverance rover that uses nuclear power to produce oxygen from the Martian atmosphere. (34-36) .Figure 10 shows nuclear energy on Mars.

12. Smart Material

Smart materials have great potential for use in various applications on Mars, such as in exploration and colonization. Below are some examples of smart materials that could be used on Mars, along with their details and applications.

- **Shape Memory Alloys (SMA):** SMAs are metallic alloys that can "remember" their original shape and return to it when heated. They can be used in Mars exploration and colonization as they are durable and can withstand the harsh Martian environment. (37-29). SMAs can be used in creating Martian habitats that can transform their shape to adapt to the changing environment. For example, a Mars habitat built with SMA could be expanded when the crew arrives, but then contract when the crew leaves. SMA wires can also be used in robots for exploration and repair, as they can be programmed to change their shape according to the surroundings. SMA wires can be connected to sensors and controllers to ensure the desired shape changes are executed accurately and safely (38-42).
- **Self-healing materials:** Self-healing materials are smart materials that can repair themselves in case of damage or wear and tear. These materials can be used on Mars in various applications, such as in creating durable and long-lasting equipment and infrastructure. For example, self-healing concrete can be used in building habitats and infrastructure on Mars, reducing the need for frequent repairs. Similarly, self-healing coatings can be used on equipment to protect them from damage and reduce the need for maintenance. The self-healing material can be programmed to repair itself when it

detects damage or wear, which can be triggered by sensors or be programmed to occur at specific intervals. (39-43)

- **Thermoelectric Materials:** Thermoelectric materials can be used on Mars for power generation and waste heat recovery. The temperature difference between the Martian surface and the atmosphere can be used to generate electricity using thermoelectric generators. (40-30-31). These generators can be used to power remote sensors, communication systems, and other equipment. Thermoelectric materials can also be used to recover waste heat generated by equipment and use it to generate electricity. The thermoelectric material can be designed to optimize the efficiency of the generator to maximize the amount of energy generated (41-44).

13. place for construction on Mars

Mars has been a focal point of space exploration in recent years, with various agencies and private companies planning to establish human settlements on the red planet. One of the critical aspects of building a sustainable Martian settlement is identifying suitable locations for construction. In this article, we will explore some of the best places for construction on Mars, along with their advantages and disadvantages (49).

- **Tharsis Plateau:** Tharsis Plateau is a vast volcanic plateau that stretches over 4000 km and is situated near the equator of Mars. The plateau contains some of the tallest volcanoes in the solar system, including Olympus Mons, which is more than three times the height of Mount Everest. The high elevation of the plateau provides several advantages for construction, including lower atmospheric pressure, which can reduce the amount of radiation exposure to the inhabitants. However, the Tharsis Plateau is also known for its high level of volcanic activity, which can pose significant challenges for construction. The frequent volcanic eruptions and lava

flows can damage or destroy buildings and infrastructure. Additionally, the high altitude can make it difficult to transport equipment and materials to the site (50).

- **Valles Marineris:** Valles Marineris is a vast canyon system on Mars that stretches over 4000 km and is more than 10 times longer and five times deeper than the Grand Canyon. The canyon system is located near the equator and is one of the most geologically active regions on the planet. The area contains several geological formations that are of interest to scientists, including layered deposits and potential water sources. The canyon system provides several advantages for construction, including natural protection from radiation, wind, and dust storms. The canyon walls can also provide shelter from the harsh Martian environment, and the canyon floor may contain useful resources such as water and minerals. However, the steep walls of the canyon can make it difficult to build structures and transport materials to the site. The narrow canyon floor may also limit the amount of available space for construction (51).
- **Arcadia Planitia:** Arcadia Planitia is a vast plain located near the Martian equator and is one of the flattest regions on the planet. The area contains several interesting geological formations, including buried glaciers and potential mineral deposits. The flat terrain provides several advantages for construction, including easy access to the site, ample space for building structures, and a stable foundation for structures. Additionally, the area is relatively calm, with minimal wind and dust storms, making it an ideal location for solar panels and other renewable energy sources. The plain may also contain water resources that could be used for human consumption and agriculture. However, the plain's low elevation may result in higher radiation exposure due to the planet's thin atmosphere. The area may also be prone

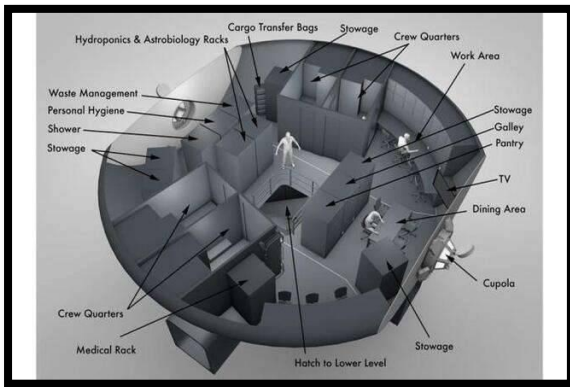
to occasional flooding due to the presence of buried glaciers and potential water resources (52-5).

14. Construction technologies on Mars

The Martian environment is very different from Earth, so construction technologies that work on Earth may not necessarily work on Mars (54). The most significant challenge on Mars is the thin atmosphere, which means that the surface is exposed to a high level of radiation and temperature extremes. The Martian surface is also made up of fine-grained soil, called regolith, which presents unique challenges for construction (55). One possible solution to these challenges is 3D printing technology. 3D printing technology could be used to build structures on Mars using local resources. The idea is to use the Martian regolith as the raw material for 3D printing. The regolith could be excavated, processed, and then used as the feedstock for the 3D printer. The printer would then build up the structure layer by layer, using the regolith as the building material. This approach would reduce the amount of material that needs to be transported from Earth and would allow structures to be built more quickly (56). Another construction technology that could be used on Mars is inflatable structures. Inflatable structures are lightweight and can be compacted for transport. Once on Mars, they can be inflated and then covered with a layer of regolith for added protection from the elements. Inflatable structures have already been used on the International Space Station and have proven to be reliable and effective (57). Another possibility is to use robots for construction. Robots could be sent to Mars to do the initial construction work, such as excavating and processing the regolith, and building the foundations for structures. The robots could then be programmed to construct the structures themselves, using a combination of 3D printing and inflatable technologies. This approach would reduce the risk to human life and could be more cost-effective in the long run (58). One of the biggest challenges in constructing structures on Mars is creating a habitable environment. Mars has a very thin atmosphere, which means that the temperature can vary greatly between day and night. To create a habitable environment, structures would need to

be insulated to maintain a stable temperature. One possible solution is to use aerogel, a lightweight, highly insulating material, as the insulation material. Aerogel has already been used in spacecraft and has proven to be very effective at insulating against extreme temperatures (59). Figure 11 shows the construction technology on Mars.

Figure 11: Construction on mars (91)



15. required for building on Mars

Building a sustainable human settlement on Mars would require careful planning and consideration of the specific needs and requirements of the settlers. The number of rooms and other spaces required for a Mars settlement would depend on a variety of factors, including the size and purpose of the structure, the number of settlers, and the resources available on Mars (60). A basic human settlement on Mars would need to provide a comfortable and habitable environment for the settlers, while also addressing the unique challenges of living on Mars, such as the harsh climate and limited resources. Some of the rooms and spaces that would be required for a Mars settlement include: Figure 12 shows the places required for building on Mars.



Figure 13: Living Quarters (92)

- **Living Quarters:** Living quarters would be the primary living space for the settlers. These quarters would need to provide a comfortable and safe environment for the settlers to sleep, eat, and socialize. Living quarters would likely be individual or shared living spaces, depending on the number of settlers and the available space (61-45). Figure 13 shows the living area on Mars.
- **Laboratory:** A laboratory would be necessary for scientific research and experimentation. The laboratory would need to be equipped with specialized equipment and storage areas for samples. Research on Mars could focus on a range of topics, including geology, astrobiology, and environmental science (62-46). Figure 14 shows the part of the laboratory on Mars.

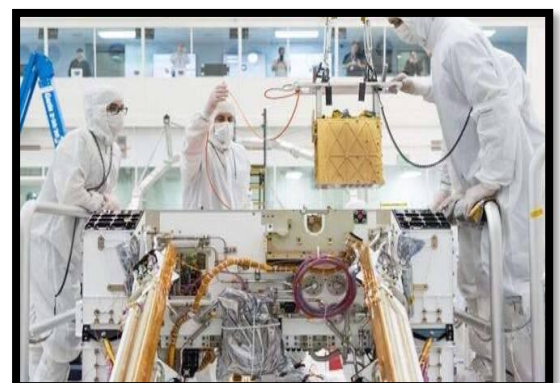


Figure 14: labratory (93)

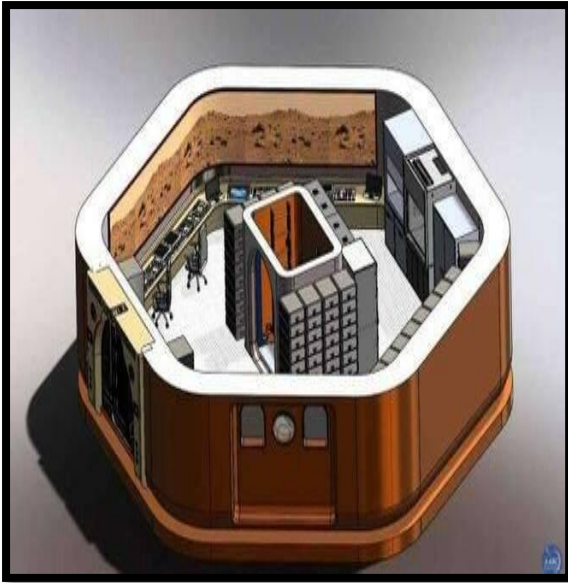


Figure 17: workshop place (92)



Figure 16: Green House on mars (92)

- **Medical Facilities:** Medical facilities would be necessary to provide healthcare for the settlers. The medical facilities would include a medical bay, an examination room, and storage for medical supplies and equipment. In addition, medical personnel would be required to provide medical care and to monitor the health of the settlers (63-47). Figure 15 shows the part of the digital clinic on Mars.



Figure 15: Digital Health on mars(94)

- **Greenhouses:** Greenhouses would be required to grow crops for food and oxygen production. The greenhouse would need to be large enough to support the needs of the settlement and would need to be equipped with the necessary technology to create a suitable growing environment. The greenhouse would be a critical component of the settlement, as it would provide food, oxygen, and a connection to the natural environment (64). Figure 16 shows the part of the green building on Mars.
- **Workshop:** A workshop would be necessary to provide a space for maintenance and repair of equipment and machinery. This would be an important space for the settlement, as all equipment and machinery would need to be maintained and repaired regularly to ensure that it functions properly (48). Figure 17 shows a part of the workshop on Mars.
- **Storage Areas:** Storage areas would be required for food, water, equipment, and supplies. Storage areas would need to be designed to protect the supplies from the harsh Martian environment and would need to be well-organized and easily accessible (65). Figure 18 shows a part of the maintenance of equipment on Mars.

- **Waste Management Facilities:** Waste management facilities would be necessary to dispose of human waste and other garbage. The waste management facilities would need to be designed to minimize the environmental impact of the settlement and to ensure that the waste is properly disposed of (65).



Figure 18: storage area (92)

In terms of the number of rooms required, estimates for a Mars settlement range from 10-20 rooms or modules for a small settlement, to as many as 100 modules for a larger settlement. These modules would likely be connected by tunnels or other passageways to create a cohesive settlement. In addition to these basic rooms and spaces, a Mars settlement would also require infrastructure to support the needs of the settlement. This infrastructure would include power generation and distribution systems, water and air management systems, and communication systems. The settlement would also require transportation systems, such as rovers or other vehicles, to explore the Martian environment and to transport supplies and equipment (66-67-68-69-70-71-72-73).

16. Advantages of construction on Mars

Construction on Mars offers several advantages for human exploration and settlement. Here are some of the benefits:

- **Reduced cost:** Building structures on Mars reduces the cost of transporting building materials from Earth, which is expensive due to the high cost of launch and transport (74).

- **Sustainability:** Using Martian resources such as regolith, which is abundant on the planet, can provide a sustainable building material for construction (75).
- **Adaptability:** Smart construction techniques such as modular construction and 3D printing allow for quick and easy assembly and disassembly of structures, making it easier to adapt to changing needs and conditions (76).
- **Faster construction:** With fewer regulatory hurdles, and due to reduced gravity, it is easier and quicker to construct buildings on Mars (77).
- **Scientific benefits:** Building structures on Mars provides opportunities for scientific research, such as studying the Martian environment, geology, and atmosphere (78).
- **Improved safety:** Smart construction techniques using sensors and IoT technologies can monitor the structural integrity of buildings, improving safety for astronauts living and working on Mars (79)

17. disadvantages of construction on Mars

While there are many advantages to construction on Mars, there are also several disadvantages and challenges that need to be addressed. Here are some of the main disadvantages of construction on Mars:

- **Harsh environment:** The Martian environment is harsh, with extreme temperature variations, high levels of radiation, and dust storms. This poses a significant challenge for construction and can impact the safety of astronauts (80).
- **Lack of resources:** While there are resources on Mars such as regolith, there is a limited supply of water and other materials that are essential for construction. This can limit the scale and scope of construction projects (81).
- **Communication delay:** Due to the distance between Earth and Mars, there is a significant communication delay. This can pose a challenge for remote construction and can impact the safety of astronauts (82).
- **Regulatory challenges:** There are regulatory challenges associated with building

structures on Mars, including legal frameworks, safety regulations, and environmental standards (83)

- High upfront costs: While construction on Mars can reduce the cost of transporting materials from Earth, there are still high upfront costs associated with developing and deploying the necessary infrastructure and equipment for construction (84).

18. Conclusion

The recent revelations about water and the potential existence of life on Mars, our solar system's nearest planetary neighbor, have spurred a resurgence in ensoiasm for further Mars exploration. The idea of establishing Mars as a potential future habitat for humanity is brimming with promise, but it also necessitates the formulation of vital assumptions and hypotheses as we set forth on this captivating endeavor. This paper delves into the proposition and comprehensive examination of the various in-situ resources available for the construction of infrastructure on the Red Planet. The research yields key findings: Martian soil, basalt, and

Martian concrete emerge as promising construction materials, but they must be engineered to withstand Mars' extreme environmental conditions, including low atmospheric pressure, harsh temperatures, temperature fluctuations, and relentless space radiation. The realization of intelligent architecture on Mars is deemed indispensable, given the uncertainties about the Martian environment's impact on human habitation. The proposition to employ 3D printing technology to create construction materials using indigenous resources presents a viable solution. To execute this intelligent construction process, a combination of robots equipped with swarm robotics capabilities and automated management systems is essential, with real-time control from Earth being imperative. Developing materials that align with the criteria of resilience, durability, and cost-efficiency depends on our capacity to identify suitable in-situ resources for construction and achieve a profound understanding of the Martian environmental conditions, laying the foundation for future exploration and, potentially, human colonization on Mars.

19. References

- [1]. Mahaney, W., Milner, M., Netoff, D., Malloch, D., Dohm, J., Baker, V., Miyamoto, H., Hare, T., & Komatsu, G. (2004). Ancient wet aeolian environments on Earth: Clues to presence of fossil/live microorganisms on Mars. *Icarus*, 171, 39-53. <https://doi.org/10.1016/j.ICARUS.2004.04.014>.
- [2]. Basilevsky, A., Neukum, G., Ivanov, B., Werner, S., Gesselt, S., Head, J., Denk, T., Jaumann, R., Hoffmann, H., Hauber, E., McCord, T., & Team, T. (2005). Morphology and geological structure of the western part of the Olympus Mons volcano on Mars from the analysis of the Mars Express HRSC imagery. *Solar System Research*, 39, 85-101. <https://doi.org/10.1007/S11208-005-0025-2>.
- [3]. Alderton, David Elias, Scott A., Lucas, Spencer G., Kusky, Timothy M., Wang, Lu. "Encyclopedia of Geology." Cnii Research, 2021, cir.nii.ac.jp/crid/1130013077300418446.
- [4]. Fedorova, A., Montmessin, F., Korablev, O., Luginin, M., Trokhimovskiy, A., Belyaev, D., Ignatiev, N., Lefèvre, F., Alday, J., Irwin, P., Olsen, K., Bertaux, J., Millour, E., Määtänen, A., Shakun, A., Grigoriev, A., Patrakeev, A., Korsa, S., Kokonkov, N., Baggio, L., Forget, F., & Wilson, C. (2020). Stormy water on Mars: The distribution and saturation of atmospheric water during the dusty season. *Science*, 367, 297 - 300. <https://doi.org/10.1126/science.aay9522>.
- [5]. Ouyang, Z. Y., & Xiao, F. G. (2011). Major scientific issues involved in Mars exploration. *Spacecraft Environment Engineering*, 28(3), 205-217.
- [6]. Chaffin, M., Chaufray, J., Deighan, J., Schneider, N., McClintock, W., Stewart, A., Thiemann, E., Clarke, J., Holsclaw, G., Jain, S., Crismani, M., Stiepen, A., Montmessin, F., Eparvier, F., Chamberlain, P., & Jakosky, B. (2015). Three-dimensional structure in the Mars H corona revealed by IUVS on MAVEN. *Geophysical Research Letters*, 42, 9001 - 9008. <https://doi.org/10.1002/2015GL065287>.
- [7]. National Geographic, 2009. Mars Exploration, Mars Rovers Information, Facts, News, Photos.

- [8]. Banin, A. (1998). The scientific impact of the Viking mission: Survey of the publication record. *Advances in Space Research*, 22, 445-447. [https://doi.org/10.1016/S0273-1177\(98\)00084-2](https://doi.org/10.1016/S0273-1177(98)00084-2).
- [9]. Fairén, A., Parro, V., Schulze-Makuch, D., & Whyte, L. (2017). Searching for Life on Mars Before It Is Too Late. *Astrobiology*, 17, 962 - 970. <https://doi.org/10.1089/ast.2017.1703>.
- [10]. Moore, C. (2010). Technology development for human exploration of Mars. *Acta Astronautica*, 67, 1170-1175. <https://doi.org/10.1016/j.actaastro.2010.06.031>.
- [11]. Kosambe, S. (2019). NASA's Exploration Missions to the Red Planet. *Journal of Aircraft and Spacecraft Technology*. <https://doi.org/10.3844/JASTSP.2019.154.171>.
- [12]. Diniega, S., Bramson, A., Buratti, B., Buhler, P., Burr, D., Chojnacki, M., Conway, S., Dundas, C., Hansen, C., McEwen, A., Lapôtre, M., Levy, J., Keown, L., Piqueux, S., Portyankina, G., Swann, C., Titus, T., & Widmer, J. (2021). Modern Mars' geomorphological activity, driven by wind, frost, and gravity. *Geomorphology*, 380, 107627. <https://doi.org/10.1016/j.geomorph.2021.107627>.
- [13]. Michalski, J., Onstott, T., Mojzsis, S., Mustard, J., Chan, Q., Niles, P., & Johnson, S. (2017). The Martian subsurface as a potential window into the origin of life. *Nature Geoscience*, 11, 21-26. <https://doi.org/10.1038/s41561-017-0015-2>.
- [14]. Moore, C. (2010). Technology development for human exploration of Mars. *Acta Astronautica*, 67, 1170-1175. <https://doi.org/10.1016/j.actaastro.2010.06.031>.
- [15]. Haqq-Misra, J. (2015). Toward a Sustainable Land Use Policy for Mars. , 43-49. https://doi.org/10.1007/978-3-319-18063-2_4.
- [16]. Leovy, C., 2001. Weather and climate on Mars. *Nature* 6843 (412), 245–249
- [17]. Williams, D.R., 2004. Mars Fact Sheet
- [18]. Cassata, W. (2017). Meteorite constraints on Martian atmospheric loss and paleoclimate. *Earth and Planetary Science Letters*, 479, 322-329. <https://doi.org/10.1016/j.epsl.2017.09.034>.
- [19]. Head, J., Marchant, D., & Ghatan, G. (2004). Glacial deposits on the rim of a Hesperian-Amazonian outflow channel source trough: Mangala Valles, Mars. *Geophysical Research Letters*, 31. <https://doi.org/10.1029/2004GL020294>.
- [20]. Wan, L., Wendner, R., & Cusatis, G. (2015). A novel material for in situ construction on Mars: experiments and numerical simulations. *Construction and Building Materials*, 120, 222-231. <https://doi.org/10.1016/j.conbuildmat.2016.05.046>.
- [21]. Karlsson, N., Holt, J., & Hindmarsh, R. (2011). Testing for flow in the north polar layered deposits of Mars using radar stratigraphy and a simple 3D ice-flow model. *Geophysical Research Letters*, 38. <https://doi.org/10.1029/2011GL049630>.
- [22]. Chapman, M. (2003). Sub-ice volcanoes and ancient oceans/lakes: A Martian challenge. *Global and Planetary Change*, 35, 185-198. [https://doi.org/10.1016/S0921-8181\(02\)00126-1](https://doi.org/10.1016/S0921-8181(02)00126-1).
- [23]. Sager, W., Zhang, J., Korenaga, J., Sano, T., Koppers, A., Widdowson, M., & Mahoney, J. (2013). An immense shield volcano within the Shatsky Rise oceanic plateau, northwest Pacific Ocean. *Nature Geoscience*, 6, 976-981. <https://doi.org/10.1038/NGEO1934>.
- [24]. Baumgartner, R., Baratoux, D., Fiorentini, M., & Gaillard, F. (2017). Numerical modeling of erosion and assimilation of sulfur-rich substrate by martian lava flows: implications for the genesis of massive sulfide mineralization on Mars. *Icarus*, 296, 257-274. <https://doi.org/10.1016/j.icarus.2017.06.016>.
- [25]. Williams, R., Grotzinger, J., Dietrich, W., Gupta, S., Sumner, D., Wiens, R., Mangold, N., Malin, M., Edgett, K., Maurice, S., Forni, O., Gasnault, O., Ollila, A., Newsom, H., Dromart, G., Palucis, M., Yingst, R., Anderson, R., Herkenhoff, K., Mouélic, S., Goetz, W., Madsen, M., Koefoed, A., Jensen, J., Bridges, J., Schwenzer, S., Lewis, K., Stack, K., Rubin, D., Kah, L., Bell, J., Farmer, J., Sullivan, R., Beek, T., Blaney, D., Pariser, O., & Deen, R. (2013). Martian Fluvial Conglomerates at Gale Crater. *Science*, 340, 1068 - 1072. <https://doi.org/10.1126/science.1237317>.
- [26]. Mancinelli, R., & Banin, A. (2003). Where is the nitrogen on Mars. *International Journal of Astrobiology*, 2, 217 - 225. <https://doi.org/10.1017/S1473550403001599>.
- [27]. Lane, M., Dyar, M., & Bishop, J. (2004). Spectroscopic evidence for hydrous iron sulfate in the Martian soil. *Geophysical Research Letters*, 31. <https://doi.org/10.1029/2004GL021231>.
- [28]. Heavens, N., Kleinböhl, A., Chaffin, M., Halekas, J., Kass, D., Hayne, P., McCleese, D., Piqueux, S., Shirley, J., & Schofield, J. (2018). Hydrogen escape from Mars enhanced by deep convection in dust storms. *Nature Astronomy*, 2, 126-132. <https://doi.org/10.1038/S41550-017-0353-4>.

- [29]. Achal, V., Mukherjee, A., & Reddy, M. (2011). Microbial Concrete: Way to Enhance the Durability of Building Structures. *Journal of Materials in Civil Engineering*, 23, 730-734. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0000159](https://doi.org/10.1061/(ASCE)MT.1943-5533.0000159).
- [30]. Goldspiel, J., & Squyres, S. (2000). Groundwater Sapping and Valley Formation on Mars. *Icarus*, 148, 176-192. <https://doi.org/10.1006/ICAR.2000.6465>.
- [31]. Mohammed, S., & Poornima, V. (2018). Strength and durability study of sulphur concrete with replaced fine aggregate. *Materials Today: Proceedings*, 5, 23888-23897. <https://doi.org/10.1016/j.MATPR.2018.10.181>.
- [32]. Amador, E., Bandfield, J., Brazelton, W., & Kelley, D. (2017). The Lost City Hydrothermal Field: A Spectroscopic and Astrobiological Analogue for Nili Fossae, Mars.. *Astrobiology*, 17 11, 1138-1160. <https://doi.org/10.1089/ast.2016.1606>.
- [33]. Delgado-Bonal, A., Martín-Torres, F., Vázquez-Martín, S., & Zorzano, M. (2016). Solar and wind exergy potentials for Mars. *Energy*, 102, 550-558. <https://doi.org/10.1016/j.ENERGY.2016.02.110>.
- [34]. Pedraza, J. (2017). The Future of Small Modular Reactors. , 257-267. https://doi.org/10.1007/978-3-319-52216-6_7.
- [35]. Delgado-Bonal, A., Martín-Torres, F., Vázquez-Martín, S., & Zorzano, M. (2016). Solar and wind exergy potentials for Mars. *Energy*, 102, 550-558. <https://doi.org/10.1016/j.ENERGY.2016.02.110>.
- [36]. Kulasekara, H., & Seynulabdeen, V. (2019). A Review of Geothermal Energy for Future Power Generation. 2019 5th International Conference on Advances in Electrical Engineering (ICAEE), 223-228. <https://doi.org/10.1109/ICAEE48663.2019.8975470>.
- [37]. Acitei, D., Sandhu, A., Abdullah, M., Vizureanu, P., & Abdullah, A. (2013). On the Structure of Shape Memory Alloys. *Key Engineering Materials*, 594-595, 140 - 145. <https://doi.org/10.4028/www.scientific.net/KEM.594-595.140>.
- [38]. Qiu, Z., Yao, X., Yuan, J., & Soutis, C. (2006). Experimental research on strain monitoring in composite plates using embedded SMA wires. *Smart Materials and Structures*, 15, 1047 - 1053. <https://doi.org/10.1088/0964-1726/15/4/018>.
- [39]. Madara, S., Raj, N., & Selvan, C. (2018). Review of research and developments in self healing composite materials. *IOP Conference Series: Materials Science and Engineering*, 346. <https://doi.org/10.1088/1757-899X/346/1/012011>.
- [40]. Gou, X., Xiao, H., & Yang, S. (2010). Modeling, experimental study and optimization on low-temperature waste heat thermoelectric generator system. *Applied Energy*, 87, 3131-3136. <https://doi.org/10.1016/j.APENERGY.2010.02.013>.
- [41]. Ge, M., Li, Z., Wang, Y., Zhao, Y., Zhu, Y., Wang, S., & Liu, L. (2021). Experimental study on thermoelectric power generation based on cryogenic liquid cold energy. *Energy*, 220, 119746. <https://doi.org/10.1016/j.ENERGY.2020.119746>.
- [42]. Leng, J., Lu, H., Liu, Y., Huang, W., & Du, S. (2009). Shape-Memory Polymers—A Class of Novel Smart Materials. *Mrs Bulletin*, 34, 848-855. <https://doi.org/10.1557/MRS2009.235>.
- [43]. Songsukthawan, P., & Jettanasen, C. (2017). Generation and storage of electrical energy from piezoelectric materials. 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia), 2256-2259. <https://doi.org/10.1109/IFEEC.2017.7992403>.
- [44]. Remmele, J., Shen, D., Mustonen, T., & Fruehauf, N. (2015). High Performance and Long-Term Stability in Ambiently Fabricated Segmented Solid-State Polymer Electrochromic Displays. *ACS applied materials & interfaces*, 7 22, 12001-8. <https://doi.org/10.1021/acsami.5b02090>.
- [45]. Kereszturi, Á., & Appéré, T. (2014). Searching for springtime zonal liquid interfacial water on Mars. *Icarus*, 238, 66-76. <https://doi.org/10.1016/j.ICARUS.2014.05.001>.
- [46]. Davies, D. (1981). The Mars water cycle. *Icarus*, 45, 398-414. [https://doi.org/10.1016/0019-1035\(81\)90043-9](https://doi.org/10.1016/0019-1035(81)90043-9).
- [47]. Pronk, A., Mistur, M., Li, Q., Liu, X., Blok, R., Liu, R., Wu, Y., Luo, P., & Dong, Y. (2019). The 2017–18 design and construction of ice composite structures in Harbin. *Structures*. <https://doi.org/10.1016/j.ISTRUC.2019.01.020>.

- [48]. Real, D., Dumanyan, I., & Hotz, N. (2016). Renewable hydrogen production by solar-powered methanol reforming. *International Journal of Hydrogen Energy*, 41, 11914-11924. <https://doi.org/10.1016/j.ijhydene.2016.02.086>.
- [49]. Moore, C. (2010). Technology development for human exploration of Mars. *Acta Astronautica*, 67, 1170-1175. <https://doi.org/10.1016/j.actaastro.2010.06.031>.
- [50]. Bouley, S., Baratoux, D., Matsuyama, I., Forget, F., Séjourné, A., Turbet, M., & Costard, F. (2016). Late Tharsis formation and implications for early Mars. *Nature*, 531, 344-347. <https://doi.org/10.1038/nature17171>.
- [51]. Flahaut, J., Quantin, C., Clenet, H., Allemand, P., Mustard, J., & Thomas, P. (2012). Pristine Noachian crust and key geologic transitions in the lower walls of Valles Marineris: Insights into early igneous processes on Mars. *Icarus*, 221, 420-435. <https://doi.org/10.1016/j.icarus.2011.12.027>.
- [52]. Hibbard, S., Williams, N., Golombek, M., Osinski, G., & Godin, E. (2021). Evidence for widespread glaciation in Arcadia Planitia, Mars. *Icarus*, 359, 114298. <https://doi.org/10.1016/j.icarus.2020.114298>.
- [53]. Soare, R., Conway, S., Pearce, G., Costard, F., & Séjourné, A. (2013). Sub-kilometre (intra-crater) mounds in Utopia Planitia, Mars: character, occurrence and possible formation hypotheses. *Icarus*, 225, 982-991. <https://doi.org/10.1016/j.icarus.2012.06.003>.
- [54]. Dehant, V., Hoolst, T., & Defraigne, P. (2000). Comparison Between the Nutations of the Planet Mars and the Nutations of the Earth. *Surveys in Geophysics*, 21, 89-110. <https://doi.org/10.1023/A:1006716529241>.
- [55]. Scott, A., Oze, C., Tang, Y., & O'Loughlin, A. (2017). Development of a Martian regolith simulant for in-situ resource utilization testing. *Acta Astronautica*, 131, 45-49. <https://doi.org/10.1016/j.actaastro.2016.11.024>.
- [56]. Dadi, G., Goodrum, P., Taylor, T., & Maloney, W. (2014). Effectiveness of communication of spatial engineering information through 3D CAD and 3D printed models. *Visualization in Engineering*, 2, 1-12. <https://doi.org/10.1186/S40327-014-0009-8>.
- [57]. Chandra, A., Thangavelautham, J., & Babuscia, A. (2018). Modular inflatable space structures. 2018 IEEE Aerospace Conference, 1-9. <https://doi.org/10.1109/AERO.2018.8396754>.
- [58]. Sheshpari, M., Fujii, Y., & Tani, T. (2017). Underground structures in Mars excavated by tunneling methods for sheltering humans. *Tunnelling and Underground Space Technology*, 64, 61-73. <https://doi.org/10.1016/j.tust.2016.12.015>.
- [59]. Sheshpari, M., Fujii, Y., & Tani, T. (2017). Underground structures in Mars excavated by tunneling methods for sheltering humans. *Tunnelling and Underground Space Technology*, 64, 61-73. <https://doi.org/10.1016/j.tust.2016.12.015>.
- [60]. Moore, C. (2010). Technology development for human exploration of Mars. *Acta Astronautica*, 67, 1170-1175. <https://doi.org/10.1016/j.actaastro.2010.06.031>.
- [61]. Kennedy, R., Buys, L., & Miller, E. (2015). Residents' experiences of privacy and comfort in multi-storey apartment dwellings in subtropical Brisbane. <https://doi.org/10.3390/SU7067741>.
- [62]. Mateo-Martí, E., Prieto-Ballesteros, O., Sobrado, J., Gómez-Elvira, J., & Martín-Gago, J. (2006). A chamber for studying planetary environments and its applications to astrobiology. *Measurement Science and Technology*, 17, 2274 - 2280. <https://doi.org/10.1088/0957-0233/17/8/031>.
- [63]. Lichstein, J., Ghandour, R., & Mann, M. (2018). Access to the Medical Home Among Children With and Without Special Health Care Needs. *Pediatrics*, 142. <https://doi.org/10.1542/peds.2018-1795>.
- [64]. Haeuplik-Meusburger, S., Paterson, C., Schubert, D., & Zabel, P. (2014). Greenhouses and their humanizing synergies. *Acta Astronautica*, 96, 138-150. <https://doi.org/10.1016/j.actaastro.2013.11.031>.
- [65]. Jokstad, A., & Fan, P. (2006). Amalgam waste management. *International dental journal*, 56 3, 147-53. <https://doi.org/10.1111/j.1875-595X.2006.TB00087.X>.
- [66]. Li, M., Vliet, J., Ke, X., & Verburg, P. (2019). Mapping settlement systems in China and their change trajectories between 1990 and 2010. *Habitat International*, 94, 102069. <https://doi.org/10.1016/j.habitatint.2019.102069>.

- [67]. Ehresmann, B., Hassler, D., Zeitlin, C., Guo, J., Wimmer-Schweingruber, R., Khaksari, S., & Loeffler, S. (2021). Natural Radiation Shielding on Mars Measured With the MSL/RAD Instrument. *Journal of Geophysical Research: Planets*, 126. <https://doi.org/10.1029/2021JE006851>.
- [68]. Gołofit-Szymczak, M., & Górny, R. (2018). Microbiological air quality in office buildings equipped with dventilation systems. *Indoor Air*, 28, 792–805. <https://doi.org/10.1111/ina.12495>.
- [69]. Ghenai, C., & Bettayeb, M. (2020). Design and optimization of grid-tied and off-grid solar PV systems for super-efficient electrical appliances. *Energy Efficiency*, 13, 291-305. <https://doi.org/10.1007/S12053-019-09773-3>.
- [70]. Sadori, L., Susanna, F., & Persiani, C. (2006). Archaeobotanical data and crop storage evidence from an early Bronze Age 2 burnt house at Arslantepe, Malatya, Turkey. *Vegetation History and Archaeobotany*, 15, 205-215. <https://doi.org/10.1007/S00334-005-0029-3>.
- [71]. Hill, K., & Gagneja, K. (2018). Concept network design for a young Mars science station and Trans-planetary communication. 2018 Fourth International Conference on Mobile and Secure Services (MobiSecServ), 1-8. <https://doi.org/10.1109/MOBISECSERV.2018.8311448>.
- [72]. Lai, D., Zhou, C., Huang, J., Jiang, Y., Long, Z., & Chen, Q. (2014). Outdoor space quality: A field study in an urban residential community in central China. *Energy and Buildings*, 68, 713-720. <https://doi.org/10.1016/j.enbuild.2013.02.051>.
- [73]. Jiang, B., & Mamishev, A. (2004). Robotic monitoring of power systems. *IEEE Transactions on Power Delivery*, 19, 912-918. <https://doi.org/10.1109/TPWRD.2004.829918>.
- [74]. Zubrin, R. (1994). The design of lunar and Mars transportation systems utilizing extra-terrestrial resources. *Acta Astronautica*, 32, 617-628. [https://doi.org/10.1016/0094-5765\(94\)90072-8](https://doi.org/10.1016/0094-5765(94)90072-8).
- [75]. Oze, C., Beisel, J., Dabsys, E., Dall, J., North, G., Scott, A., López, A., Holmes, R., & Fendorf, S. (2021). Perchlorate and Agriculture on Mars. *Soil Systems*. <https://doi.org/10.3390/soilsystems5030037>.
- [76]. Tahmasebinia, F., Niemelä, M., Sepasgozar, S., Lai, T., Su, W., Reddy, K., Shirowzhan, S., Sepasgozar, S., & Marroquin, F. (2018). Three-Dimensional Printing Using Recycled High-Density Polyethylene: Technological Challenges and Future Directions for Construction. *Buildings*. <https://doi.org/10.3390/BUILDINGS8110165>.
- [77]. Scheerbaum, G. (2000). In-Situ Manufacture of Martian Construction Materials. *Space*, 934-940. [https://doi.org/10.1061/40479\(204\)111](https://doi.org/10.1061/40479(204)111).
- [78]. Reches, Y. (2019). Concrete on Mars: Options, challenges, and solutions for binder-based construction on the Red Planet. *Cement and Concrete Composites*. <https://doi.org/10.1016/j.cemconcomp.2019.103349>.
- [79]. Carrión, F., Doyle, J., & Lozano, A. (2003). Structural health monitoring and damage detection using a sub-domain inverse method. *Smart Materials and Structures*, 12, 776-784. <https://doi.org/10.1088/0964-1726/12/5/015>.
- [80]. Farrell, W., Delory, G., & Atreya, S. (2006). Martian dust storms as a possible sink of atmospheric methane. *Geophysical Research Letters*, 33. <https://doi.org/10.1029/2006GL027210>.
- [81]. Goldspiel, J., & Squyres, S. (2000). Groundwater Sapping and Valley Formation on Mars. *Icarus*, 148, 176-192. <https://doi.org/10.1006/ICAR.2000.6465>.
- [82]. Kelly, A., & Kanas, N. (1993). Communication between space crews and ground personnel: a survey of astronauts and cosmonauts.. *Aviation, space, and environmental medicine*, 64 9 Pt 1, 795-800
- [83]. Wang, L., Zhang, P., Ma, L., Cong, X., & Skibniewski, M. (2020). DEVELOPING A CORPORATE SOCIAL RESPONSIBILITY FRAMEWORK FOR SUSTAINABLE CONSTRUCTION USING PARTIAL LEAST SQUARES STRUCTURAL EQUATION MODELING. *Technological and Economic Development of Economy*, 26, 186-212. <https://doi.org/10.3846/tede.2020.11263>.
- [84]. Scheerbaum, G. (2000). In-Situ Manufacture of Martian Construction Materials. *Space*, 934-940. [https://doi.org/10.1061/40479\(204\)111](https://doi.org/10.1061/40479(204)111).
- [85]. <https://www.space.com/29414-mars-colony-science-fiction-authors.html>
- [86]. <https://courses.lumenlearning.com/suny-astronomy/chapter/the-geology-of-mars/>
- [87]. <https://www.science.org.au/curious/space-time/mars>
- [88]. <https://sites.northwestern.edu/nasachallenge/martian-concrete/>

- [89]. <https://www.waaree.com/blog/role-of-solar-energy-for-colonising-the-planet-mars>
- [90]. <https://www.universetoday.com/153467/nasa-is-building-a-nuclear-reactor-to-power-lunar-and-martian-exploration/>
- [91]. <https://www.archdaily.com/993439/how-is-architecture-supporting-exploration-of-the-moon-and-mars>
- [92]. <https://www.loveproperty.com/gallerylist/76210/revealed-what-homes-on-mars-could-actually-look-like>
- [93]. https://www.google.com/search?q=labratory+place+on+mars&tbm=isch&ved=2ahUKEwimtdSj4cSCAxWXTqQEHV0nAxUQ2-cCegQIABAA&oq=labratory+place+on+mars&gs_lcp=CgNpbWcQAzoECCMQJ1CUDFi6FmDzHGgAcAB4AIABaIgB5gOSAQM2LjGYAQCGAQGqAQOnd3Mtd2l6LWltZ8ABAQ&sclient=img&ei=UBJU ZabNH5edkdUP3c6MqAE&bih=1012&biw=1077#imgsrc=9BOQ4fqFjl4RKM
- [94]. <https://medicalfuturist.com/simply-wont-go-mars-without-digital-health/>

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Figure I.13: Article Certificate



EXPLORING MARS DATA: A PATH TO HUMAN HABITATION

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ABSTRACT

The colonization of Mars is a subject of rising interest among space ensoiasts and scientists. Creating suitable dwellings for settlers is one of the most important challenges as humanity ponder a permanent presence on Mars. Mars has unique construction obstacles, such as a lack of atmosphere and significant temperature changes. Yet, recent technical advances have led to the development of novel ideas for Martian structures that might possibly shelter people for lengthy periods of time. This Article will examine some of the existing concepts for Martian architecture, as well as the difficulties connected with constructing on Mars, such as limited resources and extreme climatic conditions. The concepts described in this Article offer a glimpse of what may be feasible for future space exploration and colonization, despite the fact that there is still much work to be done in building usable and sustainable living environments on Mars.

Keywords: Mars, Smart Building, Materials, Habitation, Management

Highlights: Exploring Mars Data: A Path to Human Habitation" illuminates the critical role of data in paving the way for human settlement on the Red Planet. Through rigorous analysis of Mars-related information, this exploration promises to unlock crucial insights, addressing challenges and shaping the blueprint for future habitation efforts. This endeavour underscores the transformative power of data-driven exploration in our quest to extend human presence beyond Earth.

1. Introduction

The process of planning, constructing, and maintaining buildings that are safe and livable for humans on Mars is called building management. Given the rising interest in space travel and colonization, it is necessary to create human-supporting, self-sufficient homes on Mars (1). Building management on Mars requires a complete grasp of the planet's severe climate and unique problems. Mars has a thin atmosphere, significant temperature variations, exposure to radiation, and a dearth of oxygen and water that is breathable. These elements provide formidable obstacles to the construction and maintenance of human home (2). Building management on Mars must focus on resource conservation and sustainable techniques in order to overcome these obstacles. This includes developing buildings that can resist the severe climate and maximizing the use of existing resources, such as renewable energy sources like solar power and Mars' regolith as construction materials. Moreover, building management on Mars must emphasize the people' health and safety. Implementing systems for air and water filtration, waste management, and emergency

response procedures is required (3). the management of buildings on Mars requires a multidisciplinary approach that integrates knowledge from domains like design, engineering, biology, and sustainability. It is conceivable to create viable homes on Mars that can support human existence and open the path for future exploration and colonization of the Red Planet with careful planning and inventive ideas (4). an imaginary view of life on Mars in figure number 1.



Figure 1: A view of life on Mars (54)

2. Methodology

As its primary research methodology, the research article in question depends heavily on library resources and a thorough examination of earlier research. This method comprises a thorough assessment of existing literature and scholarly works in order to build a solid foundation for the research, providing a rich and well-informed viewpoint on the issue.

3. The definition of intelligence in construction

Intelligence in building may refer to the use of modern technology and data analytics to enhance the functionality, efficiency, and sustainability of buildings. It entails integrating many building systems, such as lighting, heating, ventilation, and air conditioning (HVAC), security, and energy management, into a single intelligent system that can monitor and control the building's activities (5). Building intelligence may also refer to a structure's capacity to adapt to the demands and preferences of its residents. Using sensors and other technology to collect data on aspects like as temperature, lighting, and air quality, which may be utilized to change building systems in real time (6). Intelligence in buildings strives to provide inhabitants with a more pleasant, energy-efficient, and sustainable environment, while also decreasing operating costs and enhancing the building's overall performance (7). In Figure 2, the construction by the device.



: Smart construction on Mars (55)2Figure

4. Importance of intelligent building on Mars

The need for intelligent structures on Mars stems from the desire to develop efficient and sustainable human homes on the planet. Being a harsh and unfriendly environment, Mars offers a number of obstacles to human existence, including as excessive temperatures, lack of atmosphere, high radiation levels, and limited supplies (8). Smart buildings outfitted with cutting-edge technologies such as sensors, automation systems, artificial intelligence, and renewable energy sources can help mitigate some of these challenges by optimizing resource utilization, reducing energy consumption, and enhancing the overall living conditions of the occupants (9). Smart buildings may, for instance, monitor and manage temperature, air quality, and lighting levels, ensuring that the inside environment stays conducive to human habitation. They can also gather and store energy from renewable sources such as solar, wind, and geothermal, therefore decreasing dependency on fossil fuels and carbon emissions. In addition, smart buildings may promote communication, cooperation, and remote operations, allowing scientists and astronauts to conduct study and operate on the planet more effectively and safely (10). In figure 3 an imaginary city on Mars.

- Restricted resources: Mars is a hostile environment with little water, air, and energy supplies. By monitoring and managing the consumption of these resources, smart buildings might assist maximize their utilization (11).
- Severe climate: Temperatures on Mars range from -80°C to 20°C , making its environment exceedingly harsh. Intelligent structures might assist manage the temperature and provide a livable environment for human colonists (12).
- Safety: By monitoring for possible threats, like as radiation exposure or atmospheric changes, intelligent structures might assist to assure the safety of human settlers. (13).
- Efficiency: Smart buildings may boost efficiency in a variety of ways, including the automation of processes, optimization of resource use, and reduction of waste (14).



Figure 3: imaginary city on Mars (56)

5. Smart building on Mars

A smart building on Mars is a highly sophisticated and technologically integrated structure that utilizes numerous cutting-edge technologies to maximize resource usage, decrease energy consumption, and offer a safe and pleasant living environment for human inhabitants. Probably, intelligent structures on Mars will contain sophisticated sensors, automation systems, artificial intelligence, renewable energy sources, and high-speed communication networks (15). These characteristics will enable the building to monitor and manage environmental elements like as temperature, air quality, lighting, and water consumption, ensuring that the inside environment stays livable and healthy. Solar, wind, and geothermal energy will be used to fuel the operations of intelligent structures on Mars (16). This will aid in reducing dependency on fossil fuels, which are finite and may have significant environmental effects. In addition, intelligent buildings on Mars will likely have emergency response systems, predictive maintenance, and problem detection to ensure the safety and security of the facility and its residents in the event of unanticipated catastrophes (17). In Figure 4, an imaginary city

on Mars and human spaceships for transport to Mars.



Figure 4: imaginary city on Mars and human spaceships (57)

6. suitable location for constructing on Mars

The ideal location for constructing on Mars would be within the region of Elysium Planitia, a vast, flat plain near the planet's equator. This area offers several advantages for human settlement and construction. First, its relatively low elevation reduces radiation exposure and provides a more stable environment for structures. Second, the flat terrain simplifies construction and minimizes the challenges of uneven ground. Third, the equatorial position ensures a more moderate climate compared to other regions, allowing for easier temperature

control. Additionally, Elysium Planitia is of scientific interest, containing evidence of ancient volcanic activity. Utilizing this region for construction would optimize safety, accessibility, and scientific exploration, laying the foundation for sustainable human presence on Mars (18). In Figure 5, a Mars city Nüwa.

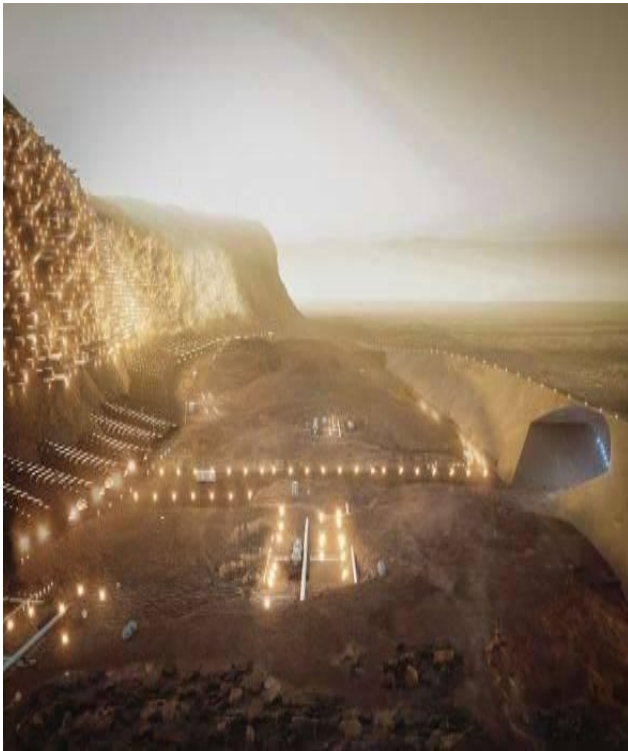


Figure 5: Mars city Nüwa would be built into a cliff (58)

7. Developing objectives on Mars

The primary objectives of human presence and development on Mars include establishing a sustainable habitat, advancing scientific exploration, and enabling future colonization. Firstly, creating a self-sustaining habitat involves developing life support systems, resource utilization, and efficient waste recycling to ensure long-term survival. Scientific exploration aims to unlock the mysteries of Mars, studying its geology, atmosphere, and potential for past or present life (20). Furthermore, the development of technologies for in-situ resource utilization is crucial to reduce reliance on Earth for supplies. Establishing Mars as a stepping stone for human colonization is another key objective, involving the construction of infrastructure, such as habitats and transportation systems, to support a growing population. Overall, these objectives align with humanity's pursuit of knowledge, sustainability, and the expansion of our presence beyond Earth (19). In figure 5 a mission to Mars with the astronaut and the settlement.



Figure 6: Mission to Mars (59)

8. intelligent system in the Martian structures

Intelligent systems in Martian structures play pivotal roles in ensuring safety, efficiency, and sustainability. Their duties encompass a range of functions, including environmental control and life support systems management. These systems regulate air composition, temperature, and pressure to create a habitable environment for humans. Power and energy management is crucial, optimizing the use of available resources such as solar or nuclear energy to sustain operations. Intelligent systems are also responsible for monitoring and maintaining structural integrity, identifying and addressing potential issues, and mitigating risks like dust storms or seismic activity. Communication systems, both internal and external, are managed to facilitate cracksless interaction between Martian structures and with Earth. Additionally, these systems play a role in resource utilization, overseeing the extraction and processing of materials for construction and supporting overall sustainability. Below are some simple examples (21).

- Temperatures: on Mars range from -125°C to 20°C, and the planet's environment is notoriously harsh and severe. As an intelligent system, you would be responsible for adjusting the indoor temperature and humidity to

maintain the comfort of the residents.
(21). In figure 7 the temperature of Mars.

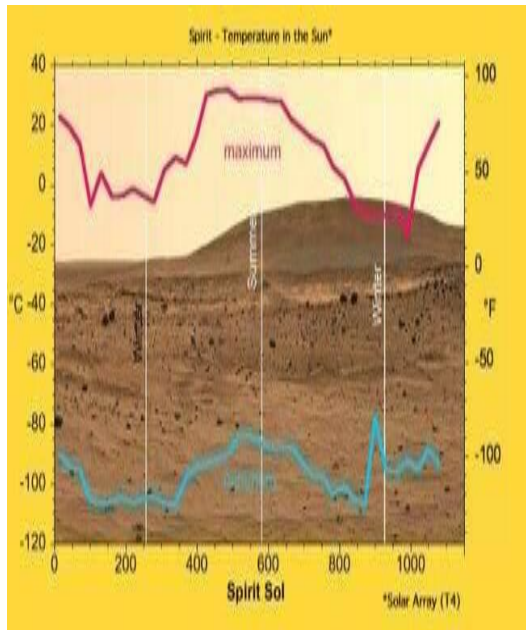


Figure 7: Temperatures: on Mars (60)

- **Energy management:** On Mars, energy is a valuable resource, and as an intelligent system, you would be responsible for managing the house's energy use. This would require managing the power supply and monitoring the consumption of appliances and lights to ensure that energy is being utilized effectively. (22) In Figure 8, the management and collection of energy on Mars.



Figure 8: collection of energy on Mars (61)

- **Security:** Mars would be a high-risk environment, and as an intelligent system, you would be responsible for guaranteeing the safety and security of the dwelling and its inhabitants. This would include monitoring the outside and inside of the residence for possible threats and intrusions. (23) In Figure 9, security on Mars, which can be any way.



Figure 9: POLICE SOLVE MURDERS ON MARS (62)

- **Maintenance:** Since Mars is a harsh environment, upkeep is essential for the survival of the home and its inhabitants. As an intelligent system, you would be responsible for spotting possible maintenance problems before they became significant. (23). In figure 9, the environment of Mars.



Figure 10: Maintenance ON MARS (63)

- **Communication:** Contact with Earth would be essential for the house's and its inhabitants' survival. You would be responsible for managing the house's

communication systems and ensuring that messages are delivered and received reliably as an intelligent system. (24) In figure 11, communications at Mars.



Figure 11: communications at Mars (64)

- Health monitoring: Since Mars would be a hard environment for the human body, you, as an intelligent system, would be responsible for monitoring the residents' health and alerting them to possible health problems. (25) In Figure 12, the health check of astronauts in space.



Figure 12: health check of astronauts in space (65)

9. Benefits of intelligent system in Martian buildings

There are several benefits to implementing intelligent systems in Martian structures, including:

- Energy efficiency: Intelligent systems can monitor and regulate the building's energy use, ensuring that energy is utilized effectively. This is especially crucial on Mars, where energy sources may be scarce (26).
- Automation: Intelligent technologies may automate a variety of operations inside a structure, including altering lighting and temperature, opening and shutting doors, and regulating air quality. This may lessen the residents' burden and enhance their quality of life. (27)
- Remote monitoring and control: Intelligent systems may be remotely monitored and controlled, enabling the building's inhabitants to govern the structure from a distance. This is especially advantageous for structures on Mars, where travel may be difficult and time-consuming. (28)
- Safety: Intelligent systems can identify and react to safety threats including fires, leaks, and air quality problems. This may aid in protecting both the inhabitants and the structure itself. (29)
- Adaptability: Intelligent systems can adapt the building's systems to the demands of the residents by learning from their behavior. This might increase the building's overall comfort and efficiency. (30)
- Maintenance: Intelligent systems can monitor the state of a building's systems and notify the inhabitants of any problems requiring repair. This may aid in preventing equipment failure and lowering maintenance expenses. (31)

10. disadvantages of intelligent system in Martian buildings

Although intelligent systems in Martian structures provide several benefits, there are also some drawbacks to consider:

- High initial costs: Installation and maintenance of intelligent systems may be costly, which may be problematic in a distant and hostile environment such as Mars. (32)
- Technical complexity: Intelligent systems depend on modern technology, and the complexity of these systems may make them challenging to manage and maintain. This may

provide a difficulty for explorers on Mars who lack substantial technical skills. (33)

- Reliability issues: Intelligent systems are susceptible to faults and failures, which might be a significant concern in a Martian structure. Failure of the system might result in the loss of vital functions or possibly risk the inhabitants' lives. (34)
- Limited flexibility: Intelligent systems are intended to function within defined boundaries and may not be able to adapt to unforeseen circumstances. This might provide a difficulty in the event of an emergency or if Mars's environment changes in an unanticipated manner. (35)
- Cybersecurity risks: Intelligent systems are susceptible to hacking and hacks, which might threaten the Martian building's and its residents' safety and security. This danger would need the implementation of effective cybersecurity safeguards. (36)

11. The techniques used in the construction of Mars

Human settlement on Mars will need the deployment of modern systems and technology to assure safety, comfort, and long-term viability. These are some examples of systems that may be used in the construction of Mars:

- In-situ resource utilization (ISRU) systems: These systems use the resources available on Mars (such as soil and ice) to manufacture construction materials, fuel, and other essential resources for human habitation. For instance, NASA's Mars Ice House idea suggests constructing a radiation-resistant dwelling utilizing ice from Mars' polar regions. (37)
- 3D printing: 3D printing has been suggested as a method for constructing buildings on Mars using local resources. NASA's 2019 Mars Habitat competition includes a 3D printing category, in which teams printed functioning homes using a variety of materials. (38) In figure 13, the construction of the residence in the laboratory.



Figure 13: 3D-Printed Extraterrestrial Habitats (66)

- Autonomous construction robots: These robots might be used to construct buildings on Mars, removing the need for human employees in dangerous situations. In 2019, NASA's Swarmathon competition involved teams building algorithms enabling autonomous robots to construct structures on Mars in collaboration. (39) In figure 14, a robot for construction on Mars.



Figure 14: Martian Builders: The Robots of the Mars Colony (67)

- Inflatable habitats: These constructions might be carried to Mars in a compressed state and expanded once they reached the surface. The Bigelow Expandable Activity Module (BEAM) has

been successfully tested on the International Space Station and may also be utilized on Mars. (40) In figure 14, a The Innovation Behind Hassell's Mars Settlement.

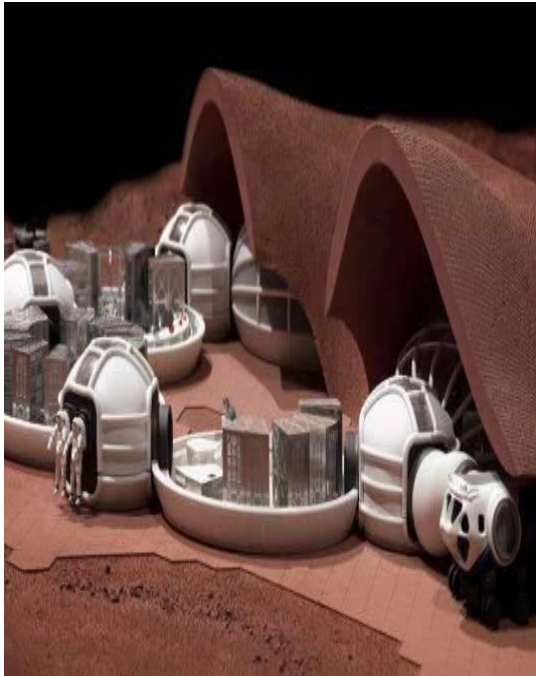


Figure 15: The Innovation Behind Hassell's Mars Settlement (68)

12. Construction materials for Mars

It would be impossible to transfer vast quantities of building materials from Earth to Mars. So, construction materials would need to be discovered or created on Mars. Here are some potential sources of materials:

- **Regolith:** The surface of Mars is covered with a layer of loose rock and dust known as regolith. Regolith might be compacted to generate a material suitable for construction. Regolith may be melted and combined with other substances to produce bricks, ceramics, and structures resembling glass. (41)
- **Martian soil:** Martian dirt may be utilized as a construction material that can be turned into a product similar to concrete. The Martian soil includes iron oxide, which may be utilized to build a substance similar to concrete. (42)
- **Ice:** The polar regions of Mars are covered with ice. The ice might be melted and used as a water supply for construction materials, or it could be

used directly as a building material. Moreover, ice might be used to form a radiation barrier for structures. (43)

- **Basalt:** Basalt is a kind of volcanic rock found on Mars. Crushed basalt might be used with a binder to form a substance similar to concrete (44).
- **Carbon fiber:** Carbon fiber can be produced from the carbon dioxide in the Martian atmosphere. Carbon fiber might be utilized to develop structural materials that are both lightweight and robust. (45)

Ultimately, the building materials utilized on Mars will need to be lightweight, sturdy, and resistant to the severe climate. They will also need to be sustainable, taking into consideration the planet's finite resources. To enable the successful exploration and possible colonization of Mars, the development of sophisticated materials and building methods will be essential.

13. Smart materials on Mars

Smart materials are those whose characteristics can be altered or controlled by external stimuli such as temperature, light, or electrical current. These materials have several potential uses, including as space travel and colonization. Being a hostile and difficult environment, Mars would profit immensely from the usage of intelligent materials in different applications. These are some potential uses of intelligent materials on Mars:

- **Thermal regulation:** Intelligent materials may be utilized to manage the temperature of dwellings and other Martian buildings. For instance, shape memory alloys may alter their form in reaction to variations in temperature, enabling them to function as switches to open or shut vents or windows to manage the temperature inside buildings. (46)
- **Radiation shielding:** Mars' sparse atmosphere provides minimal protection against solar and galactic radiation. Smart materials may be utilized to produce radiation shields with the ability to adapt their characteristics to various sources of radiation. (47)
- **Energy harvesting:** Intelligent materials may be employed to capture energy from the Martian environment, such as

sunshine or temperature gradients, in order to power equipment and systems. (48)

- Water collection and purification: Intelligent materials may be utilized to gather and filter water on Mars, which is essential for human survival. For instance, superabsorbent polymers may gather water from the atmosphere, while nanofilters can remove contaminants from water. (49)

Using intelligent materials on Mars might make habitation and exploration more effective, sustainable, and secure.

14. Classification of smart materials in Mars building

Smart materials are those that can alter their characteristics in reaction to external stimuli such as temperature, light, pressure, or electric fields. In the context of constructing structures on Mars, intelligent materials may be utilized to construct structures that can react to variations in temperature, radiation levels, and air pressure.

There are various kinds of intelligent building materials that might be used in the construction of Martian structures, including:

- Shape memory alloys (SMAs): After being distorted, these materials may recall and return to their original shape. SMAs might be utilized to produce self-healing materials capable of repairing themselves after being injured by Mars' harsh climate. (46)
- Piezoelectric materials: When squeezed or stretched, these materials create an electric charge. They might be used to develop energy-harvesting devices that produce power from the Martian wind or other mechanical energy sources. (50)
- Phase-change materials: These materials may store and release heat when they transform from one phase to another (e.g., solid to liquid). These might be used to manage the temperature within Martian structures,

keeping them warm at night and cool during the day. (51)

- Electrochromic materials: These materials change color or transparency in response to an electric current. These might be utilized to make intelligent windows whose tinting adjusts in response to variations in Martian light levels, aiding in the regulation of the inside temperature. (52)
- Self-healing materials: Some materials have the capacity to repair themselves after being harmed. They might be utilized to construct durable, self-repairing building materials that can resist the harsh Martian climate. (53)

Using intelligent materials in Martian building construction might result in more durable and flexible buildings that can resist the planet's severe circumstances.

15. Conclusion

the construction of structures on Mars brings unique problems and possibilities, which need creative approaches and technology. The creation of intelligent structures and systems on Mars may aid in ensuring the safety and viability of human colonies on the planet. Intelligent systems may facilitate effective energy management, waste management, and communication between building occupants and the outside world. The selection of a suitable place for construction on Mars is crucial for the mission's safety and success. The area must have availability to resources such as water and minerals, be devoid of potentially hazardous geological characteristics, and have a climate conducive to human settlement. For the construction of safe and long-lasting buildings on the planet, it will be necessary to use modern and resilient materials, such as those being developed particularly for Mars. Ultimately, the building management and construction procedures used on Mars will be essential for the planet's successful exploration and possible settlement. Humans may one day establish a permanent presence on Mars and realize the full potential of space exploration by using the most advanced technology and breakthroughs.

References

- [1]. Chen, M., Goyal, R., Majji, M., & Skelton, R. (2020). Design and analysis of a growable artificial gravity space habitat. *Aerospace Science and Technology*, 106, 106147. <https://doi.org/10.1016/j.ast.2020.106147>.
- [2]. Liebske, C., & Khan, A. (2019). On the principal building blocks of Mars and Earth. *Icarus*. <https://doi.org/10.1016/j.ICARUS.2019.01.014>.
- [3]. Hwang, B., & Tan, J. (2012). Green building project management: obstacles and solutions for sustainable development. *Sustainable Development*, 20, 335-349. <https://doi.org/10.1002/SD.492>.
- [4]. Sheshpari, M., Fujii, Y., & Tani, T. (2017). Underground structures in Mars excavated by tunneling methods for sheltering humans. *Tunnelling and Underground Space Technology*, 64, 61-73. <https://doi.org/10.1016/j.TUST.2016.12.015>.
- [5]. Sha, H., Xu, P., Yang, Z., Chen, Y., & Tang, J. (2019). Overview of computational intelligence for building energy system design. *Renewable and Sustainable Energy Reviews*. <https://doi.org/10.1016/j.RSER.2019.03.018>.
- [6]. Volkov, A., & Batov, E. (2015). Simulation of Building Operations for Calculating Building Intelligence Quotient. *Procedia Engineering*, 111, 845-848. <https://doi.org/10.1016/j.PROENG.2015.07.156>.
- [7]. AlFaris, F., Juaidi, A., & Manzano-Agugliaro, F. (2017). Intelligent homes' technologies to optimize the energy performance for the net zero energy home. *Energy and Buildings*, 153, 262-274. <https://doi.org/10.1016/j.ENBUILD.2017.07.089>.
- [8]. Sheshpari, M., Fujii, Y., & Tani, T. (2017). Underground structures in Mars excavated by tunneling methods for sheltering humans. *Tunnelling and Underground Space Technology*, 64, 61-73. <https://doi.org/10.1016/j.TUST.2016.12.015>.
- [9]. Panchalingam, R., & Chan, K. (2019). A state-of-the-art review on artificial intelligence for Smart Buildings. *Intelligent Buildings International*, 13, 203 - 226. <https://doi.org/10.1080/17508975.2019.1613219>.
- [10]. Apanaviciene, R., Vanagas, A., & Fokaides, P. (2020). Smart Building Integration into a Smart City (SBISC): Development of a New Evaluation Framework. *Energies*, 13, 2190. <https://doi.org/10.3390/en13092190>.
- [11]. Weiss, B., Yung, Y., & Nealson, K. (2000). Atmospheric energy for subsurface life on Mars?. *Proceedings of the National Academy of Sciences of the United States of America*, 97 4, 1395-9 . <https://doi.org/10.1073/PNAS.030538097>.
- [12]. Coblentz, W., Lampland, C., & Menzel, D. (1927). TEMPERATURES OF MARS, 1926, AS DERIVED FROM THE WATER-CELL TRANSMISSIONS. *Publications of the Astronomical Society of the Pacific*, 39, 97 - 97. <https://doi.org/10.1086/123685>.
- [13]. Haiyuan, W., Zhisheng, H., Ning, Z., & Yuzhong, H. (2013). A Monitoring System for the Safety of Building Structure Based on Semantic Technology. *2013 Fourth International Conference on Intelligent Systems Design and Engineering Applications*, 15-18. <https://doi.org/10.1109/ISDEA.2013.410>.

- [14]. Wang, S. (2016). Making buildings smarter, grid-friendly, and responsive to smart grids. *Science and Technology for the Built Environment*, 22, 629 - 632. <https://doi.org/10.1080/23744731.2016.1200888>.
- [15]. Wei, T., Chen, X., Li, X., & Zhu, Q. (2018). Model-based and Data-driven Approaches for Building Automation and Control. 2018 IEEE/ACM International Conference on Computer-Aided Design (ICCAD), 1-8. <https://doi.org/10.1145/3240765.3243485>.
- [16]. Delgado-Bonal, A., Martín-Torres, F., Vázquez-Martín, S., & Zorzano, M. (2016). Solar and wind exergy potentials for Mars. *Energy*, 102, 550-558. <https://doi.org/10.1016/j.ENERGY.2016.02.110>.
- [17]. Kyriacou, A., Timotheou, S., Michaelides, M., Panayiotou, C., & Polycarpou, M. (2017). Partitioning of Intelligent Buildings for Distributed Contaminant Detection and Isolation. *IEEE Transactions on Emerging Topics in Computational Intelligence*, 1, 72-86. <https://doi.org/10.1109/TETCI.2017.2665119>.
- [18]. Balme, M., Gallagher, C., Page, D., Murray, J., & Muller, J. (2009). Sorted stone circles in Elysium Planitia, Mars: Implications for recent martian climate. *Icarus*, 200, 30-38. <https://doi.org/10.1016/j.ICARUS.2008.11.010>.
- [19]. Sanders, G. (2011). Comparison of Lunar and Mars In-Situ Resource Utilization for Future Robotic and Human Missions. . <https://doi.org/10.2514/6.2011-120>.
- [20]. Heldmann, J., Marinova, M., Lim, D., Wilson, D., Carrato, P., Kennedy, K., Esbeck, A., Colaprete, T., Elphic, R., Captain, J., Zacny, K., Stolov, L., Mellerowicz, B., Palmowski, J., Bramson, A., Putzig, N., Morgan, G., Sizemore, H., & Coyan, J. (2021). Mission Architecture Using the SpaceX Starship Vehicle to Enable a Sustained Human Presence on Mars. *New Space*, 10, 259 - 273. <https://doi.org/10.1089/space.2020.0058>.
- [21]. Yamashita, M., Ishikawa, Y., Kitaya, Y., Goto, E., Arai, M., Hashimoto, H., Tomita-Yokotani, K., Hirafuji, M., Omori, K., Shiraishi, A., Tani, A., Toki, K., Yokota, H., & Fujita, O. (2006). An Overview of Challenges in Modeling Heat and Mass Transfer for Living on Mars. *Annals of the New York Academy of Sciences*, 1077. <https://doi.org/10.1196/annals.1362.012>.
- [22]. Hurtado, L., Nguyen, P., & Kling, W. (2015). Smart grid and smart building inter-operation using agent-based particle swarm optimization. *Sustainable Energy, Grids and Networks*, 2, 32-40. <https://doi.org/10.1016/j.SEGAN.2015.03.003>.
- [23]. Fang, L., Mei, B., Jiang, L., & Sun, J. (2020). Investigation of Intelligent Safety Management Information System for Nuclear Power Construction Projects. *Proceedings of the 3rd International Conference on Information Technologies and Electrical Engineering*. <https://doi.org/10.1145/3452940.3453058>.
- [24]. Yuen, J. (2013). *Deep Space Telecommunications Systems Engineering*. . <https://doi.org/10.1007/978-1-4757-4923-6>.
- [25]. Ai, G., Ib, K., Ad, E., & Aa, S. (2003). Problems of diagnostics and prophylaxis in a Martian flight. *Aerospace and environmental medicine*, 37, 22-31.
- [26]. Wu, Y., & Li, F. (2011). Research and Design of Intelligent Building Energy Management System. *Advanced Materials Research*, 368-373, 3745 - 3748. <https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMR.368-373.3745>.

- [27]. Zhang, S. (2016). Application Analysis of Electrical Automation in Building Intelligent Systems Development. , 1205-1208. <https://doi.org/10.2991/ICEEECS-16.2016.233>.
- [28]. Zhehu, H. (2014). Design and Application of Remote Monitoring System for Rectification of High-rise Building. Structural Engineers.
- [29]. Dong, W. (2010). Research on the Intelligent Analysis and Monitoring System About High-level Structures. Journal of Sichuan University of Science & Engineering.
- [30]. Sierra, E., Hossian, A., Rodríguez, D., García-Martínez, M., Britos, P., & García-Martínez, R. (2008). Optimizing Building's Environments Performance Using Intelligent Systems. , 486-491. https://doi.org/10.1007/978-3-540-69052-8_51.
- [31]. Topolsky, D., Topolskaya, I., Mitin, V., Topolsky, N., Yumagulov, N., & Gonenko, T. (2020). Non-Contact Condition Monitoring of Electrical Drive. 2020 Ural Symposium on Biomedical Engineering, Radioelectronics and Information Technology (USBREIT), 436-439. <https://doi.org/10.1109/USBREIT48449.2020.9117794>.
- [32]. R-Moreno, M., Duncan, B., & Bergman, L. (2019). Special Issue: Selected Methods and Techniques for Intelligent Systems for Space. IEEE Aerospace and Electronic Systems Magazine. <https://doi.org/10.1109/MAES.2019.2918613>.
- [33]. Doyle, R., Chien, S., Kortenkamp, D., & Woods, M. (2016). Introduction to the Special Issue on Intelligent Systems for Space Exploration. J. Aerosp. Inf. Syst., 13, 279. <https://doi.org/10.2514/1.1010487>.
- [34]. Kaynak, O., Grant, E., & Honderd, G. (1993). Intelligent Systems: Safety, Reliability and Maintainability Issues. . <https://doi.org/10.1007/978-3-642-58021-5>.
- [35]. Burl, M., Thompson, D., deGranville, C., & Bornstein, B. (2016). Rockster: Onboard Rock Segmentation Through Edge Regrouping. Journal of Aerospace Information Systems, 13, 329-342. <https://doi.org/10.2514/1.1010381>.
- [36]. Brooks, D. (2011). Intelligent buildings: an investigation into current and emerging security vulnerabilities in automated building systems using an applied defeat methodology. . <https://doi.org/10.4225/75/57A00D7CAC5C0>.
- [37]. Sacksteder, K., & Sanders, G. (2007). In-Situ Resource Utilization for Lunar and Mars Exploration. . <https://doi.org/10.2514/6.2007-345>.
- [38]. Leach, N. (2014). 3D Printing in Space. Architectural Design, 84, 108-113. <https://doi.org/10.1002/AD.1840>.
- [39]. Simmons, R., Singh, S., Heger, F., Hiatt, L., Koterba, S., Melchior, N., & Sellner, B. (2007). Human-Robot Teams for Large-Scale Assembly. . <https://doi.org/10.1184/R1/6555074.V1>.
- [40]. Zatakia, S. (2006). Design Concepts for Interior Configurations of Lunar/Mars Inflatable Habitat Modules. , 1-8. [https://doi.org/10.1061/40830\(188\)83](https://doi.org/10.1061/40830(188)83).
- [41]. Mueller, R., Sibille, L., Hintze, P., Lippitt, T., Mantovani, J., Nugent, M., & Townsend, I. (2015). Additive Construction using Basalt Regolith Fines. , 394-403. <https://doi.org/10.1061/9780784479179.042>.
- [42]. Lane, M., Dyar, M., & Bishop, J. (2004). Spectroscopic evidence for hydrous iron sulfate in the Martian soil. Geophysical Research Letters, 31. <https://doi.org/10.1029/2004GL021231>.

- [43]. Kaufmann, E., & Hagermann, A. (2017). Experimental investigation of insolation-driven dust ejection from Mars' CO₂ ice caps. *Icarus*, 282, 118-126. <https://doi.org/10.1016/j.ICARUS.2016.09.039>.
- [44]. Scott, A., Oze, C., O'Loughlin, A., & Tang, Y. (2015). Development and Application of Martian Regolith Simulant Using Volcanic Material from Banks Peninsula, New Zealand. , 69-75. <https://doi.org/10.1061/9780784479179.009>.
- [45]. Martin, A. (2013). Volume Averaged Modeling of the Oxidation of Porous Carbon Fiber Material. , 1-11. <https://doi.org/10.2514/6.2013-2636>.
- [46]. Mazurek-Budzyńska, M., Razzaq, M., Behl, M., & Lendlein, A. (2002). Shape-memory polymers.. *Angewandte Chemie*, 41 12, 2035-57 . [https://doi.org/10.1002/1521-3773\(20020617\)41:12<2034::AID-ANIE2034>3.0.CO;2-M](https://doi.org/10.1002/1521-3773(20020617)41:12<2034::AID-ANIE2034>3.0.CO;2-M).
- [47]. Sargent, S. (2018). Radiation Shielding Bricks for Mars Using Martian Regolith Simulant and Hydrogen-Rich Polymers. . <https://doi.org/10.21220/S2-ACWH-K853>.
- [48]. Beeby, S., Cao, Z., & Almussallam, A. (2013). Kinetic, thermoelectric and solar energy harvesting technologies for smart textiles. , 306-328. <https://doi.org/10.1533/9780857093530.2.306>.
- [49]. Kabiri, K., Omidian, H., Zohuriaan-Mehr, M., & Doroudiani, S. (2011). Superabsorbent hydrogel composites and nanocomposites: A review. *Polymer Composites*, 32, 277-289. <https://doi.org/10.1002/PC.21046>.
- [50]. Sezer, N., & Koç, M. (2021). A comprehensive review on the state-of-the-art of piezoelectric energy harvesting. *Nano Energy*, 80, 105567. <https://doi.org/10.1016/j.nanoen.2020.105567>.
- [51]. Huang, X., Zhu, C., Lin, Y., & Fang, G. (2019). Thermal properties and applications of microencapsulated PCM for thermal energy storage: A review. *Applied Thermal Engineering*. <https://doi.org/10.1016/j.APPLTHERMALENG.2018.11.007>.
- [52]. Cardoso, M., Pereira, R., Pereira, S., Gonçalves, H., Silva, M., Carlos, L., Nunes, S., Fortunato, E., Ferreira, R., Rego, R., & Bermudez, V. (2018). Three-Mode Modulation Electrochromic Device with High Energy Efficiency for Windows of Buildings Located in Continental Climatic Regions. *Advanced Sustainable Systems*, 3. <https://doi.org/10.1002/adsu.201800115>.
- [53]. Billiet, S., Hillewaere, X., Teixeira, R., & Prez, F. (2013). Chemistry of crosslinking processes for self-healing polymers.. *Macromolecular rapid communications*, 34 4, 290-309. <https://doi.org/10.1002/marc.201200689>.
- [54]. <https://ts2.space/en/exploring-martian-like-environments-on-earth-unveiling-the-secrets-of-interplanetary-habitation/>
- [55]. <https://ai.business/2016/07/18/how-jaxa-nasa-and-european-space-agency-are-developing-extraterrestrial-autonomous-construction-using-artificial-intelligence/>
- [56]. <https://www.snexplores.org/article/lets-learn-about-surviving-a-trip-to-mars>
- [57]. <https://www.space.com/41935-mars-base-alpha-2028-elon-musk.html>
- [58]. <https://www.dezeen.com/2021/04/07/nuwa-mars-city-cliffside-abiboo/>
- [59]. <https://www.mensaforkids.org/teach/lesson-plans/mission-to-mars/>

- [60]. <https://mars.nasa.gov/mer/spotlight/20070612.html>
- [61]. <https://news.mit.edu/2022/design-mars-propellant-production-trucks-wins-nasa-competition-0711>
- [62]. <https://www.theatlantic.com/science/archive/2018/09/mars-pd/569668/>
- [63]. <https://www.space.com/nasa-astronauts-30-day-mars-mission-science>
- [64]. <https://www.thespacereview.com/article/3257/1>
- [65]. <https://www.nature.com/articles/s41591-021-01665-3>
- [66]. um.ieee.org/3d-printers-could-build-future-homes-on-mars
- [67]. <https://www.vx-c.com/building-on-mars/robot-builders-mars-colony>
- [68]. <https://parametric-architecture.com/the-innovation-behind-hassells-settlement-design-for-mars/>

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CONSTRUCTION ON MARS

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Abstract

Terraforming Mars is a crucial endeavor due to pressing issues on Earth, including resource depletion. As our planet's resources dwindle, Mars offers a potential solution through colonization and construction. Terraforming involves altering Mars' environment to make it habitable for humans and other organisms. Key steps include creating a thicker atmosphere to retain heat, generating a stable climate, and introducing liquid water by melting polar ice caps. These changes could support plant growth and potentially sustain a human population. However, terraforming Mars is an immense challenge. Mars has a thin atmosphere with minimal greenhouse gases, making it cold and inhospitable. Additionally, building habitats, establishing infrastructure, and ensuring sustainability demand advanced technologies and significant resources. While the idea of colonizing Mars offers hope for humanity's future, it's crucial to approach this endeavor thoughtfully and ethically. As we explore this path, we must weigh the benefits against the challenges and carefully consider our responsibilities as both planetary stewards and pioneers. In this article, we have a look at the issues that are needed to build a house on Mars and we will analyze it in general.

Keywords: building, Mars planet, terraforming, construction, future

Introduction

The fourth planet from the sun is Mars. It merely has a diameter that is half that of the earth. However, the earth exhibits a variety of traits, and these traits make us think that life may also exist on Mars. These astronauts discovered that Mars is a frigid, arid planet that resembles the Moon more than the Earth. The Martian atmosphere has an exceedingly low density, about 50 km above sea level, comparable to the Earth's atmosphere (1). A modest amount of water and carbon dioxide make up the majority of this atmosphere. Nitrogen and oxygen have not been identified in it, though they certainly

exist in minuscule amounts. The air on Mars is so thin that UV radiation, which is harmful to the majority of living organisms, can easily travel there from space. The polar caps are made of frozen water, and a sizable portion of Mars' surface was once covered in water. More than the other planets, Mars has captured the interest of scientists. This is due to two key factors. Mars is the planet that is closest to Earth among those that are farthest from the Sun. One of the brightest celestial objects in our night sky, Mars occasionally passes within a relatively short orbital range of the Earth, which is 56 million kilometres away. This planet is orange-red in appearance and is clearly visible to the unaided eye. There are numerous similarities between Mars and Earth. A Martian day is only a little over

40 minutes shorter than ours. An atmosphere exists on Mars. It has seasons and an ice cover on its poles, just like the earth. Many scientists formerly thought that there could be a garden on our planet. Since then, other unmanned spacecraft have visited Mars, and reports and photographs have returned to Earth (2). These texts almost provide us with proof that there is no life on this planet, but perhaps Mars' former climate was more conducive to life. Unfortunately, the Martian atmosphere, which primarily contains carbon dioxide and a trace quantity of water vapour, is not breathable for humans. Intense interest in Mars exploration and the potential for future Martian migration has been generated by these characteristics of Mars and its distinctive geography and landforms. Future Mars exploration missions will continue to make progress with the aim of better understanding Mars' internal structure and external environment, as well as laying the groundwork for the eventual realisation of a human mission to the planet. As a result, Mars buildings are crucial for the administration of building information. mostly because these researchers are only starting out (3,4). Figure 1 shows the contrasts between the two Sierras.



Figure 1. Comparison of the planet Earth and Mars (Esa, 2018)

Methodology

This article attempts to provide thorough information regarding the future of construction on Mars based on prior studies and a review of the literature. The resources available on Mars will be used for this purpose to study and investigate the facilities and goods required for development projects on this planet.

study area

The best chance that a planet has the necessary quantity of water to host life is Mars. However, from both an engineering and an economic

perspective, the most crucial question is whether it is feasible to live there. As was already said, Mars is the planet closest to Earth, but there is one major difference: there is no oxygen-rich atmosphere on Mars. As a result, the main duties involve warming and thickening the atmosphere there. The initial colonists had to construct an underground shelter in order to comprehend this truth (5). Figure 2.

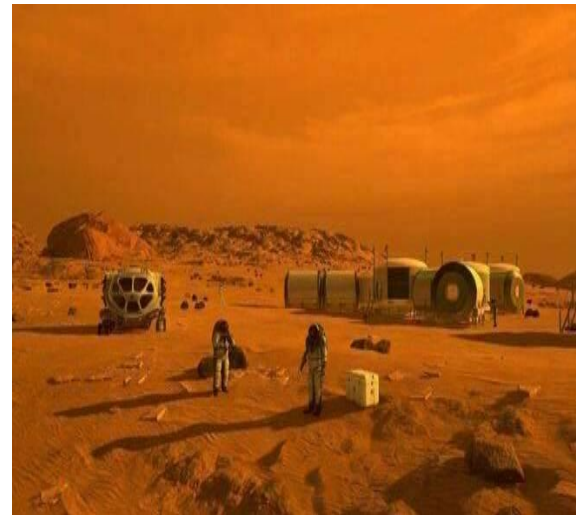


Figure 2. A settlement on Mars (Robert Lea. 2023)

For the Martians, building shelters is crucial because of the planet's low air pressure, intense solar radiation, and requirement for colonies that can last without pressure suits. The first colonists and planetary engineers should reside in their spacecraft and in habitation modules that have been transported from Earth. Structures must be built using the materials at hand because there are no cement manufacturers or forests to harvest on Mars. On Mars, there are plenty of rocks and dirt; similar building materials have been employed for thousands of years on Earth. Caves, stone that has been stacked and mortared, adobe, and rammed earth are all examples of this type of construction. Cast stabilized earth, earth-bag buildings, and dug subsurface rooms are more recent examples (6).

Buildings formation

Building structures on Mars presents unique challenges and opportunities due to the planet's harsh environment and distinct characteristics. The buildings intended for Mars colonization must be designed to provide essential life support, protect against extreme temperatures,

and support the well-being of human inhabitants (7). The architecture of Martian buildings would likely incorporate modular and self-sustaining designs. To counteract the thin atmosphere and high levels of radiation, structures could be partially buried or constructed with thick walls using Martian regolith as a building material. This would provide natural insulation and protection against radiation, as well as stabilize temperatures within the living spaces. These buildings might consist of interconnected modules, each serving specific functions such as living quarters, research areas, and food production zones (8). Figure 3 shows building Formation on Mars.

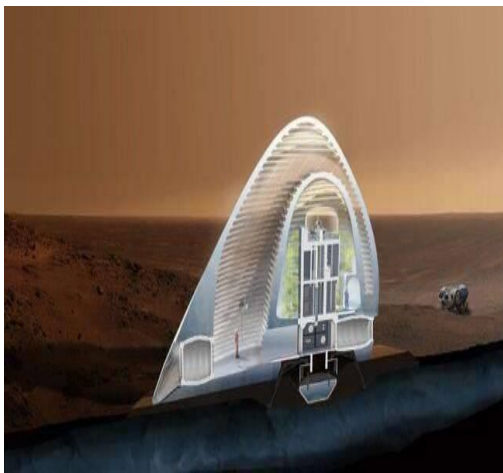


Figure 3. building formation on mars (Anthony Cuthbertson, 2021)

Challenges of Construction on Mars:

As Ehlmann, et al (9) note, the prospective benefits Martian exploration overrides the costs. It had been investigated and reported that in a long term perspective, even the expense analysis rationalizes the Martian exploration when it is compared to the other governmental expenditures. The Several technological aspects are present for colonization of Mars. Issues such as low gravity, low atmospheric pressure, temperature variation throughout a day, etc. The list even goes down to the most human's basic needs namely food, water, oxygen, shelter, and clothing. Solutions had been scientifically studied to overcome these barriers. To name a few in accordance with Elhmann (9). evaluation the technological advancement mentioned in table 1 can be seen as an approach towards these problems:

Table 1 Facing challenges and solutions in Mars mission (Gharizadeh at el, 2019)

Challenge to a human Mars mission	Technology development	Technology development
The negative effect of microgravity and solar radiations on human	Pharmacological and mechanical prevention techniques	Prevention, detection, and treatment of illnesses ranging from osteoporosis
Limited air, water, and food resources	Closed loop life-support systems	Conservation, waste management and recycling
Limited energy supply	Solar energy, low energy uses, graphene panels	Renewable efficient energy sources; energy

Innovative Construction Techniques (3D Printer)

3D printing, or additive manufacturing, constitutes a revolutionary suite of technologies that facilitate the creation of three-dimensional objects by layering material to form a complete product. The core principle involves translating a digital design into a tangible object through a sequential layering process. This versatility spans from crafting elementary items like chess pieces to fabricating intricate components like rocket engine parts. In the realm of construction, 3D printing follows a similar *modus operandi* but operates on a grander scale (12). This method involves employing a 3D printer to deposit layers of various materials to build structures layer by layer. Notably, this technique's efficacy is not restricted to traditional construction materials alone; it extends to an array of substances including concrete, cement, mortar, plastics, mud, rice waste, sand, and even metals and stones. Recent research is heralding a profound development in this field by proposing that Mars' indigenous soil itself holds the potential to serve as a feasible medium for 3D printing structures (13). This discovery bears significant implications for prospective human habitation on the Red Planet. By harnessing Martian soil as a raw material, future settlers and explorers could potentially utilize 3D printing technology to construct habitable shelters, research stations, and other essential infrastructure. This could dramatically streamline the complexities associated with transporting construction materials from Earth,

thereby reducing cost, risk, and logistical challenges (14). The form of the settlement's building via 3D printer is shown below.



Figure 4. construction of the settlement by 3D printer (Madeleine, 2022)

Materials and Resources

The biggest problem regarding materials for colonists is the fact that there are none available on the Mars (15). In order to successfully create a sustainable and safe colony for future humans, one must bring either the materials, the technology, or both from Earth for developing and creating long-term housing units for the lunar and Martian astronauts (16). While the composition of the moon and Mars are different than the Earth in some ways, they also share some similarities. Most importantly the natural regolith, or rocky soils, of these planetoids can potentially be used to create the necessary building materials for housing and other buildings and structures (17). There are also plentiful mineral resources including iron, titanium, nickel, aluminum, sulfur, chlorine and calcium. Silicon dioxide is the most common material on Mars, according to measurements taken by the Viking space probes, and is also a basic ingredient of glass (18).

Materials That Can Be Used to Construct on Mars

Flexibility, strength, and durability have been the fundamental concerns of professionals while exploring materials to construct on mars. Potential sub-materials that could be used to build buildings on Mars include:

Martian Soil: Martian soil was defined as a weakly consolidated weathered material mainly composed of regolith, aeolian, or fluvial deposits. It also includes a subtle mixture of mineral sediments, ores of dust, and soil. Researchers

believe that martian soil can be used as an aggregate for construction (19,21). When supported by engineering and mechanics, the particles theoretically showcased an incredible ability to bond with each other. This implies that when compressed together, they could be used to form building blocks and serve as an alternative for bricks (20,22). Figure 5 depicts a sample of Martin soil.



Figure 5. a sample of martin soil (Baillot, 2017)

Basalt: In the event of a volcanic eruption, the solid rocky remains of the lava, on cooling down turn into igneous rock. These rocks are extensively available throughout mars, with the chemical richness of magnesium and iron. These clusters of rock are mainly categorized based on their availability and the elements that they bind with (23). Some types include lime-ash basalt, which is rich in high silica glass, pyroxene basalt, which contains olivine, and lime-ash basalt which constitutes olivine and lime-ash. The most advantageous property of using basalt for construction is its ability to act as an in-situ resource for 3D printing. Also when heated and extruded, it produces stone wool, which could be used for thermal insulation and protection of surfaced buildings. It could also be used for the construction of cobblestones and decorative crafts (24). Figure 6 depicts a sample of basalt.



Figure 6. a sample of basalt (augite basalt, 2019)

Volcanic Ash: Another residual of a volcanic eruption is the molten magma which breaks down into smaller particles to form volcanic ash.

This element, when combined with lime, creates hydrates of the elements and bonds with them to showcase hydraulic gelling abilities, which can be used in combination with cement, either as an admixture for concrete or simply as a binding material to help bind the structure together. With the availability of extensive amounts of iron-containing volcanic ash, throughout the surface of Mars, it becomes an essential element that could potentially be used for future constructions on the planet (25). Figure 7 depicts a volcano on Mars.



Figure 7. volcano on Mars (Esa, 2010)

Martian Concrete: Concrete primarily requires three elements for its production. The first is an aggregate, for which as discussed earlier, an ample amount of Martian soil could be used. The next is water, which can be found on the polar caps of the planet, in the form of ice. And the last is a binder that uses a combination of sulfur or other polymers with regolith to sustain high-strength bonds under varying atmospheric pressures and temperatures. Similarly, magnesium-based geopolymers could also be used (26). Figure 6 depicts a piece of Martian concrete.



Figure 8. a sample of Martian concrete (Bob Yirka, 2016)

Habitat Design and Functionality

Habitat design and functionality on Mars necessitate innovative solutions due to the planet's harsh environment and unique challenges. Mars has a thin atmosphere, extreme temperatures, and high levels of radiation, which

demand specialized habitats to ensure the safety and well-being of human occupants (27). Designing habitats for Mars involves several key considerations. First, the structure must provide effective shielding against radiation and insulation against temperature fluctuations. Materials with high radiation resistance and insulating properties are crucial. Additionally, the habitat should be airtight to maintain a breathable atmosphere, possibly relying on advanced life support systems to recycle air and manage waste. Functionality is paramount to support human life and activities (28). Habitats need to incorporate advanced life support technologies to produce food, water, and oxygen. Closed-loop ecosystems that recycle resources can minimize dependence on Earth supplies. Furthermore, integrating renewable energy sources like solar panels is essential to power habitats and reduce reliance on limited local resources. Flexibility and expandability are also important. Habitats should be designed to accommodate growth as the Mars settlement evolves (29). This could involve modular construction, allowing for the addition of new sections or modules as needed. Additionally, the habitat layout should consider psychological well-being, incorporating communal spaces, natural lighting simulation, and greenery to counteract potential feelings of isolation and confinement (30). Figure 9 depicts an example of a hypothetical design on Mars.



Figure 9. simulated design on Mars (Tyler Koslow, 2015)

Development line:

Future research directions in the realm of Mars construction offer exciting opportunities for scientific investigation and innovation. One line of inquiry could be to look into new technology designed for Martian construction. Researchers can investigate the development and

implementation of advanced 3D printing techniques, robotics, and automation systems, which will be required for the construction of habitats, infrastructure, and other structures on Mars. Examining the particular technical hurdles connected with Martian architecture is another intriguing field of inquiry. Researchers can look into topics including adapting construction methods to Mars' harsh environment, dealing with limited resources like water and energy, and developing effective waste management and recycling systems in a closed-loop ecosystem. Furthermore, investigating innovative materials appropriate for Martian construction is an important research field. Scientists can explore locally derived minerals on Mars, such as regolith and ice, to design building materials that are both sustainable and resistant to the planet's severe circumstances. Investigating the characteristics and technical potential of these materials, as well as testing their durability under Martian conditions, could be part of the research. At the end, future research in Martian construction could take numerous paths, including breakthroughs in construction technology, answers to technical obstacles, and the production of novel Martian building materials. Researchers can pave the road for long-term and successful human exploration and colonization of Mars by addressing these issues, making it a

more habitable and feasible destination for future missions.

Conclusion:

Construction on Mars signifies an awe-inspiring leap in human capabilities, embodying the relentless pursuit of progress and the human spirit's indomitable nature. Through a synergistic fusion of spacefaring expertise and cutting-edge engineering, the prospects of establishing a viable settlement on the red planet are steadily maturing. By harnessing local resources, like Martian regolith and ice, and leveraging 3D printing and autonomous construction, we're poised to erect habitats and infrastructure that can withstand the planet's harsh conditions. This venture symbolizes humanity's audacity to expand its horizons, prompting collaboration among diverse fields and international partners. Lessons from terrestrial sustainable practices must be ingeniously adapted, addressing challenges like radiation exposure and life support systems. The evolving narrative of Mars construction narrates not just a technological saga, but also a testament to human adaptability, resilience, and unity in the face of the unknown.

Reference

1. National Aeronautics and Space Administration. Available from Internet: <<http://mars.jpl.nasa.gov/>>.
2. Wazman. Lots of People Have Theories About Neil Armstrong's 'One Small Step for Man' Quote, Here's What We Really Know, 2019, Online available from <https://time.com/5621999/neil-armstrong-quote/>
3. A. Todhunter, M. Crowley, and F. Sartipi, "Construction productivity indices in socialism compared with capitalism," *Journal of Construction Materials*, vol. 1, no. 1, 2019, doi: <https://doi.org/10.36756/JCM.v1.1.2>.
4. [2] A. Todhunter, M. Crowley, M. Gholamisheverini, and F. Sartipi, "Advanced technological implementation of construction and demolition waste recycling," *Journal of Construction Materials*, vol. 1, no. 1, 2019, doi: <https://doi.org/10.36756/JCM.v1.1.3>.
5. The Green Geek. Terraforming Mars – part 2. Available from Internet: <<http://www.greengeek.ca/terraforming-mars-part-2/>>.
6. NASA Quest: Possibility of colonizing Mars. Available from Internet: <http://quest.nasa.gov/mars/ask/colony/Colonization_of_Mars_by_humans.txt>.
7. <http://quest.nasa.gov/mars/ask/colony/Colonization_of_Mars_by_humans.txt>. 4. The Green Geek. Terraforming Mars – part 4. Available from Internet.
8. Mars Ice House: Tour a Concept Martian Home in Pictures, 2018, Online available from <https://www.space.com/39761-mars-ice-house-concept-in-pictures.html>.
9. B. L. Ehlmann et al., "Humans to Mars: A feasibility and cost-benefit analysis," *Acta astronautica*, vol. 56, no. 9-12, pp. 851-858, 2005.

10. M. Gamil, A. Gharizadeh, and F. Sartipi, "A review on graphene reinforced cement composite: technical approach for ecofriendly construction," *Journal of Construction Materials*, vol. 1, no. 1, 2019, doi: <https://doi.org/10.36756/JCM.v1.1.4>. Institute of Construction Materials.
11. F. Sartipi, A. Gharizadeh, and M. Gamil, "Electrical resistance of graphene reinforced cement paste," *Journal of Construction Materials*, vol. 1, no. 1, 2019, doi:
12. Bak, D. (2008). Rapid prototyping or rapid production? 3D printing processes move industry towards the latter. *Assembly Automation Rapid Prototyping Journal* Iss *Rapid Prototyping Journal*, 23(1), 340–345. Retrieved from <https://doi.org/10.1108/01445150310501190>
13. Mueller, S., Mohr, T., Guenther, K., Frohnhofen, J., &Baudisch, P. (2014). faBrickation: Fast 3D Printing of Functional Objects by Integrating Construction Kit Building Blocks. Retrieved from <http://dx.doi.org/10.1145/2556288.2557005>
14. Tibbits, S. (2014). 4D printing: Multi-material shape change. *Architectural Design*, 84(1), 116– 121. <https://doi.org/10.1002/ad.1710>
15. R. Garner. How to Protect Astronauts from Space Radiation on Mars, NASA, 2015, Online available from <https://www.nasa.gov/feature/goddard/real-martians-how-to-protect-astronauts-from-space-radiation-on-mars>.
16. N. Savage. To build settlements on Mars, we'll need materials chemistry, 2017, Online available from <https://cen.acs.org/content/cen/articles/96/i1/build-settlements-Mars-ll-need.html>.
17. M. Iranfar, and S. S. Muhy Al-Din. The Cognition of the Architectural Styles Role on Thermal Performance in Houses of Semi-Arid Climates: Analysis of Building Envelope Materials, *Civil Engineering and Architecture*, Vol. 8, No. 5, pp. 929 - 941, 2020, DOI:10.13189/cea.2020.080520
18. Materials Scientists Make Martian Concrete, *MIT Technology Review*, 2016, Online available from <https://www.technologyreview.com/s/545216/materials-scientists-make-martian-concrete/>.
19. J. Bell et al., "Mineralogic and compositional properties of Martian soil and dust: Results from Mars Pathfinder," *Journal of Geophysical Research: Planets*, vol. 105, no. E1, pp. 1721- 1755, 2000.
20. M. Fateri, A. Gebhardt, and M. Khosravi, "Experimental investigation of selective laser melting of lunar regolith for in-situ applications," in *International Mechanical Engineering Congress and Exposition (ASME)*, 2013, vol. 2.
21. G. Jordan. Can Plants Grow with Mars Soil, NASA, 2015, Online available from <https://www.nasa.gov/feature/can-plants-grow-with-mars-soil>.
22. B. Granath. Lunar, Martian Greenhouses Designed to Mimic Those on Earth, NASA, 2017, Online available from <https://www.nasa.gov/feature/lunar-martian-greenhouses-designed-to-mimic-those-on-earth>.
23. Kemmerer, B.W. (2019), A Compositional Analysis of Artificial and Terrestrial Analog Martian Regolith Simulants. Dissertation, Space Sciences: Astronomy/Astrophysics Florida Institute of Technology.
24. Sumanarathna, A.R. (2020), An Introduction to Geology Of Mars. South Asian Astrobiology & Earth Science Research Unit: Eco Astronomy Sri Lanka, Presentation, May 2020 DOI: 10.13140/RG.2.2.11022.38720
25. Toups, L., Hoffman, S. and Watts, K. (2016). Mars Surface Systems Common Capabilities and Challenges for Human Missions. [ebook] Available at: <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20160001039.pdf> [Accessed 1 Nov. 2017].
26. E.W. Clifton, Design and construction for a permanent presence on Mars, *The Case for Mars V*, Mar 26 – Mar 29 1993, Univelt Inc, Boulder, CO, United states, 2000, pp. 451-458.
27. T. Sinn, and O. Doule. Inflatable structures for Mars Base 10, 42nd International Conference on Environmental Systems, 1-12, 2012.
28. T. Talbert. NASA Seeks Ideas for Where on Mars the Next Giant Leap Will Take Place, NASA, 2015, Online available from <https://www.nasa.gov/journeymars/mars-exploration-zones>
29. E. Mahoney. Where on Mars Might Humans First Land, NASA, 2015, Online available from <https://www.nasa.gov/feature/where-on-mars-might-humans-first-land>.
30. S. Häuplik-Meusburger, and O. Bannova. Space Architecture Education for Engineers and Architects, Space.
31. https://www.esa.int/ESA_Multimedia/Images/2018/04/Comparing_the_atmospheres_of_Mars_and_Earth

32. <https://www.space.com/mars-settlements-people-personalities-number>
33. <https://www.independent.co.uk/space/elon-musk-mars-city-wealth-b1784062.html>
34. <https://www.3dnatives.com/en/using-3d-printing-to-conquer-outer-space-210420226/>
35. <https://www.science.org/content/article/bricks-made-martian-soil-may-be-stronger-steel-reinforced-concrete>
36. <https://fineart.ha.com/itm/meteorites/martian/nwa-8159-martian-meteoritemartian-augite-basalt-moroccofound-2013/a/5438-72121.s>
37. https://www.esa.int/Science_Exploration/Space_Science/Mars_Express/Volcanic_ash_in_Meridiani_Planum
38. <https://phys.org/news/2016-01-martian-concrete-materials-red-planet.html>
39. <https://3dprintingindustry.com/news/3d-printing-a-habitat-made-of-mars-earth-the-sfero-concept-57449/>

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BUILDING INFORMATION MODELING FOR PRECAST CONCRETE COMPONENTS IN DEVELOPED NATIONS

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Abstract

Since the construction sector consumes a significant part of each country's capital and inevitably affects the development of other countries, especially emerging countries, it is necessary to use methods, techniques, and technology in this business. He led the development of several construction projects that produced quality, durable buildings in less time and at a lower cost. BIM building information modeling technology, which, after a few years since its inception, has occupied a significant part of the global construction market, is one of the most useful and important technologies in the world and a revolution in the construction industry. The high sensitivity of the construction and implementation of prefabricated concrete structures on the one hand and the growing need to build fast and cost-effective structures on the other hand, prompted many construction companies around the world to use this technology in the construction of structures. The use of precast concrete is presented in this research in order to investigate the role of building information modeling technology in the creation of precast concrete buildings and also the benefits of using this technology for such structures, using library studies and past research to obtain results.

Keywords: Structures, BIM, Concrete, Technology, Construction

Introduction

Due to the unique implementation challenges and hurdles that the majority of construction projects face, it is vital to employ contemporary technology to address these issues in order to have an influence on the two crucial elements of time and cost. Avoid being impacted by things that have a negative impact on a project's success or failure. Currently, there has been significant advancement in the introduction of numerous ways and procedures. The use of Building Information Modeling (BIM) technology and its integration with the re-engineering process and its incredibly impressive advantages in the process of building and implementing projects, for instance, by numerous engineering organizations, particularly civil, architectural, and facility engineers worldwide, is increasing. Civil engineers have gotten used to it and employ this technology to streamline their projects, particularly prefabricated concrete constructions (1). Prefabricated concrete components are seen in figure 1. (21).



Figure 1: prefabricated concrete parts (21)

In these situations, in addition to the project's direct negative impacts, there may also be indirect negative effects, among which it is possible to note the diminished reputation. In addition to the aforementioned negative consequences for the project, there may also be beneficial benefits, such as when we are compelled to adopt current technology to cope with the changes imposed on the project. As a consequence, we unintentionally influence the building engineering community's introduction of a new technology. This alone might be seen as

advantageous. Building information modeling technology is one of the practical and effective innovations that recently joined the nation's construction industry. As a result of the significant transformation and revolution that the introduction of this technology into engineering has brought about in the fields of civil engineering and architecture, it is essential to take concrete steps to improve the nation's building conditions by conducting enough research in this area. (1) Figure 2 shows how a building has been transformed into a digital duplicate by modeling the building data. (20)

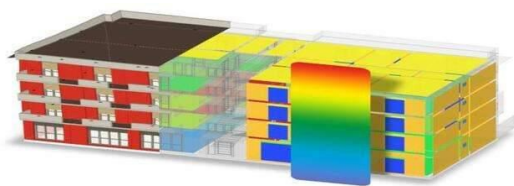


Figure 2: Digital replica (20)

Literature Review

Building information modeling has been the subject of several studies, all of which dealt with various facets and applications of the subject. Each study, using a different methodology, has shown the need to investigate the current state, efficacy, and knowledge of the advantages of this technology and has contributed to its advancement, development, and broader use. The evaluated studies are generally grouped into three groups. The first group includes studies that have been done to examine the level of acceptability of building information modeling as well as the barriers to and issues with its implementation. The second area consists of studies that have looked at the uses, advantages, and efficiency of developing information modeling technology; the third category is devoted to studies that have been done to create a model for bettering and understanding technology. (4)

They found obstacles to the implementation of building information modeling in a different research. This study, which gathered the opinions of construction industry experts through a questionnaire, revealed that they are uninterested in and inexperienced in building information modeling. It also revealed that the biggest barriers to its adoption among

policymakers are a lack of support and a lack of motivation to promote it. Other barriers to the implementation of this technology in Iran include a lack of awareness and understanding as well as the absence of training materials. Additional barriers to the use of this technology were found to include opposition to altering conventional practices, expenses, the speed of the Internet, a lack of critical infrastructure, and ignorance of possible advantages (5).

However, compared to other nations in the globe, the United States of America is far ahead in the creation of scientific publications in the area of building information modeling, according to research done up to the end of 2015. The Scandinavian nations also have 59 of the papers produced in this branch of science globally. This subject is based on the analysis of the chart created in 2012 by Carneiro et al. Additional research was conducted till 2015, and the order and rating of the nations are still in place. It should be noted that the stark contrast depicted in the diagram below may be the result of varying operating systems, a greater value placed on new technologies, the presence of educational institutions with a focus on building information modeling and construction management, as well as other factors. (6) The number of publications published in developed nations is shown in Figure 3.

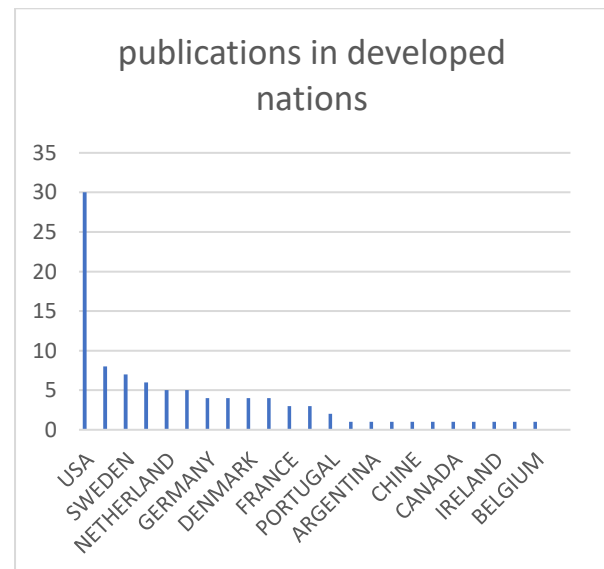


Figure 3: Articles published in the field of building information modeling by countries until 2015

Methodology

I have written this article using library methods and previous research. On the other hand, using articles up to 2015, I reviewed the previous research that shows the impact of BIM on the construction industry. In this article, I have described the effect of precast concrete using beams.

Building information modeling

The creation, use, and management of vital building design and project data via the use of technology, or BIM, allows for the creation of intelligent 3D digital models that can be seen and used throughout the life cycle of a building. (2-3) BIM software is based on 3D parametric modeling, a technique that links pertinent data to digital replicas of real-world building components (such as walls, columns, electrical, and plumbing) to describe their characteristics (3). Geometry, relationship geometric properties (such as parallelism, offset from), material quality, design performance, supplier, timetable, cost, and other details are examples of this information (3). A sophisticated 3D building model is created using BIM platforms, and BIM audit and analysis tools are utilized to investigate or enhance the depth of information in the model (3). in Figure 4 that by using building information modeling, you can view and check all project information before starting.



Figure 4: Building information modeling (22)

Building information modeling advantages

- Time-related issues: Using BIM often cuts down on the amount of time needed to generate construction drawings.
- 4D models: By using 4D tools, the construction planning chain may be evaluated and shared with other members of the project team. The components of the building model should be organized into groups based on the phases of

construction and connected to project planning activities.

- Cost-related issues: One of the benefits of BIM is that each component provides data on its length, breadth, and height, as well as any other information required for a quantitative estimate of the project.
- Eliminating waste: The capacity to swiftly build alternative models, keep the information and coherence of the specified model (preventing interference), and generate automated reports all contribute to stable and trustworthy data that is mostly discarded and recreated. reduces the amount of effort and waiting for information.
- Quality: With BIM's many possibilities, it is simple to provide the chance for the quality to be verified and the ultimate objective of higher-quality buildings to be realized. (7)

Building information modeling Disadvantages

- Low adoption of new technologies and traditional working methods in construction projects, particularly in developing nations.
- The requirement for job training for employees and operators in contracting firms, consulting firms, and organizations.
- One of the barriers to building information modeling's widespread adoption is that, according to some businesses, it simply refers to 3D design. (7)

BUILDING INFORMATION MODELING IN SPAIN AND OTHER DEVELOPED NATIONS

The European Union's Directive 2014/24/UE has been put into effect in the Spanish construction sector. The Building Information Modeling (BIM) Directive, which will go into force in 2016, allows Member States to promote, utilize, and even require the use of BIM in building projects receiving EU funding. Spanish AEC experts use building information modeling to show that BIM technologies are now only deployed during the design phase of residential developments. This approach is seldom used in other kinds of projects or throughout the phases of building, operation, and maintenance. However, experts predict that it would take between three and five years BIM to be fully used in building projects

(10). Building information modeling shown in Spain in Figure 4.

Building Information Modeling (BIM) is becoming more and more common in Spain, particularly in the construction and architectural sectors. Building information modeling (BIM) has recently been backed by the Spanish government in public projects, which has aided in raising awareness and promoting its use in the private sector. The use of BIM in Spain is encouraged by a number of professional associations, including the Spanish Association of Surveying and Mapping, the Spanish Association of Engineering and Architecture Firms, and the Spanish Association of Construction Companies. These groups educate clients and other stakeholders about the benefits of BIM and provide training and support to professionals who want to adopt it. Additionally, there are an increasing number of international companies like Autodesk and Trimble as well as Spanish companies like CYPE and Tekla who provide the BIM software. These companies provide a range of BIM tools and solutions, including as project management and collaboration platforms, design and modeling software, and more. A number of regulatory initiatives have been started by the Spanish government to promote the use of BIM in public projects. BIM, for instance, is now required for all public building projects in Spain as of 2018. In order to monitor the adoption of BIM across several sectors and to promote software tool standardization and interoperability, the government has also formed a BIM Commission. (23). In table number 1, the definitions of advanced countries regarding the modeling of building information.

Country	Initiative
Australia	The Built Environment Industry Initiative Council published recommendations to establish requirements for fully collaborative BIM on Government building procurements by 1 July 2016, however no action was taken. New South Wales' Health Infrastructure has mandated BIM deliverables on all projects over \$30 million (9)
China	A BIM initiative is included in China's 2013 5-year plan, and a development of national guidelines has begun. (10)
Denmark	Denmark's government agencies implemented the Digital

	Construction program in 2007 which requires projects over 5.5m Euros to use the IFC format and produce certain deliverables for facilities management (11)
Finland	The government required models to meet the IFC standard on all projects in 2007 and has outlined its objective to have "all-embracing, integrated model based operations in designing, building and property servicing and maintenance in a few years" (11)
Norway	The government agency responsible for construction projects, Statsbygg, in 2010 required that all properties use the IFC based BIM for the lifecycle whole lifecycle of the facility. (12)
Singapore	Singapore's government is applying for a mandate for BIM by 2015, as well as providing incentives for "early pathfinders" (12). In addition to this, CORENET, a government development, is a fully funded resource provided by the government for automated code checking of models. (11)
South Korea	South Korea's Public Procurement Service has made it compulsory for all projects over SK50m and for all public sector projects by 2016 (12)
United Kingdom	The UK Government Construction Strategy, published in 2011, set the requirement for the implementation of fully-collaborative BIM on all of its projects by 2016" (13).
USA	The General Services Administration has required mandatory BIM submission for governmental projects since 2008 (10)

Table 1: BIM Initiatives around the world

Building information modeling in prefabricated concrete parts

Precast concrete is often defined as concrete that is manufactured and treated in a factory setting before being delivered to the project site. Due to industrial manufacturing, this kind of concrete is made in a way that ensures good quality. Despite the fact that BIM is used in building projects, it is also seen necessary in the prefab business. BIM is a relatively new concept that initially has a narrow definition that only refers to the CAD model and information associated with it before

expanding throughout the course of an organization's life cycle. Therefore, if BIM is properly implemented, it may modify the project participants' responsibilities and communication, as well as lower the project's cost and duration. (3) Constructing information modeling has many uses today, from designing and constructing structures to operating them and even destroying them. By digitally exhibiting the building's attributes, this technology assists the project management and stakeholders in making the best choice at every step. Modeling of building information all construction management tasks, which are based on contract papers, are reliant on the two types of maps and specifications, in that maps are used to define the scope of the work and technical specifications are used to determine its quality. In actuality, these two categories are used to set the performance assessment standards for contractors. We already know that the execution plans of various design groups are generated independently but in collaboration with one another in the typical manner of construction management. On the one hand, plans and specifications are provided separately. Everyone can see the apparent drawbacks of this approach, and maybe the worst ones are the lack of cooperation, errors, and redoing work. In Figure 5, the design of precast concrete is done using the required design software.

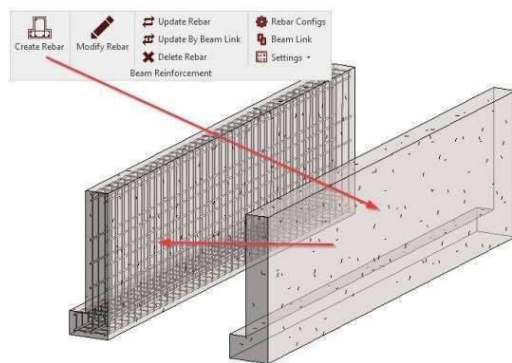


Figure 5: Precast concrete design using software (23)

Advantages OF Precast concrete

- High speed construction
- lower costs
- high quality parts
- storage of parts
- ability to operate in adverse weather
- construction of temporary structures and reuse of parts;

- easier control of creep and shrinkage of prefabricated parts
- less manpower
- better planning and project management
- better use of pre-tensioning and post-tensioning techniques (14-1).

Disadvantages of precast concrete

- High initial investment is required
- Unique arrangements for transporting and implementing components need to be designed and considered
- Parts need to be adjusted and weigh a certain amount
- There are design and implementation constraints (14–15).

Construction information modeling technology in precast concrete

- Ability to analyze the structure
- Capability to review construction phases
- Possibility of precise planning of workshop equipment
- Scheduling schedule and sequence of manufacturing operations of prefabricated parts
- Estimation of the construction cost of the prefabricated structure
- Integration of information from subcontractors and material
- Coordination between systems (16-17-18)

Steps to use BIM in precast concrete

In general, there will be three main stages in the phased review of the building by BIM, which are:

Step 1) Before construction

Step 2) under construction

Step 3) After construction

It should be observed that the aforementioned stages are not clearly separated from one another; rather, they are all interconnected. Following these steps will help you arrive at design strategies that reduce the environmental effect of your building while considering its life cycle. Pre-construction activities include site selection, building design, and activities related to building design that take place prior to the establishment and use of materials. The sustainable design strategy considers the effects

on the environment of structural design, building orientation, its impact on the surrounding landscape, and the materials utilized. A building's physical construction and usage are referred to as the "construction stage" of a building's life cycle. The sustainable design approach looks at how buildings are constructed and run in order to identify solutions to decrease the negative environmental consequences of resource usage. They also consider the long-term consequences of the surrounding environment on the health of the building's tenants. (19)

The post-construction phase begins as soon as the structure has served its purpose. At this point, the building materials will either be repurposed into new constructions or will be dumped back into nature as trash. A crucial aspect of the sustainable design approach is reducing construction waste by recycling and reusing buildings and construction materials. (19)

A building's physical construction and usage are referred to as the "construction stage" of a building's life cycle. In order to identify strategies to lessen the negative environmental consequences of resource use, the design, construction, and operation of buildings are evaluated. The long-term health consequences of the building's surroundings on its occupants are also taken into consideration. The post-construction phase begins as soon as the structure has served its purpose. At this point, the building materials will either be repurposed into new constructions or will be dumped back into nature as trash. A crucial aspect of the sustainable design approach is reducing construction waste by recycling and reusing buildings and construction materials.

The five primary subgroups that make up the work process are: Utilizing BIM to divide up additional implementation phases

- First phase: before construction
- Second phase: construction
- The third phase: accurate and detailed design
- The fourth phase: preliminary design
- The fifth phase: planning

The effect of using BIM in precast concrete

In general, the following aspects may be taken into account when evaluating the impact of BIM

on the technical parameters of concrete structures:

Weight: By incorporating the weight of the concrete component in the information data, the executive engineers may gain significantly. For instance, it will be able to select the kind and tonnage of the required crane by entering the part's weight and telling the installation engineer of it, guaranteeing safety during installation. The delivery of components also uses more conventional techniques and adequate equipment, which is crucial economically.

Dimensions: By knowing the part's dimensions and including them in the Bim data, it is possible to more precisely examine the part's location and the space that is available for its installation. Additionally, it is possible to choose the best equipment for transporting and installing the part while also avoiding implementation issues.

Fire resistance: As one of the primary considerations in the design and construction of concrete structures' fire resistance choice, ASTM E, prefabricated concrete panels composed of light grains, silica, carbonate, and light sand vary in their fire resistance and depend on the piece's thickness. In this standard, the amount of fire resistance lasting between one and four hours is considered. Understanding the prefabricated component's degree of fire resistance, which relies on the materials used and the thickness of the piece (for example, in parking lots or commercial areas with significant traffic), will help you pick the best place and circumstance for deploying it.

Implementation method: Implementation is one of the most critical and crucial phases in the building precast concrete components. It is feasible to describe the working environment, including the temperature, in BIM.

Part coding: The installation order of the pieces and the position of each part may be researched by entering the code and the number of the prefabricated part in BIM.

Connections: The right and principled installation of components may be achieved by using the right form of connection between prefabricated elements, such as beams, columns, slabs, foundations, etc.

Consumable components: One of the most significant and determining aspects in the

creation of prefabricated parts is the consumption of components and their physical and chemical properties. The aforementioned details and attributes are equally applicable to Bim. (1)

Design: BIM allows for the entry of data pertaining to the design of prefabricated members, applicable rules, the amount of steel utilized in the component, etc. (1)

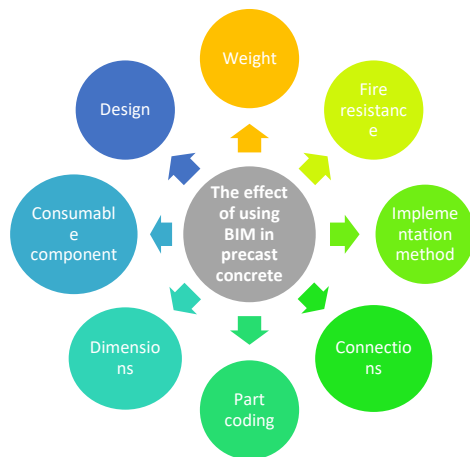


Figure 5: A summary of the impact of BIM on precast concrete parts (author)

Conclusion

Precast concrete structures can benefit from using the BIM method in many ways, such as speeding up project completion, improving

workshop management, installing parts without any unintentional errors, properly coding parts and streamlining the installation process, producing precast concrete with high quality (due to the monitoring of consumables and the factory process of its manufacture), and better managing parts transportation without any potential problems. In light of the aforementioned benefits, it is advised that BIM technology be used in all prefabricated buildings, whether they are high-rise or multi-story, in order to speed up the construction process and improve accuracy and efficiency of implementation. To maximize accuracy in the process and avoid some from being overlooked, take into account the specifics and executive details of the prefabricated concrete structures, including connections, plates, reinforcements, apertures, etc. It will be impossible to escape the finer points of employing the BIM approach. In addition to their complexity, prefabricated parts also have various production methods. As a result, the concrete mixes produced in various locations differ significantly from one another due to the various materials used there and the unique climatic conditions of each location. They are, in general, prefabricated concrete structures built with building information modeling technology can be built more accurately from the design stage to operation, avoid some unpleasant possibilities and events that could delay the project's construction, and reduce unnecessary costs.

References

1. Arash Dadashi, 2019, in structures (BIM), the effect of using precast concrete building information modeling
2. Succar, B. (2009). Building information modeling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3), 357-375.
3. Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: a guide to building information modeling for owners, managers, designers*. John Wiley & Sons.
4. Mamter, S., Abdolaziz, A., Zulkepli, J. (2017). Root causes occurrence of low BIM adoption in Malaysia: System dynamics modeling approach. *The 3rd International Conference on Construction and Building Engineering*. Palembang, Indonesia.
5. Hosseini M., Azari, E., Tivendale, L., Banihashemi, S., Chileshe, N. (2016). Building Information Modeling (BIM) in Iran: an exploratory study. *Journal of engineering, project, and production management*, 6(2), 78-89(in Persian).
6. Rezaei Akbar et al., 2019, review of the integration of building information modeling with the prefab industry in advanced countries and Iran, *Research Quarterly in Science, Engineering and Technology*, Volume 6, Number 1

7. Dunn, J. E. (2007). Building Information Modeling Specialist. Retrieved from: www.kcrevit.com/Job_Postings_Main.htm
8. SILVIA ANDRÉS, ARÁNZAZU DE LA PEÑA, PATRICIA DEL SOLAR, MARÍA DOLORES VIVAS, 2017, Implementation of BIM in Spanish construction industry, building and management
9. McGowan, S (2013), Bishop to King, *EcoLibrium-AIRAH Journal*, 13(9), 22-29.
10. Hong Kong Construction Industry Council (2013). Final Draft Report of the Roadmap for BIM Strategic Implementation in Hong Kong's Construction Industry, HKCIC
11. buildingSMART Australasia (2012). National Building Information Modeling Initiative. Volume 1: Strategy. buildingSMART Australasia
12. Chew, A. and Riley, M. (2013). What is going on with BIM? On the way to 6D. *International Construction Law Review*, 30(3), 253-265.
13. UK Government Cabinet Office (2011). Industrial Strategy: Government and Industry in Partnership, Retrieved from: [https://www.gov.uk/government/publications/building-information-modeling]
14. Hughes, S. R., and B. C. Crisp. "Structural Precast Concrete in Melbourne, Australia." *Australasian Structural Engineering Conference 2008: Engaging with Structural Engineering*. Meeting Planners, 2008.
15. Park, Robert. (2003). *Seismic Design of Precast Concrete Building Structures*. FIB-Féd. Int. du Béton Vol. 27.
16. Dawood, N., and Mallasi, Z. (2006). Construction Workplace Planning: Assignment and Analysis Utilizing 4D Visualization Technologies. *Computer-aided Civil and Infrastructure Engineering*, Pgs. 498-513.
17. Lu, W., Huang, G. Q., & Li, H. (2011). Scenarios for applying RFID technology in construction project management. *Automation in Construction*, 20(2), 101-106.
18. Polat, G. (2008). Factors affecting the use of precast concrete systems in the United States. *Journal of Construction Engineering and Management*, 134(3), 169-178.
19. Darby, S. (2006). The Effectiveness of Feedback on Energy Consumption. A Review for Defra of the Literature on Metering, Billing and Direct Displays. University of Oxford, Oxford, UK: Environmental Change Institute.
20. <https://parametric-architecture.com/building-information-modeling-bim-dimensions-4d-5d-6d/>
21. https://www.engineeringnews.co.za/article/precast-concrete-manufacturing-complements-construction-sector-2020-05-29/rep_id:4136
22. <https://www.ecs.co.za/building-information-modeling-bim-is-the-future/>
23. https://www.bft-international.com/en/artikel/bft_Rebar-modeling_automation_for_Revit_introduced-3536787.html

J. Glossery and Definition

2D: $W * d * h$ is a fundamental mathematical formula representing the dimensions of an object or space. It involves multiplying the width, depth, and height of an entity to determine its total size or volume.

3D: An x-y-z matrix is a three-dimensional structure whereby the x-axis and y-axis denote the first two dimensions and the z-axis is the third dimension. In a graphic image, the x denotes width, y denotes height and the z represents depth. An x-y-z matrix is also known as a 3d matrix.

4D: A dimension in addition to length, width, and depth, used so as to be able to employ geometrical language in discussing phenomena that depend on four variables: time is considered a fourth dimension for locating points in space-time.

5D: 5d is a five-dimensional way of showing the physical & functional aspects of any project. You can find the 5d information sharing in level 2, full collaboration, of the bim along with 4d. 5d adds the element of costs to the already existing time management and cde components of information sharing in construction.

3D printer: 3d printing or additive manufacturing is the construction of a three-dimensional object from a cad model or a digital 3d model. It can be done in a variety of processes in which material is deposited, joined or solidified under computer control, with the material being added together, typically layer by layer.

ADEPT: An approach for enabling autonomous decentralized peer-to-peer telemetry (adept). A first adept peer senses adept peers to interconnect where the adept peers are identified as adept light peer, adept standard peer and adept peer exchange based on respectively increasing iot device capability. The first adept peer sends and receives requests to interconnect to the adept peers based on messaging. The first adept peer transfers files where the files are distributed toward peer-to-peer networks, creating peer consensus and interconnecting the first adept peer to the adept peers based on the peer consensus. Adept peers execute transactions and contracts by decentralized peer to peer consensus network and consensus ledger to enable autonomous device coordination.

AECO: The architecture, engineering, and construction (aec) services sector provides a host of services surrounding the planning and building of commercial and residential projects that employ design and construction professionals in the planning and implementation of often multi-billion-dollar projects.

AI: Artificial intelligence (ai), the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings.

AEC/FM/D: The architecture, engineering, construction, and facility management (aec-fm) industry is increasingly affected by digital technologies that monitor sensor network data and control automation systems.

AGC: America is the leading association for the construction industry. With over 27,000 member firms, agc provides a full range of services satisfying the needs and concerns of its members, thereby improving the quality of construction and protecting the public interest.

Amazon EC2: Amazon elastic compute cloud (amazon ec2) is a web service that provides secure, resizable compute capacity in the cloud. It is designed to make web-scale cloud computing easier for developers. Amazon ec2's simple web service interface allows you to obtain and configure capacity with minimal friction.

ACID: Advance construction (ac) is a funds management technique authorized in federal highway law. The general rule under federal appropriations law requires a federal agency to obligate (commit) federal funds for the full federal share of any project at the time it approves the project.

AES: The advanced encryption standard (aes) is an algorithm that uses the same key to encrypt and decrypt protected data.

AIM: An aim, or asset information model, provides all the information necessary to support the management of an asset. For example, it logs its precise location, operational data, information about work carried out and its existing condition.

AIA: As the largest design organization in the world, aia is working to transform the day-to-day practice of architecture to achieve a zero-carbon, resilient, healthy, just, equitable built environment, for everyone. Architects founded aia in 1857.

Bitcoin: Bitcoin is the first decentralized cryptocurrency. Nodes in the peer-to-peer bitcoin network verify transactions through cryptography and record them in a public distributed ledger, called a blockchain, without central oversight.

BM: Business model or method (bm) is a plan for the successful operation of a business, identifying sources of revenue, the intended customer base, products, and details of financing that includes how the business makes money or how to deliver value to the customers at an appropriate cost. The bm is a framework for finding a systematic way to make long-term value for an organisation while delivering value to customers and capturing value through monetisation strategies. The bm (business model or method) may be a class of patents which disclose and claim new methods of doing business that is combined with technology, resulting in a new way of doing business.

BIMCHAIN: The bimchain solution allows you to notarize and verify any type of data and bim file in the blockchain. It is possible to validate the exchange process, the roles, the skills of the actors involved in the processes and all the information that contributes to demonstrating ownership of the corporate know-how.

BC: A blockchain (bc) is essentially a decentralized ledger that records every transaction made in the network, known as a 'block', the body of which comprises encrypted data of the entire transaction history.

BIM: Building information modeling is a process involving the generation and management of digital representations of the physical and functional characteristics of places. Bim is supported by various tools, technologies and contracts.

Bcxml: With the new internet language xml, extensible mark-up language [1], it is possible to define and communicate both content and mark-up. This means that xml supports the development of xml vocabularies as required by bc. The european ist 10303 'econstruct' project is doing just this with the development of bcxml (building construction xml).

Bsdd: The buildingsmart data dictionary (bsdd) is an online service that hosts classifications and their properties, allowed values, units and translations. The bsdd allows linking between all the content inside the database. It provides a standardized workflow to guarantee data quality and information consistency.

BMS: A building management system (bms) or building automation and control system (bacs) is a system that manages and monitors all building systems, including the electrical system, hvac system, renewable energy production, and electricity and gas meters.

BCC: Bcc contract is a type of contract signed between investors to divide profits or products without establishing an economic entity.

BCS: Bcs – building control systems – is specialist op het gebied van klimaat, energie en beveiliging waarbinnen wij controle bieden over uw gebouw. Tot onze werkzaamheden behoort onder andere: - airconditioning - warmtepompen - zonnepanelen - laadpalen - elektra - beveiliging".

BSI: Bsi's essac (electrotechnical standardization strategic advisory council) is the national committee of the iec for the uk. Bsi is a non-profit distributing organization and offers global services in the linked fields of standardization, systems assessment, product certification, training and advisory services.

BAS: A building automation system (bas) is a network designed to connect and automate certain functions inside a building. All of the building control systems, from lighting and hvac (heating, ventilation & air conditioning) to fire and security systems—all wired through one set of controls.

BEMS: Building energy management systems (bems) control the functions of the building, allowing a smooth operation and efficient functioning of the building. This description elaborates on the bems technology.

CAD: Computer-aided design is the use of computers to aid in the creation, modification, analysis, or optimization of a design. This software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

COBie: Construction operations building information exchange (cobie) is a united states-originated specification relating to managed asset information including space and equipment. It is closely associated with building information modeling (bim) approaches to design, construction, and management of built assets.

CMMS: A computerized maintenance management system or cmms is software that centralizes maintenance information and facilitates the processes of maintenance operations. It helps optimize the utilization and availability of physical equipment like vehicles, machinery, communications, plant infrastructures and other assets.

Currency: Currency describes the money or official means of payment in a country or region. The best-known currencies include the u.s. dollar, euro, japanese yen, british pound and swiss franc.

CMMI: Capability maturity model integration is a process level improvement training and appraisal program. Administered by the cmmi institute, a subsidiary of isaca, it was developed at carnegie mellon university. It is required by many u.s. government contracts, especially in software development.

CMM: The capability maturity model is a development model created in 1986 after a study of data collected from organizations that contracted with the u.s. department of defense, who founded the research.

CCM: Gcms depict the climate using a three-dimensional grid over the globe (see below), typically having a horizontal resolution of between 250 and 600 km, 10 to

20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans.

CIC: Construction industry council is the representative forum for professional bodies, research organisations and specialist business associations in the united kingdom construction industry.

Cryptographically: The science or study of the techniques of secret writing, especially code and cipher systems, methods, and the like.: compare cryptanalysis (def. 2). The procedures, processes, methods, etc., of making and using secret writing, as codes or ciphers.

CSA: Cloud security alliance is a not-for-profit organization with the mission to “promote the use of best practices for providing security assurance within cloud computing, and to provide education on the uses of cloud computing to help secure all other forms of computing.

CDE: A cde is a cloud-based space where information from construction projects is stored and accessible to project participants. This access depends on participants' requirements or level of authorization, as well as their contractual obligations.

CIA: Confidentiality protects information (data) from unauthorized access. Integrity is the accuracy and consistency of data as well as the completeness and reliability of systems. Availability is the ability for users to access systems and information when needed, even under duress

CRMS: Resource management software describes the digital tools used to allocate, assign, and track employees, finances, and equipment across projects. Get demo. Most modern business projects require a range of different resources to reach completion.

CFD: A contract for differences (cfd) is a financial contract that pays the differences in the settlement price between the open and closing trades. Cfds essentially allow investors to trade the direction of securities over the very short-term and are especially popular in fx and commodities products.

DBFT: Delegated byzantine fault tolerance (dbft) is a sophisticated algorithm meant to facilitate consensus on a blockchain. Although it is not in common use as of yet, it represents an alternative to simpler proof of stake, proof of importance and proof of work methods.

DAC: Dacs are businesses that operate according to regulations stored in computer programs known as smart contracts. Decentralized autonomous corporations are

abbreviated as dacs. A dac's financial transaction record and the remainder of its operations are immutably and irreversibly embodied on a blockchain.

DAO: A decentralized autonomous organization, sometimes called a decentralized autonomous corporation, is an organization managed in whole or in part by decentralized computer program, with voting and finances handled through a blockchain. In general terms, daos are member-owned communities without centralized leadership.

DDC: Direct digital control, known as “ddc” is at the heart of building automation. Ddc measures environmental conditions and compares the measurements to the desired settings (a.k.a. setpoints). It calculates an appropriate response if the two aren't equal, and sends out control signals to correct for any difference.

ENCRYPTED: In cryptography, encryption is the process of encoding information. This process converts the original representation of the information, known as plaintext, into an alternative form known as ciphertext. Ideally, only authorized parties can decipher a ciphertext back to plaintext and access the original information.

Ethereum: Ethereum is a decentralized blockchain with smart contract functionality. Ether is the native cryptocurrency of the platform. Among cryptocurrencies, ether is second only to bitcoin in market capitalization. It is open-source software. Ethereum was conceived in 2013 by programmer vitalik buterin .

ECDSA: The elliptic curve digital signature algorithm (ecdsa) is a digital signature algorithm (dsa) which uses keys derived from elliptic curve cryptography (ecc). It is a particularly efficient equation based on public key cryptography (pkc).
ERM The framework to manage the exchange rates between eu currencies, and ensures stability.

FM: Facility management or facilities management is a professional management discipline focused on the efficient and effective delivery of logistics and other support services related to real property and buildings.

Fuzzy AHP: Fuzzy analytic hierarchy process is the integration method of qualitative and quantitative methods. The main difference between fahp and ahp is that fahp can classify evaluation factors into target level, criterion level, and factor level.

Framework: In general, a framework is a real or conceptual structure intended to serve as a support or guide for the building of something that expands the structure into something useful.

GHOST: Ghost protocol is a security measure that was first introduced in the ethereum blockchain. It aims to enhance the security of blockchains by addressing the issue of orphaned blocks. Orphaned blocks are blocks that are not included in the main blockchain due to conflicts in data.

GIS: Gis, or geographic information systems, are computer-based tools used to store, visualize, analyze, and interpret geographic data. Geographic data (also called spatial, or geospatial data) identifies the geographic location of features.

GBXML: The green building xml schema is an open schema developed to facilitate transfer of building data stored in building information models to engineering analysis tools. It enables interoperability between bim and building performance simulation, which is relevant to sustainable building design and operation.

GUID: A guid (globally unique identifier) is a 128-bit text string that represents an identification (id). Organizations generate guids when a unique reference number is needed to identify information on a computer or network. A guid can be used to id hardware, software, accounts, documents and other items.

HTML: Hypertext markup language or html is the standard markup language for documents designed to be displayed in a web browser. It defines the content and structure of web content. It is often assisted by technologies such as cascading style sheets and scripting languages such as javascript.

HVAC: Hvac stands for heating, ventilation, and air conditioning. It refers to the systems that regulate and move heated and cooled air throughout residential and commercial buildings, from homes to offices to indoor stadiums.

HMI: Hmi stands for human machine interface. Generally, it refers to a screen or dashboard that communicates information, data and metrics using graphics or visual representations of numbers. The screen is controlled by an operator who monitors and controls equipment and processes in factories and plants.

Hash: A hash function is any function that can be used to map data of arbitrary size to fixed-size values, though there are some hash functions that support variable length output. The values returned by a hash function are called hash values, hash codes, hash digests, digests, or simply hashes.

HAN: As the name suggests, a han is a very small network that usually covers a single home. Any device that is connected to this network will be able to share

resources, for example the internet, smart appliances, printers, smart meters and even some security systems.

IOT: The internet of things (iot) refers to the process of connecting everyday physical objects to the internet—from common household objects like lightbulbs; to healthcare assets like medical devices; to wearables, smart devices, and even smart cities.

ICT: Information and communication technology, abbreviated as ict, covers all technical means used to handle information and aid communication. This includes both computer and network hardware, as well as their software.

ISO: The international organization for standardization is an independent, non-governmental, international standard development organization composed of representatives from the national standards organizations of member countries. Membership requirements are given in article 3 of the iso statutes.

IPD: Integrated project delivery (ipd) is a construction project delivery method that seeks the efficiency and involvement of all participants (people, systems, business structures and practices) through all phases of design, fabrication, and construction. Ipd combines ideas from integrated practice and lean construction.

IP: An internet protocol address is a numerical label such as 192.0.2.1 that is assigned to a device connected to a computer network that uses the internet protocol for communication. Ip addresses serve two main functions: network interface identification, and location addressing.

IDM: It is the information delivery manual (idm) (sometimes referred to as an information delivery specification (ids)) that identifies the series of processes undertaken during a built asset's lifecycle together with the information that is required in order for these processes to be carried out.

IFD: Information framework for dictionaries (ifd) is a mechanism (standard) that facilitates creating multilingual dictionaries, terminologies, or ontology's. Ifd provides a feasible method to link ifcs (based bim) to existing knowledge systems, project and product specific databases, etc.

IFC: The industry foundation classes is a cad data exchange data schema intended for description of architectural, building and construction industry data. It is a platform-neutral, open data schema specification that is not controlled by a single vendor or group of vendors.

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ISO29481-1:2010: Organization and digitization of information about buildings and civil engineering works, including building information modeling (bim).

ISO 19650: Iso 19650 forms part of the uk bim framework, the overarching approach to implementing bim in the uk. Conforming to iso 19650 means that you are aligned to the uk information management mandate. Products & services.

IFCOWL: Ifcowl provides a web ontology language (owl) representation of the industry foundation classes (ifc) schema. Ifc is the open standard for representing building and construction data (see buildingsmart). The ifcowl ontology has the same status as the express and xsd schemas of ifc.

IFCXML: Fc-xml is an xml format defined by iso 10303-28 ("step-xml"), having file extension ". Ifcxml". This format is suitable for interoperability with xml tools and exchanging partial building models. Due to the large size of typical building models, this format is less common in practice.

IPFS: The interplanetary file system is a protocol, hypermedia and file sharing peer-to-peer network for storing and sharing data in a distributed file system. Ipfs uses content-addressing to uniquely identify each file in a global namespace connecting ipfs hosts.

JSC Mars-1a: This low-ti lunar mare simulant was originally named johnson space center one (jsc-1) and was later replicated as jsc-1a. Jsc-1/1a is crushed from basaltic ash (jsc-1/1a source material) mined at flagstaff, arizona. Minimally processed jsc-1/1a source material is also available as a lunar mare simulant.

LC: Lifecycle bim is the practice of creating, maintaining and utilizing building information to manage operations and maintenance of buildings throughout their operational lifecycles. Facility managers are finding value in a number of areas of building operations that benefit from enhanced data. Bim lifecycle participants.

LCA: Life-cycle analysis (lca), also known as life-cycle assessment, is a primary tool used to support decision-making for sustainable development. According to the u.s. environmental protection agency, lca is a tool to evaluate the potential environmental impacts of a product, material, process, or activity.

LOD: The level of development (lod) specification is a reference that enables practitioners in the aec industry to specify and articulate with a high level of

clarity, the content and reliability of building information models (bims) at various stages in the design and construction process.

MDV: A multivariate data visualization tool for clinical laboratory data and other time-varying continuous measurements.

MVD: A model view definition (mvd) is a subset of the overall ifc schema to describe data exchange for a specific use or workflow, narrowing the scope depending on the need of the receiver.

MPa: Megapascal (abbrev. Mpa) - a basic unit of pressure or tension measurement in the international system of weights and measures. 1 mpa = 145 psi, 1 mpa = 1 n/mm². For oil field applications, units of measurement smaller than 1 psi usually have little meaning.

MAWD: Based on measurements made by the curiosity rover, the corresponding figure for the surface of mars is approximately 230 msv/year. More generally, one model estimated that the dose equivalent rate on the surface of mars ranges from 156.4 msv/year (at solar maximum) to 273.8 msv/year (at solar minimum).

NG: Next-Gen·Er·A·Tion 'nekst·je-Nə-'rā-Shən. Variants Or Less Commonly Next Generation. : Of Or Relating To A Potential, Forthcoming, Or Brand-New Version Of An Existing Product Or Technology : Next-Gen. The Older Hardware Companies Don't Have The Field To Themselves.

Node: A blockchain node is a device, usually a computer, that participates in a blockchain network. It runs the blockchain protocol's software, allowing it to help validate transactions and keep the network secure. Blockchain nodes communicate with each other. The more nodes there are, the more decentralized the network is.

NAT: Nat stands for network address translation. It's a way to map multiple private addresses inside a local network to a public ip address before transferring the information onto the internet. Organizations that want multiple devices to employ a single ip address use nat, as do most home routers.

NPSA: The national protective security authority, formerly the centre for the protection of national infrastructure, is the national technical authority in the united kingdom for physical and personnel protective security, maintaining expertise in counter terrorism as well as state threats.

NBIMS: The national bim standard-united states™ (nbims-us™) provides consensus-based standards through referencing existing standards, documenting

information exchanges and delivering best business practices for the entire built environment.

NBS: Nbs is a uk-based business providing construction specification information used by architects, engineers and other building professionals to describe the materials, standards and workmanship of a construction project. It was launched in 1973 and its information is now used by over 5000 offices.

NaCL: Sodium chloride, also known as salt, common salt, table salt or halite, is an ionic compound with the chemical formula nacl, representing a 1:1 ratio of sodium and chloride ions. Sodium chloride is the primary salt in seawater and in the extracellular fluid of many multicellular organisms.

NIST: The national institute of standards and technology is an agency of the united states department of commerce whose mission is to promote american innovation and industrial competitiveness.

NASA: The national aeronautics and space administration is an independent agency of the u.s. federal government responsible for the civil space program, aeronautics research, and space research.

NOSQL: Nosql is an approach to database management that can accommodate a wide variety of data models, including key-value, document, columnar and graph formats. A nosql database generally means that it is non-relational, distributed, flexible and scalable.

OMNICLASS: Omniclass is a comprehensive classification system for the construction industry, encompassing key elements of both masterformat® and uniformat® for building lifecycle and project management.

OPENBIM: Openbim extends the benefits of bim (building information modeling) by improving the accessibility, usability, management and sustainability of digital data in the built asset industry. At its core, openbim is a collaborative process that is vendor neutral.

Phyton: Python is a high-level, general-purpose programming language. Its design philosophy emphasizes code readability with the use of significant indentation. Python is dynamically typed and garbage-collected. It supports multiple programming paradigms, including structured, object-oriented and functional programming.

POW: Proof of work (pow) is a decentralized consensus mechanism that requires network members to expend effort in solving an encrypted hexadecimal number.

Proof of work is also called mining, in reference to receiving a reward for work done.

POS: Proof-of-stake protocols are a class of consensus mechanisms for blockchains that work by selecting validators in proportion to their quantity of holdings in the associated cryptocurrency. This is done to avoid the computational cost of proof-of-work schemes.

P2P: Peer-to-peer computing or networking is a distributed application architecture that partitions tasks or workloads between peers. Peers are equally privileged, equipotent participants in the network, forming a peer-to-peer network of nodes .

PBFT: Practical byzantine fault tolerance (pbft) an optimization of bft, introduced by miguel castro and barbara liskov in 1999, implemented in modern systems to improve performance and security. Pbft algorithm. Works under the assumption that less than 1/3 of the nodes are malicious.

PKIS: A public key infrastructure is a set of roles, policies, hardware, software and procedures needed to create, manage, distribute, use, store and revoke digital certificates and manage public-key encryption.

PIM: Product information management is the process of managing all the information required to market and sell products through distribution channels. This product data is created by an internal organization to support a multichannel marketing strategy.

PAS 1192-5:2015: Pas 1192-5:2015 is a specification for security-minded building information modeling (bim), digital built environments and smart asset management.

PLC: A programmable logic controller (plc) or programmable controller is an industrial computer that has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, machines, robotic devices, or any activity that requires high reliability, ease of programming, and process fault diagnosis.

RFID: Rfid (radio frequency identification) is a form of wireless communication that incorporates the use of electromagnetic or electrostatic coupling in the radio frequency portion of the electromagnetic spectrum to uniquely identify an object, animal or person.

SCP: While it's tempting to dismiss the scp as some crazy conspiracy website, the administrators clearly and frequently acknowledge that the foundation is

essentially an art and creative writing experiment. In their words, "the foundation, "its anomalies, and everything else that's been written about is fictional.

SDT: Self-determination theory (sdt) is a motivational theory of personality, development, and social processes that examines how social contexts and individual differences facilitate different types of motivation, especially autonomous motivation and controlled motivation, and in turn predict learning, performance

SPIE Spie is an international not-for-profit professional society for optics and photonics technology, founded in 1955.

SQL: Structured query language (sql) is a programming language for storing and processing information in a relational database. A relational database stores information in tabular form, with rows and columns representing different data attributes and the various relationships between the data values.

SMES: Small and medium-sized enterprises or small and medium-sized businesses are businesses whose personnel and revenue numbers fall below certain limits. The abbreviation "sme" is used by international organizations such as the world bank, the oecd, european union, the united nations, and the world trade organization.

SB: A smart building converges various building-wide systems—such as hvac, lighting, alarms, and security—into a single it managed network infrastructure. It often uses foundational technology such as power over ethernet (poe) to accomplish this convergence.

Space shuttle: The space shuttle is a retired, partially reusable low earth orbital spacecraft system operated from 1981 to 2011 by the u.s. national aeronautics and space administration as part of the space shuttle program.

SCADA: Supervisory control and data acquisition (scada) systems are used for controlling, monitoring, and analyzing industrial devices and processes. The system consists of both software and hardware components and enables remote and on-site gathering of data from the industrial equipment.

TLS: Transport layer security is a cryptographic protocol designed to provide communications security over a computer network. The protocol is widely used in applications such as email, instant messaging, and voice over ip, but its use in securing https remains the most publicly visible.

UNL: Unls are the lists of validators a given participant believes will not conspire to defraud them. Each server operator can choose their own unl, usually based on

a default set provided by a trusted publisher. (a default set from a publisher is sometimes called a default unl, or dunl.

UNICLASS: Uniclass is a unified classification system for the built environment covering all sectors and roles, delivered by nbs. Uniclass classification specification.

VM: In computing, a virtual machine is the virtualization or emulation of a computer system. Virtual machines are based on computer architectures and provide the functionality of a physical computer. Their implementations may involve specialized hardware, software, or a combination of the two.

XHTML: Extensible hypertext markup language (xhtml) is part of the family of xml markup languages which mirrors or extends versions of the widely used hypertext markup language (html), the language in which web pages are formulated. Xhtml. Filename extension. .xhtml, .xht, .xml, .html, .htm.

ZK-SNARKS: The most well-known example of zk-snarks is their use in shielding cryptocurrency transactions. Zcash is the first widespread application of zk-snarks. This privacy coin allows users to choose between private and transparent addresses. When a user chooses a private address, zk-snarks shield the transaction data.