

UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Arquitectura de Madrid



Digital Interactions:
Architecture for the Augmented Era.

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Álvaro López Rodríguez
Master of Architecture

Madrid, 2025



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Doctoral Degree in Advanced Architectural Projects

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Under the supervision of:
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Author: Álvaro López Rodríguez

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Thesis Supervision: Dr. José Luis Esteban Penelas, Catedrático de Proyectos Arquitectónicos. Universidad Europea de Madrid.

External Reviewers: Dr. Milad Showkatbakhsh & Dr. Özgüç Bertuğ Çapınaman & Dr. Diego Pinochet Fuentes

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Abstract

The rapid transformation of society into a fully digital state is reshaping the manufacturing industry and the built environment. The integration of automation robotics and 3D printing technologies is challenging the conventional notion of architecture and its historical construction techniques. Additionally, the social changes resulting from this transformation, coupled with the growing urbanisation trend, are impacting the local population and their preservation of identity and cultural heritage. As a consequence, workers in mainstream construction companies are becoming more homogeneous, and the distinctiveness of artisans and skilled craftsmen is diminishing in favour of a more efficient and profitable construction sector. These changes are driving the emergence of a technology-focused building industry that is losing its human touch and heritage. Traditional craftsmanship and building techniques are disappearing, replaced by technological systems that disregard and overlook local knowledge and expertise. Simultaneously, the significant shifts in manufacturing labour brought about by the digital revolution are exacerbating the loss of traditional skills and craftsmanship. The workforce is migrating to other industries, jeopardising the preservation of local communities' skilled labour. Consequently, access to skilled labour is increasingly limited, particularly in less developed or remote areas. The once diverse ecosystem of the built environment is gradually diminishing, promoting uniformity that compromises architectural diversity and identity, thereby impeding the conservation of historical heritage. Traditional practices face a critical juncture where adaptation to the digital society is essential for their survival. However, technology may hold the solution to the erosion of knowledge and skills. The notable advancements in Augmented Reality (AR) technologies over the past decade, along with the parallel development of Mixed Reality (MR), could profoundly impact how manufacturing skills are recorded, archived, and transmitted in the future. Moreover, these technologies offer the potential for seamless integration from digital design to fabrication. Consequently, the preservation of traditional methods can be ensured by incorporating them into the digital society. This approach also fosters the concept of the humanistic creator who engages in the entire process, from design to fabrication. This situation presents an opportunity to empower local labour and reinstate the significance of craftsmanship. In this context, this thesis introduces a novel architectural model that seeks to preserve traditional making and building methods while integrating traditional knowledge with digital design by implementing Mixed Realities in the

built environment. The thesis will examine this new approach through the analysis of six architectural experiences that demonstrate how the utilisation of Augmented Reality in manufacturing and construction can establish a distinctive ecosystem and compare it with automation and mainstream design. Ultimately, this thesis will establish a new paradigm of design rooted in values that can infuse digital design with the human factor it is currently lacking while simultaneously empowering and safeguarding local communities and heritage within a digital framework.

Resumen

La cada vez más rápida transformación de la sociedad hacia un estado completamente digital está cambiando la forma de la industria de manufactura y la edificación. La inclusión de tecnologías como la automatización, la robótica o la impresión 3D está alterando la concepción tradicional de metodologías de construcción históricas. A su vez, los cambios sociales derivados de este escenario y el incremento de la migración hacia las ciudades están afectando a las poblaciones locales y su preservación de la identidad y tradiciones. La mano de obra se está homogeneizando a través de corporaciones de la construcción, y la prevalencia del constructor o el artesano está siendo diluida en reemplazo de una industria de la construcción más eficiente y rentable. Estos cambios están también empujando a la arquitectura hacia un nuevo tipo de industria de la construcción centrada en tecnología que a su vez está perdiendo el factor humano así como sus tradiciones. Las técnicas antiguas y tradicionales de manufactura están desapareciendo, siendo reemplazadas por sistemas tecnológicos que niegan y olvidan el conocimiento de construcción y fabricación local. A su vez, los importantes cambios en los trabajadores de fabricación derivados de la revolución digital están acentuando la pérdida de artes tradicionales y el conocimiento de artesanía. La fuerza laboral está migrando hacia otras industrias y la preservación de comunidades locales está en riesgo. Como resultado, la limitación del acceso a trabajadores formados está en aumento, especialmente en las zonas menos desarrolladas o remotas. La hasta ahora variada ecología de la edificación está decreciendo lentamente, promoviendo uniformidad y afectando la diversidad y la identidad de la arquitectura, dañando la conservación del legado cultural e histórico. Las formas tradicionales están en un momento crucial donde adaptarse a la sociedad digital es esencial para garantizar su supervivencia.

Por otra parte, la solución a la pérdida de conocimiento y habilidades podría estar en la tecnología. El interesante avance de la tecnología de realidad aumentada durante la última década y el desarrollo en paralelo de las Realidades Mixtas podrían tener un impacto notable en la transmisión de habilidades de fabricación en el futuro. A la vez, estas tecnologías abren la posibilidad de una integración directa desde el diseño digital hasta la fabricación. Como resultado, la supervivencia de los métodos tradicionales puede asegurarse integrándolos dentro de la sociedad digital. Este modelo también promueve el concepto del creador humanístico que participa en todo el proceso desde el diseño hasta la fabricación.

Esto supone una oportunidad para empoderar a los trabajadores locales y recuperar la importancia del artesano.

En este escenario, esta tesis se presenta como una introducción a un nuevo modelo de arquitectura que, a través de la implementación de las Realidades Mixtas en edificación, pretende preservar las formas tradicionales de fabricación y construcción a la vez que integra el conocimiento tradicional con el diseño digital. Este trabajo analizará este nuevo enfoque a través del estudio de seis experiencias arquitectónicas que ilustran cómo el uso de la Realidad Aumentada en fabricación y construcción puede proponer una ecología única y cómo estos se comparan con la automatización y el diseño convencional. En esencia, la tesis establecerá una nueva forma de diseño basada en valores que puede proveer a la arquitectura digital del factor humano que está perdiendo y, simultáneamente, empoderar y preservar comunidades locales y patrimonio cultural en un entorno digital.

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Abbreviations and Acronyms

UPM	Universidad Politécnica de Madrid
AR	Augmented Reality.
XR	Extended Realities
MR	Mixed Realities
CAD	Computer Aided Drawing
BIM	Building Information Modelling
CAM	Computer Aided Manufacturing
CNC	Computer Numerical Control
AEC	Architecture, Engineering, and Construction
HUD	Head Mounted Display
AI	Artificial Intelligence

1. Introduction

The field of architecture is a vast environment where many professions, arts, and technologies intersect. Digital technology has had a significant impact in recent decades and has transformed the profession since its implementation. With digital technologies now moving beyond CAD towards more interactive options like Artificial Intelligence or Mixed Realities, it is essential to understand the potential evolution of the profession. This thesis aims to explore the implementation of Augmented Reality technology in architecture. It will address key questions regarding its potential impact on the field and how it can be effectively utilised. Additionally, the risks and benefits of using this technology will be analysed, and the current state of the art will be reviewed.

The thesis is divided into five stages to address the matter. The knowledge is contextualised and analysed, and conclusions and discussions are elaborated.

The first section will introduce the questions and how they will be dealt with throughout the thesis. It will also establish a specific glossary to help readers not only understand the words but also their meaning within the thesis scope.

The second section of the thesis reviews the historical evolution of craftsmanship, automation, and augmentation within architecture. This historiography seeks to understand the significance of these elements in shaping the industry's current state in connection with the thesis. The examples do not represent a complete chronology but a selected series that will help to understand the overall approach towards the technology and its analysis.

The third section of this project is focused on developing and establishing the socio-political context, as well as defining the fundamental areas that Augmented Reality is connected with. It aims to define relevant positions towards the use or implementation of this technology, along with other relevant ideas. This section will then determine the framework and identify the principal concepts to be reviewed through practical examples.

The fourth section of the thesis includes the definition of the methodology and an analysis of relevant case studies. This section focuses on defining a system that characterises the value of technology for architecture and how it is used to determine the impact and achievements of the proposed case studies. The case

studies are selected to illustrate how augmented reality can change traditional architectural processes and materials.

The fifth and final section of the study comprises the results and discussion. This section will help extract conclusions and data from the study cases. It will evaluate how the study cases have implemented Augmented Reality with the methodology system and then assess the results. The discussion will then analyse the results and speculate about the potential of AR in the architecture industry and how it can be integrated into the mainstream industry.

1.1. Research Questions and Hypothesis

The architecture field is currently facing significant challenges due to the increasing use of digital technologies, automation, and prefabrication methods. These factors have led to industrialisation and homogenisation, which have caused some concerns among architects, academics, and the broader architectural community. In order to tackle these challenges, they need to critically examine the issues and respond thoughtfully.

One of the major challenges the field is currently facing is the industrialisation of architectural processes, which is being driven by digital technologies. The use of Computer-Aided Design, Building Information Modeling, and parametric design tools has sped up the design process, making it possible for architects to create complex geometries and optimise structural systems. However, this can also lead to the homogenisation of architectural forms, as standardised software packages and algorithms can encourage repetitive design solutions, diluting architectural diversity and creativity.

Another challenge is automation in construction processes, which raises concerns about the diminishing role of skilled labour in architecture. Prefabrication and robotic construction technologies promise increased efficiency and cost-effectiveness, but they also risk sidelining traditional craftsmanship and reducing the diversity of construction methods and materials. This shift towards automation challenges architects to reconsider their role in construction and advocate for the preservation of craft and artisanal skills that contribute to architectural richness.

Furthermore, the reliance on prefabrication and digital technologies can lead to a sense of further architectural homogenisation, which is a significant concern. The use of standardised modular components and off-site manufacturing can result in the replication of building typologies and aesthetics across diverse contexts, eroding the uniqueness of local architectural identities. This raises questions about architectural designs' cultural and contextual relevance in an era dominated by industrialisation and digital uniformity.

Another relevant factor is that industrialisation and homogenisation of architecture also have ethical implications. The pursuit of efficiency and cost savings through automation and prefabrication may prioritise economic interests over social and environmental sustainability. Architects have a responsibility to

consider the broader social and environmental consequences of their architectural choices beyond the design phase.

The last matter is the impact that the loss of skilled labour and its centralisation in industrial poles can have on the preservation and continuation of local crafting traditions and, therefore, the conservation of the historical heritage of traditional communities. The prevalence of homogenised techniques and the skilled worker's migration represent a risk for the survival of these forms of architectonic expression.

The central hypothesis of this thesis is that the use of Augmented Reality in architecture and craftsmanship can have a positive impact on dealing with the questions mentioned above. This research aims to explore the possibilities and challenges of AR in the field of architecture. To achieve this, the thesis sets out to answer the research questions by establishing a series of goals. The methodology constructed will evaluate and discuss the potential, the challenges, and the unknowns posed by augmented reality technology.

The first goal of this thesis is to create a methodology to understand how to analyse and qualify augmented architecture. It is crucial to assess the challenges and obstacles that may arise during the implementation of augmented reality technologies in architectural practice. One of the main tasks of this thesis is to address these challenges systematically. These challenges can include technical limitations, user adaptation, ethical issues, and data security concerns. By identifying and articulating these challenges, this study aims to pave the way for practical solutions.

The second goal of this thesis is the creation of a systematic framework for evaluating the impact of augmented reality on traditional craftsmanship roles in architecture. As AR technologies are integrated into the architectural workflow, it is essential to understand their influence on the skills and roles of craftsmen and artisans. This evaluative framework will serve as a tool to comprehend the changing landscape of traditional craftsmanship in the context of augmented reality.

The third goal of this thesis is to speculate on the future implications of augmented reality in architecture by considering technological advancements, social shifts, and architectural trends. By envisioning scenarios where AR might become an indispensable tool in architectural design and construction, this analysis aims to

inform architectural practice by anticipating potential developments and opportunities.

This thesis embarks on a comprehensive academic exploration of augmented reality's integration into architecture. It endeavours to uncover its latent potential, confront its challenges, devise an evaluative system to assess its impact on traditional craftsmanship and speculate on its future utility. By addressing these multifaceted aspects, this research seeks to contribute significantly to the discourse on technology-driven transformations in the architectural field, offering insights and guidance for architects and scholars alike.

1.2. Definition of the Classes:

The following set of classes is meant to be a way to contextualize the thesis here presented by establishing a brief description of the mainframe topics. Every definition of this array pretends to be a micro manifesto to define the position and use of the classes across the main thesis. Although some of them will be developed into a more profound analysis later in the program, they are meant to be a quick guide to better understand a rhizomatic approach to the research.

Digital Architecture.

The historiographical analysis offers a multitude of methodologies and approaches to categorise and delineate the various stages and styles that emerge through the evolution of architectural design. The manner in which these historical architectural styles—whether connected to a specific ancient civilisation or a distinctive aesthetic—are named and classified is grounded in comprehensive scholarly research and consensus. Such classifications trace the progression from Romanesque architecture to the Neo-Gothic and classical forms, indicating a widely accepted terminology for each (Benevolo, 1980; Frampton, 1995). The terminology employed for each style is not merely arbitrary but rather meticulously defined and consistent over time.

In the analysis of a historical entity, scholars and architects can effortlessly categorize its architectural lineage through the examination of specific structural and ornamental elements such as columns, arches, vaults, and motifs. A systematic criterion facilitates the identification of a given architectural style. For instance, pointed arches, slender columns, and ribbed vaults commonly denote Gothic or Neo-Gothic influence (Banister, 1980). Such features not only provide a visual cue but also substantiate the building's architectural heritage, often precluding debates about its stylistic essence.

Notably, the consistency and clarity of this naming protocol have not sparked significant contention. This assertion holds true not only for ancient architectural designs but also for more contemporary structures up until the late 20th century. Indeed, architectural classifications such as Post-Modernism and High-Tech, which emerged prominently during the latter half of the 20th century, are now instantly recognisable in urban landscapes (Jencks, 1993; Sudjic, 2017). Similar to

their historical counterparts, these more recent styles often present a cohesive array of structural and conceptual components, typically dictated by the guiding manifestos or philosophies of their respective movements (Venturi, 1966).

The traditional means of rationalising architectural evolution, rooted in clear stylistic distinctions and categorisations, is increasingly being regarded as anachronistic in contemporary discourse. The beginning of the 1990s heralded a paradigmatic shift, with computer-aided architectural design engendering a dilution of distinct styles and a transition to regulations governed predominantly by local technical codes (Kolarevic, 2005). Consequently, there has been an intense debate regarding the appropriate categorisation of architecture crafted over the past three decades.

In the current architectural environment, some scholars speculate that we inhabit the era of the "Starchitects." In this paradigm, instead of conforming to a singular, universally recognised style, there emerges a confluence of varied aesthetics, each tethered to specific, influential architectural firms (Picon, 2010). In essence, this theory suggests a scenario akin to postmodernism, where individual "Starchitects" devise a repertoire of signature elements, subsequently appropriated and reinterpreted by other firms, reminiscent of how postmodernists engaged with classical orders in earlier decades (Jencks, 1993).

There is an opposing viewpoint to the idea that contemporary architecture simply reflects a Neo-Liberal, Post-Postmodern sensibility. This perspective argues that contemporary architecture embodies a distinct set of aesthetic principles. Proponents of this view believe that these principles are not just influenced by modern perspectives and technological advancements but are fundamentally shaped by them. Therefore, instead of simply being aided by computation, this "Experimental Architecture" is inherently computational at its core, representing a synthesis of innovative design strategies and digital technologies (Terzidis, 2006).

In the contemporary era of architectural discourse, as the profession traverses the complexities of the digital age, there has been a profound reconceptualisation of traditional norms and conventions. The once well-demarcated styles are undergoing rigorous scrutiny, adaptation, and evolution. A pivotal question persists: Will this transformation manifest as a distinctly new paradigm termed "Experimental Architecture," or will it be an extension of the architectural

philosophies propelled by eminent "Starchitects"? This dilemma remains at the forefront of scholarly exploration and debate.

An illustrating model to explain the notion of Experimental or "Digital Architecture" can be found in Mario Carpo's work, "The Digital Turn" (Carpo, 1992). Carpo delineates an emerging phase in architectural practice where shared aesthetic sensibilities or tangible design elements do not necessarily unite practitioners. Instead, they converge upon a conceptual framework in which computation emerges not merely as a tool but as a transformative language capable of generating novel architectural lexicons. This evolution transcends the paradigm of computer-aided design, metamorphosing into a computational-centric methodology of both design and fabrication. A noticeable distinction of "Digital Architecture" is its challenge to the traditional, branched relationship between design and manufacturing. It pictures an integrative *modus operandi* in which both realms are seamlessly interlinked through computational logic, culminating in mutual enhancement and optimisation (Kolarevic & Malkawi, 2005).

The quintessence of this ethos can be discerned in architectural marvels such as the pavilions showcased at the Tallinn Biennale in 2017 and 2019. While their aesthetic sensibilities and design philosophies might starkly diverge, both adopt a unified, computation-centric approach to project development.

For the purposes of nomenclatural clarity, especially within the context of broader discussions, the term "Digital Architecture" is given as a pragmatic classification. Though not universally standardised, it presents a coherent and intuitive descriptor encapsulating the aforementioned architectural paradigm, making it accessible to both the specialist and the amateur.

Parametric Design and Computational Design.

In the intricate and evolving glossary of architectural discourse, terminologies such as "Digital Architecture," "Parametric Design," and "Computational Design" have spurred extended deliberation regarding their fundamental distinctions. Central to this thesis is Mario Carpo's interpretation of these terms, which will serve as a foundational reference for discerning their usage and implications within the framework of this work (Carpo, 1992).

Parametric Design is characterised as a design methodology predicated on predefined, determinate algorithms. The utilisation of specific parameters within

these algorithms often creates anticipatable design outcomes. An intrinsic flexibility of this approach is the amenability of the design to real-time modifications through parameter adjustments. However, while this modality offers tangible operational efficiency, its computational scope remains restricted to the explicit values of the parameters. The design's suitability and validity are largely contingent on the designer's discretion, positioning parametricism primarily as a tool for streamlining the design process rather than ensuring the inherent efficacy of the design itself (Woodbury, 2010).

Computational Design operates using an algorithmic basis that processes input data holistically. Instead of evaluating data individually, a combined analysis of data values leads to the creation of an optimal design solution. However, this design philosophy doesn't support real-time interactive changes, which could limit the inherent fluidity of the design process. Additionally, the designer's role becomes less prominent as the algorithm independently navigates the design trajectory. Computational design aims to achieve optimal outcomes through an iterative process that responds to predefined criteria. If there's a need to modify the resulting design from the designer's perspective, it requires a change in the governing algorithm. Therefore, while parametricism enhances process efficiency, computational design aims for the utmost efficiency of the resulting architectural proposal (Kolarevic, 2003).

In the expansive domain of architectural discourse, especially within the digital realm, distinguishing between Parametric and Computational Design becomes imperative. Though their differences might appear subtle, these distinctions form the base for comprehending the evolving paradigms of architectural design methodologies in the technologically-driven age (Kolarevic, 2003).

Both these methodologies, in their unique ways, contribute immensely to the ethos of Digital Architecture, emphasising a comprehensive approach to design interlaced with data-centric interactions. Regardless of whether an architect leans toward a parametric or computational strategy, the resulting design outcome invariably possesses a signature that can only be attributed to the algorithmic prowess. A defining trait shared by both approaches is their foundation in digital origins, representing a shift from traditional design methods.

However, it is the real-time dynamism that stands out as a primary differential. With its inherent adaptability, Parametricism caters to the traditional "artist's eye" approach to design. This is evident in fluid architectural manifestations such

as Zaha Hadid's MAXXI Museum in Rome or the adaptive design elements showcased in BIG's Serpentine Pavilion. On the other hand, Computational Design, governed by a precision-driven ethos, results in highly optimised architectural solutions. This meticulous precision can be observed in projects like the structural explorations by the Block Research Group or the intricately detailed constructs of Digital Grotesque I and II (Gramazio & Kohler, 2016).

It is pivotal to acknowledge that neither approach is categorically superior or inferior. Instead, they represent the diverse facets of the overarching paradigm of Digital Architecture. The sensible deployment of either or both methodologies is contingent on the project's specific objectives and the design ethos being pursued. In many instances, the harmonious blending of both parametric and computational techniques can lead to pioneering architectural solutions (Oxman & Oxman, 2014).

Digital Manufacturing.

Digital Manufacturing, by a foundational definition, incorporates a spectrum of fabrication technologies that draw, either in part or wholly, from digital data and incorporate some form of automation within their operational mechanics (Rosen et al., 2015). Demonstrations of this can be observed in the ubiquitous deployment of CNC (Computer Numerical Control) reliant manufacturing modalities such as milling, 3D printing, and laser cutting. While these are not novel techniques per se, their proliferative adoption, especially in the context of digital architecture, is revolutionising traditional construction practices.

The architectural domain's manufacturing spectrum is profoundly extensive, ranging from artisanal craftsmanship at the micro-level to the macro dynamics of building architectural products. Historically, the architectural manufacturing paradigm operated on a segmented structure, in which professionals specialised in particular scales or niches, rarely venturing beyond their immediate area. For instance, experts in crafting intricate small-scale artefacts would seldom be involved in the complexities of large-scale construction. Digital Manufacturing, however, destabilises this compartmentalised attitude. Whether a minuscule component or a monumental structure, the computational and digital competencies required to create essentially remain consistent. The technological principles underpinning the assembly of, say, a microcircuit and an automobile are strikingly analogous (Burry, 2011). This uniformity of principle offers intriguing prospects in architecture, where scaling mechanisms—transitioning from

prototypical endeavours to full-blown commercial applications—can be seamlessly realised. In relation to the thesis at hand, this seamless scalability paves the way for the gradual transformation of traditional handcrafted techniques into digitally driven, streamlined manufacturing operations.

Moreover, within the horizon of Digital Manufacturing emerges the potential for mass customisation in prefabrication, a symbiosis facilitated by the union of digital design methodologies. The inherent capability of Digital Manufacturing to accommodate nuances or variances within the production of a singular component augments its adaptability share. This, in turn, promotes the assimilation of time-based vernacular techniques, enabling an enhanced optimisation of outcomes and making it a powerful tool for contemporary architectural practices (Kieran & Timberlake, 2004).

Distributed Manufacturing

Prefabrication, as a foundational principle in architecture, traces its lineage far back into the annals of the construction sector. This principle revolves around the principles of fabricating constituent elements at places distinct from their eventual integration site (Kieran & Timberlake, 2004). The contemporary period, synonymous with advanced manufacturing, has witnessed the rise of dedicated facilities—factories or workshops—orchestrating these prefabrication endeavours. Production narratives have conventionally adhered to a linear, rigidly defined schema in these settings.

However, the arrival and proliferation of Digital Manufacturing technologies have catalysed a paradigmatic shift, facilitating the engagement of more small players within the manufacturing field. This transformative perspective offers a localised manufacturing narrative, decentralising the process to involve smaller factories or artisanal workshops (Wu et al.2015).

Along with this, the nexus between manufacturer and consumer has emerged as a focal axis of this new manufacturing dynamic. Historically, the architectural goods sector remained predominantly under the guidance of a select group of large conglomerates, empowered with the requisite infrastructure for mass-producing prefabricated components. The contemporary landscape, however, reinforced by digital platforms, not only augments the connectivity between artisans and their clientele but also democratises the marketing arena for smaller manufacturers.

Such platforms spawn a decentralised manufacturing ecosystem, proliferating accessibility to diverse sources of architectural goods (Benkler, 2006).

The thesis emphasises the importance of decentralisation. It highlights the value of end-users being able to easily connect with local workshops that can produce customized products using digital manufacturing. This approach prioritises distributed manufacturing, which optimises local resources, supports local businesses, drives economic growth, and enhances infrastructure in previously underserved areas (Mota, 2011).

Mixed Realities.

The exploration of realities beyond our tangible existence has long captivated human imagination, dating as far back as our earliest cognitive consciousness. Throughout antiquity, numerous cultures have postulated the existence of intangible realms, spaces that extend beyond our physical world (Eliade, 1954). These speculative realities often embraced diverse interpretations, from utopias to dystopic realms, thereby catering to the spiritual and philosophical aspirations of societies that conceptualised them. These realms, often woven into folklore and mythological narratives, served as metaphysical projections of human desires, anxieties, and ideals.

Contemporaneously, this continuing fascination with alternate realities has seamlessly transitioned and found resonance in the space of digital technologies. In much the same line as their ancestral counterparts, modern societies envision virtual realms that delve deep into philosophical challenges and spiritual discourses. However, today's distinction lies in the transformative capacity of digital hardware and computer graphics technology, which transforms these speculative environments from mere mental constructs to tangible, visually mediated experiences (Bostrom, 2003).

Foremost among these technological advancements are the innovations in virtual reality and augmented reality. These tools serve as portals, inviting users to traverse and interact with dimensions previously deemed fantastic. Renowned futurist Michio Kaku contends that augmented technologies stand poised to revolutionise our interaction modalities, melding the digital and physical domains into a cohesive continuum (Kaku, 2011). This mixture is expected to blur the line between the virtual and the real, creating significant implications for various aspects of our socio-cultural fabric.

The sphere of Extended Realities, as conceptualised by Paul Milgram, delineates a futuristic socio-technological panorama in which the tangible "real world" mixes seamlessly with the constructed "virtual world," forging an unbroken continuum of experiential spaces (Milgram & Kishino, 1994). Such an amalgamation, while profoundly transformative, establishes a shift in the collective human consciousness, reshaping not only our perceptual matrix but also how we navigate and operationalise within this intertwined reality. The implications of XR are far-reaching, harbouring the potential to recalibrate the paradigms of design, construction, and the very inhabitation of architectural spaces.

Within the territory of the thesis, XR is referred to not merely as a technological concept but as a theoretical lens through which architectural craftsmanship's evolution and future trajectory can be scrutinised. The research postulates a renaissance in architectural practices by examining the possibilities that technologies such as augmented reality, artificial intelligence, and computer vision usher in. These digital interventions can harmoniously merge computational design with manual fabrication processes, thereby amalgamating the precision of technology with the nuances of handcrafting. Central to this discourse is the reconceptualisation of architecture, picturing it as a discipline that, through AR and related technologies, can reclaim its artisanal essence, which has been historically intrinsic to its identity (Jahn, G. 2022).

This resurgence of craftsmanship, mediated through XR, represents a new era in which architectural designs don't merely exist as physical or virtual entities but thrive at the confluence, embodying the best of both realms.

Democratic Skills.

The transference of expertise and mastery through associations, collectives, or cultural principles has been a permanent facet of human civilisation since its emerging stages. Historical records highlight the existence of early guild-like formations in ancient civilisations such as Sumer and Egypt (Kramer, 1963). Within these societies, artisans and experts of various vocations gravitated towards urban areas, fostering a symbiotic ecosystem where labour was streamlined and the population could access skilled craftsmanship with greater ease. The Roman Republic marked a pivotal moment in this evolution, instituting the "Collegia," thereby adding layers of formality and structure to these professional unions (Harper, 2001). Such establishments paved the way for what

would transform into the revered academic institutions of the medieval era, laying the foundation for universities and colleges.

As history transitioned from the medieval period to the modern era, guilds began to wield formidable influence, not merely as custodians of craft but as gatekeepers of professional domains. These guilds evolved into regulatory entities, governing aspects ranging from entry into a profession and methodological standards to the fiscal expectations of services rendered (Epstein, 1998).

In the modern environment, the manifestations of historical guilds have undeniably transformed. Yet, the fundamental objective of preserving and proliferating professional expertise remains entrenched in established institutions. Prestigious academic institutions, such as universities and vocational academies, as well as professional boards and syndicates, primarily function as the main repositories of vocational knowledge. While these entities have transitioned from once limited, elitist gateways to a more incorporating ethos via contemporary pedagogic systems, they undeniably establish barriers for numerous aspirants (Brint, 2002). The situation is made worse by the disappearance of the traditional relationship between apprentices and mentors, which used to be fundamental to artisanal professions. This could lead to a shortage of skilled labourers. This is not just a theoretical concern - it's already having real effects on specific areas within various industries.

In light of these dynamics, it becomes imperative to harness existing technological advancements to democratise and diffuse expertise to demographics previously marginalised. Innovations such as remote learning, virtual reality, and augmented manufacturing stand poised to recalibrate and broaden the scope of traditionally imparted knowledge and skills. By amalgamating these technologies with open-source platforms, there lies the potential to inaugurate a truly egalitarian framework for knowledge dissemination. Such an approach would empower individuals to assimilate essential competencies irrespective of geographical confines or socio-economic backgrounds (Hollands & Tirthali, 2014; Weller, 2014).

The Augmented Craft creator.

The employment of materials for crafting ornamental artefacts is an endeavour uniquely characteristic of human civilisation. Historically, the art of craftsmanship can be discerned from the earliest epochs, acting as a crucible in delineating distinctive cultural identities across the globe (Adamson, G. 2010). In fact, the localised disparities in artisanship have been instrumental in charting the developmental trajectories of diverse cultures, empires, and nation-states. This crafted heterogeneity, condensing both utilitarian and decorative spectrums, has been a cornerstone in the intricate tapestry of international trade, thus forging the shapes of our contemporary world (Appadurai, 1986).

Simultaneously, technological advancements have profoundly informed the transformation of artisanal methods and styles, generating an expanding pool of creative possibilities. The beginning of avant-garde machinery and techniques, coupled with the ensuing democratisation of knowledge and skills, precipitated a rapid and multifaceted evolution in the domain of craftsmanship (Risatti, 2007). In essence, technology not only enhanced the capabilities of artisans but also connected cultural divisions, enabling the dissemination and amalgamation of diverse craft traditions, thus exponentially amplifying the pace of artisanal evolution.

The latter part of the 20th century heralded the advent of augmented technologies and automation in non-military, mainstream contexts, catalysing a profound paradigm shift in the domain of crafting arts (Brynjolfsson & McAfee, 2014). Historically, the craftsman archetype was rooted in the rigours of apprenticeship, where experiential learning undergirded the journey to mastery and subsequent acknowledgement within their field. This archetype is undergoing a transformative recalibration, where the branches of digital technology are redefining traditional methodologies of creation (Dormer, 1997). Analogous to the way traditional design paradigms have been enriched by digital integrations, the classic craftsman's role is increasingly joined together with digital and automated processes.

One can observe that modern crafting is not just about physically creating an object, but also involves careful planning of the manufacturing process. A modern "Digital Craftsman" is expected to have expertise in both traditional handmade techniques and cutting-edge methods like CNC machining, 3D printing, and robotic manufacturing (Kostakis, Niaros, & Giotitsas, 2015).

However, this digital evolution has inadvertently erected a perceived dichotomy for consumers. They are presented with an ostensible choice between the rich authenticity of traditionally crafted artefacts and the precision of modern machine-manufactured items. The current binary perception that contrasts the warm, "unique" traits of handmade products with the consistency of automated creations has unintentionally limited the complete potential of integrating digital design into crafts. This often leads to it being mainly associated with automated processes (Pye, 1968). However, as the digital and traditional realms continue to converge, it is yet to be seen how this balance will evolve, potentially encouraging a more harmonious combination of both worlds.

Extended Realities represent a profound advancement in the realm of craftsmanship, effectively dismantling traditional dichotomies and ushering in the novel paradigm of the "Augmented Craft Creator" (Azuma, 1997; Milgram & Kishino, 1994). This emergent construct transcends the erstwhile boundaries, leveraging the potential of Skills Democratization that Augmented Reality generates. By synergising digital design principles with the tactile nuance of hand-based methodologies, these creators can craft digitally conceived yet distinctly unique artefacts (Billinghurst & Duenser, 2012).

This integration under the idea of AR offers a versatile matrix of fabrication in which craftspeople can oscillate between manual and automated processes while ensuring the indispensable "human touch" remains infused within the product. More interestingly, AR-based manufacturing unveils paths for executing intricate making sequences that remain elusive to conventional automated machinery or age-old techniques (Wagner, Billinghurst, & Schmalstieg, 2006).

At its core, the Augmented Craft Creator epitomises a harmonious confluence of the ancient and the avant-garde, offering a crafting culture that celebrates both heritage and innovation.

Augmented Devices

The capability of human skills has been paramount in shaping the trajectory of societal evolution and the means through which creations materialise. Interestingly, the quest for augmenting human prowess predates modern Homo sapiens, as evidenced by archaic hominids' employment of rudimentary tools (Ambrose, 2001). Delving into contemporary forms of augmentation, the Augmentation Library delineates two primary paths: Informative and Mechanical

(Engelbart, 1962). This thesis emphasises the significance and applicability of informative augmentation, particularly in augmenting and disseminating skills related to manufacturing and craftsmanship. Central to this exploration is the incorporation of Augmented Reality technology as the predominant medium.

The spectrum of hardware designed for AR experiences is diverse, bifurcating primarily into portable and external classifications. External devices encompass hardware capable of presenting AR insights but are confined geographically or to specific platforms, such as vehicles. Historically, the rudimentary reflection sights utilised in combat aircraft stand as pioneering exemplars of such mechanisms (Jones, 1995). Contemporary analogues include heads-up displays in automobiles or specialised screens facilitating augmented reality interactions. Given their longer historical lineage, such external devices have witnessed more widespread adoption and refinement. Notably, pioneering efforts in leveraging AR for assembly guidance predominantly employed these AR-integrated screens (Azuma, 1997).

Conversely, the portable category further separates into two subtypes: autonomous and non-autonomous. Autonomous devices operate independently, while non-autonomous ones rely on external inputs or devices for optimal functionality.

In the scope of augmented reality hardware, non-autonomous devices, while portable, are constrained by their inherent dependence on a more thorough computing apparatus. A prototypical exemplification of such devices is the Head Mounted Displays commonly used by fighter jet aviators. While these devices proffer essential portability by transmitting critical information directly to the pilot's line of sight, their tethered connection to the aircraft's computing system inherently limits unrestrained movement. Despite their influential role in the annals of augmentation history, the movement restrictions posed by these devices render them less ideal for widespread industrial applications, particularly in settings demanding uninhibited mobility.

In stark contrast, autonomous devices, exemplified by innovations like the HoloLens or Google Glass, support the principles of mobility and versatile functionality (Carmigniani & Furht, 2011). Such tools are designed to condense all necessary hardware components, facilitating the real-time projection of augmented information. The operational bandwidth of these devices spans a spectrum, ranging from rudimentary visualisation tasks to more intricate applications such as geolocation, as illustrated by the Trimble Navigation device

(Zhou, Duh, & Billinghamurst, 2008). Their intrinsic flexibility, coupled with their capacity to interface with diverse sensors and markers, defines them as preeminent instruments for augmented manufacturing. Their real-time feedback mechanisms, adaptive to varied environments and user interactions, can guide users across multifaceted tasks. Additionally, by monitoring and responding to user performance, they can revolutionise the fabric of the manufacturing continuum, catalysing a paradigm shift in how tasks are executed and optimised.

The deployment of hardware specifically tailored for augmentation, particularly within the realm of augmented reality, has increasingly emerged as a cornerstone for both augmented manufacturing and architecture. This transition is pivotal, not merely for the replication of existing craftsmanship paradigms but for the potential reinvention of these methodologies, catalysed by advances in artificial intelligence and sophisticated digital processes (Billinghurst, Clark, & Lee, 2015). Thus, it becomes imperative to closely scrutinise and chart the trajectory of hardware evolution, assessing its potential ramifications on the future landscape of manufacturing and craftsmanship in an augmented paradigm.

The present thesis pivots on the foundations established by contemporary hardware exemplars, such as the HoloLens 2. Yet, it is essential to underscore that the rapid pace of technological evolution mandates an exploratory approach that anticipates and even speculates upon the forthcoming iterations of these devices (Carmigniani & Furht, 2011). It is speculated that future augmentative devices will not merely amplify their inherent capabilities but will foster an increasingly symbiotic, almost seamless, interface with human users, paving the way for profound shifts in how we envision and enact craftsmanship in the digital age.

Artificial Intelligence

The field of artificial intelligence is best understood as the confluence of diverse disciplines, ranging from computer science to cognitive psychology, with the overarching goal of emulating, enhancing, or even surpassing human intelligence through computational means (Russell & Norvig, 2010). The pursuit of creating intelligent machines dates back to antiquity, with mythologies replete with tales of automatons and self-operating devices. However, the modern conceptualisation of AI, grounded in computer science, can be traced to the mid-20th century, spearheaded by researchers such as Alan Turing, who postulated the theoretical underpinnings that later came to define the field.

At its core, AI seeks to encode the processes associated with human cognition into algorithms, rendering machines capable of tasks that, when performed by humans, require intelligence (Poole & Mackworth, 2017). These tasks comprehend a broad spectrum, from perception and recognition to decision-making and natural language understanding. Notably, while the replication of human intelligence is a central endeavour in AI, the field does not restrict itself to merely mimicking human cognitive processes. Instead, it ventures beyond, leveraging computational competence to attain capabilities unattainable for humans, such as processing vast data sets at fast speeds or identifying intricate patterns in complex systems.

Two primary schools of thought guide AI's development: symbolic and connectionist. The symbolic approach, often associated with classical AI, postulates that intelligence can be emulated through the manipulation of symbols and rules, drawing parallels with logical reasoning (Newell & Simon, 1976). In stark contrast, the connectionist approach, underpinning much of today's neural network-driven machine learning, suggests that intelligence emerges from the interplay of interconnected simple units reminiscent of the human brain's neural architecture (McCulloch & Pitts, 1943).

The latter half of the 20th century witnessed several challenges and achievements in AI research, with periods of intense enthusiasm punctuated by "AI winters" – phases of stagnation and fading interest. However, the beginning of the XXI century brought forth a renaissance in AI, propelled by the confluence of three critical factors: increasing data availability, advances in computational power, and algorithmic innovations. This revitalisation culminated in deep learning, a subset of machine learning inspired by the structure of the human brain, achieving breakthroughs in tasks previously deemed impossible for machines, such as image and speech recognition (LeCun, Bengio, & Hinton, 2015).

While the advancements in AI are undoubtedly groundbreaking, they also deal with a plethora of ethical, societal, and philosophical dilemmas. As machines inch closer to human-like cognitive capabilities, questions surrounding machine consciousness, the potential obsolescence of human labour, and the very essence of intelligence become increasingly relevant (Bostrom & Yudkowsky, 2014).

AI represents humanity's ambitious endeavour to extract and, in many instances, transcend the essence of human intelligence using computational means. As we stand on the cusp of what many deem the "AI age," navigating this brave new world with a judicious blend of enthusiasm, caution, and reflection is imperative.

The architectural domain, once deeply rooted in manual design processes and intuition, is undergoing profound transformations due to the disruptive influence of artificial intelligence. Spanning various stages of architectural practice, from ideation and design to construction and facility management, the infusion of AI technologies redefines the dynamics of architectural creation and realisation (Duarte, 2001).

At the very forefront of this transformation is the domain of design. Generative design, strengthened by AI, offers architects a tool that can produce thousands of design variations by processing specified criteria such as materials, costs, and spatial requirements. Instead of laboriously sketching each design iteration, architects can now set parameters, and the AI system proposes a multitude of design solutions, each optimised for the given criteria (Del Campo et al. 2019). This exponentially amplifies the quantity and improves the quality of design outputs, as AI can identify and suggest optimal design solutions that may elude human designers.

Beyond design, AI has also manifested its potential in predictive analysis for sustainable building. With the growing urgency to address environmental concerns, architectural projects increasingly emphasise energy efficiency. AI-driven simulation tools can predict how different building materials, design choices, and orientations would affect energy consumption, enabling architects to make informed, eco-friendly decisions (Turrin et al. 2011).

Traditionally flawed by inefficiencies and high error rates, the construction phase is another area where AI is carving its niche. AI algorithms, in conjunction with robotics, are streamlining construction processes. For instance, robots equipped with AI-driven vision systems can lay bricks, conduct site inspections, or even assemble building components with precision, often surpassing human capabilities in speed and accuracy (Eastman, Teicholz, Sacks, & Liston, 2011). Moreover, AI-powered predictive analytics can forecast delays due to weather conditions, supply chain disruptions, or other unforeseen challenges, ensuring smoother project timelines.

Furthermore, post-construction, facility management, and building operations are witnessing AI's transformative touch. With the proliferation of the Internet of Things (IoT) devices, modern buildings are brimming with data. AI algorithms processing this data can optimise building operations in real-time. From predictive maintenance of building systems to optimising energy usage patterns based on

occupancy data, AI ushers in a new era of smart and responsive buildings (Del Campo M. et al. 2017). However, while AI offers immense possibilities in architecture, it is not without challenges. One significant concern is the diminishment of the human element in architectural practice. As AI systems take on more design responsibilities, there's an imminent fear of architecture losing its intuitive, human-centric touch. While AI can optimise for efficiency or cost, understanding human experience, cultural contexts, and aesthetic subtleties remains a predominantly human domain (Picon, 2010).

In conclusion, as AI continues to permeate architectural practice, its profound impacts are undeniable. From enhancing design capabilities and championing sustainability to revolutionising construction processes and building management, AI holds the promise of a more efficient, sustainable, and innovative architectural landscape. Yet, as architects and practitioners, the onus lies in harnessing AI's capabilities judiciously, ensuring that the essence of human intuition and creativity remains at the heart of architectural endeavours.

1.3. Historical Review

Object-based programming languages like C#, which this thesis focuses on, typically use a series of predefined libraries containing basic commands, methods, and functions. These libraries are often tailored to specific tasks and designed to serve the main code efficiently. Similarly, this thesis uses three main concepts, or "libraries," to structure its primary topic: the Augmentation Library, the Automation Library, and the Craftmanship Library. These concepts establish the framework within which the research is positioned.

To define and describe the information contained in these libraries, it is important to understand the methods they employ and how they should be utilised. This text will explore the evolution of three key concepts from a utilitarian perspective, presented in chronological order. To simplify the understanding of these concepts, only the most relevant events will be highlighted, while others will be left out. The aim is not to provide a thorough historical review but to establish the context in which the thesis is located. This will offer a better understanding of the positions taken in the case study analysis.

Additionally, the introduction will suggest how these three libraries have interacted and influenced each other throughout history. It will demonstrate that the three libraries are essentially connected to the same fundamental framework: the language of expression through manufacturing. This language is highly relevant as it is one of the features that distinguish humans from other species on the planet.

1.4. Library 1: The Concept of Craftmanship.

Craftsmanship has a rich history of collaboration with architecture, dating back to early human habitation in caves (Sennet, R. 2008). The integration of craftsmanship into architectural spaces can be seen in prehistoric cave paintings, demonstrating its early significance (Sennet, R. 2008). Over time, craftsmanship has evolved in both object-related and architectural contexts. This evolution is evident in various forms, including decorative paintings and intricate carpentry designs (Freidenrich, E. 2019). Throughout art history, artisanry and craftsmanship have played a crucial role in shaping architectural styles, from ancient Egypt to Art Nouveau, where decorative arts merged with spatial design (Sennet, R. 2008). Notably, even the absence of decorative elements has defined architectural styles like modernism (Curtis, W. 1982).

From a labour perspective, craftsmanship practices have adapted to changing societies and technologies throughout history. Guilds, dating back to ancient times, have regulated specific arts, governing who could practice them and how knowledge was transmitted (Freidenrich, E. 2019). Despite contemporary technical education through universities, professional associations still exert significant influence over building arts. While access to knowledge has become more open, these entities continue to shape the profession (Sennet, R. 2008).

Technological advancements have been closely intertwined with the evolution of artisanry and craftsmanship. Styles and techniques have evolved alongside improvements in tools, mechanical engineering, and thermodynamics. For example, Gothic architecture incorporated early structural optimisation techniques, while industrial processes became integral to crafting methods. Even in the post-industrial era, traditional techniques have been adapted into industrial processes to align with contemporary manufacturing requirements (Sennet, R. 2008).



Figure 1. Exeter Cathedral. Example of a decorated structural stone vault. 1440 a.c.
Exeter, United Kingdom.

As craftsmanship transitions into the post-industrial era, it faces both challenges and opportunities. The emergence of the Metaverse, a new digital realm, will transform design and artistry in various aspects. Crafting within the Metaverse will require a re-evaluation of access, implementation, techniques, materials, and physicality (Freidenrich, E. 2019). Understanding the impact of digital technologies, such as machine learning, computational design, and augmented reality, on craftsmanship will be crucial while addressing issues like skilled labour shortages, sustainability, and automation. By confronting these challenges, craftsmanship can continue to be a significant and relevant part of the future creative arts.

1.4.1. Prehistoric Times.

From a historical perspective, craftsmanship has remained largely unchanged since ancient times. While artisanry dates back to early civilisations, details on how it was organised and valued across generations are limited (Sennet, R. 2008). However, decorated objects from prehistoric times indicate a longstanding human interest in the functionality and aesthetic value of items. This preference for personalised objects may distinguish us from other tool-using animals, highlighting craftsmanship's role in shaping culture and societal differences (Guthrie, R. 2005).

Craftsmanship likely originated from the desire for personal distinction, with tools decorated by their owners in early societies. The role of the craftsman was not well-defined, and techniques were transmitted within specific social groups, making them unique (Lucie-Smith, E. 1981).



Figure 2. Silex Tools are some of the earlier tools used by hominids. Palaeolithic era, Toulouse, France.

As social groups became more organised and engaged in trade, craftsmanship expanded beyond individual communities. This exchange of goods facilitated knowledge sharing, leading to specialised craftsmanship and a division of labour (Sennet, R. 2008). Craftsmanship evolved from representing individual identity to symbolising community identity through shared culture and traditions (Lucie-Smith, E. 1981).

Examples from late Palaeolithic cultures in Asia and Eastern Europe, such as the Mousterian culture, highlight this evolution. These cultures contributed to the development of craftsmanship and technology, with similar tools and lifestyles indicating a consistent transmission of knowledge. The standardisation of manufacturing techniques allowed for easier access to functional tools, supporting sedentary lifestyles in ancient civilisations (Guthrie, R. 2005).



Figure 3. Willendorf Venus. Example of Palaeolithic art. 30.000 b.c. Natural History Museum, Vien, Austria.

1.4.2. Ancient and Classical Times

The production of artisanry and decorative arts in ancient cultures was significantly shaped by structured religions. The representation of gods and religious imagery influenced the themes in objects and architecture. Civilisations like the Sumerians, Egyptians, Greeks, Indus Valley, and Chinese underwent an architectural boom, with temples and public buildings displaying specialised decorative arts and craftsmanship. This period marked the rise of specialised artists and the development of distinct architectural styles that reflected community culture and identity. Trade flourished based on unique craftsmanship, with certain cities, such as Byblos for papyrus and Egypt for jewellery, establishing themselves as centres of production and trade.



Figure 4. Example of Ancient Egypt Craftmanship. Louvre, France.

As ancient civilisations evolved and expanded, decorative arts and craftsmanship helped unify various territories. Conquered regions adopted the artistic styles of their rulers and began creating local goods and architecture. This exchange also facilitated the movement of craftsmen and artists, allowing local artisans to blend their skills with foreign influences. Consequently, techniques and styles evolved, leading to technological advancements and improved quality in crafted products (Lucie-Smith, E. 1981).



Figure 5. Nefertiti Bust, Amarna Egypt, Neues Museum, Berlin, Germany.

During the early stages of craftsmanship, there was no clear distinction between different disciplines, and authorship was not emphasised. The creator of the pot was as important as the sculptor. In ancient Egypt, multiple individuals contributed to statue creation, and each sculptor was valued equally.

With technical advancements and increased access to handcrafted objects, a distinction arose between utilitarian items and those meant for higher purposes. This shift occurred as ordinary individuals gained access to crafted goods, prompting a need for differentiation. Additionally, the rise in artisans led to the emergence of specialised professions, often based on the quality of their work.

Certain arts became more valuable, and some artists, like Thutmose, the royal sculptor known for the Nefertiti bust, gained prominence. This division laid the groundwork for the modern understanding of the arts (Robins, G. 1997). Styles were also regulated; while styles existed in Egyptian art, ancient Greece standardised them through norms and rules that ensured consistency throughout their history.



Figure 6. Parthenon Sculptures by Phidias. 447 b.c. British Museum, London, UK.

The professionalisation and differentiation of arts gained prominence in classical Greek civilisation, distinguishing between "higher" and "lower" forms of art (Woodford, S. 1982). Three major arts—architecture, Sculpture, and Painted Ceramics—were deemed superior, while crafts like jewellery and textiles were seen as utilitarian. Renowned artists such as Callicrates and Phidias were celebrated for their contributions. Greek art also established standardised styles that differed from other cultures and persisted throughout history (Sennet, R. 2008).

Similarly, ancient Chinese artisanry categorised pottery, painting, bronze casting, jade, and calligraphy as "higher arts," emphasising utility and collaborative craftsmanship. Until the 10th century AD, recognised artists were rare, and fame emerged during the Five Kingdoms Dynasty. Spiritual and religious themes influenced artistic evolution across different dynasties (Rawson, J. 1999).



Figure 7. Jade Sculpture, Qing Empire, Song Empire, National Museum, Beijing, China.

The evolution of arts and artisanry varied greatly among civilisations, influenced by their technological advancements. Civilisations like the Etruscans and Olmecs had established arts, while others, such as early Celtic cultures and Altaic tribes, demonstrated less developed approaches to art, focusing more on local production of decorated objects and practical architecture (Sennet, R. 2008). As classical cultures grew, the gap among different civilisations narrowed, leading to changes in craftsmanship.

In the Roman Empire, arts and crafts were integral to expressing power and cultural dominance. The Romanization of conquered territories required public spaces to adopt Roman styles, facilitated by institutions known as "Collegia," which regulated the arts and crafts. These early guilds brought together artists and crafters, significantly influencing the evolution of arts and crafts. While they had limitations, their impact led to the formation of non-official trade associations and the spread of standardised knowledge in crafts, continuing to shape artistic practices even after the Empire's decline (Stewart, P. 1971).

1.4.3. Middle Age Times

During the High Middle Ages, guilds and professional associations gained popularity and were adopted in various regions such as Christian Kingdoms, China, India, and Japan (Sennet, R. 2008). Although there were minor variations, guilds shared a common purpose of preserving and trading various goods and arts. Guilds formed powerful associations in urban areas and cities that specialized in manufacturing goods related to their available local raw materials. This industrialized approach to production not only improved access to essential goods for the lower classes but also contributed to the rise of the Bourgeois class by promoting the creation of liberal professions (Freidenrich, E. 2019).



Figure 8. Portable Altar, ca 1500. Museo de las Bellas Artes, Asturias, Spain

The ancient Greek classification of arts remained influential as the number of professions grew, leading to the emergence of the "Higher Arts," which included architecture, sculpture, and painting (Sennet, R. 2008). These arts, distinguished by their elevated purpose, were influenced by religious fervour and social differentiation, serving noble interests. Architecture evolved to be seen as art, with architects recognized as artists, unlike masonry and woodworking, which stayed as craftsmanship. This shift resulted in the higher arts moving away from guild structures to a more scholarly approach with the establishment of art schools and academies (Lucie-Smith, E. 1981).



Figure 9. Polychrome Gothic Sculpture.

1.4.4. Modern-Era Times

The modern era continued trends from the Middle Ages, distinguishing between artists and artisans while emphasising professionalisation and regulation. Colonization significantly impacted arts and crafts, as the spread of European culture led to the homogenization of styles, affecting even non-European traditions (Lucie-Smith, E. 1981).

In the latter half of this era, schools and regulatory bodies emerged, establishing a dominant European-based system globally. International trade facilitated the exchange of cultures, increasing the demand for exotic crafts from Asia, America, and Africa among European upper classes, which further enhanced the global influence of European styles (Freidenrich, E. 2019).



Figure 10. Chinese Inspired German Cabinet. Ca 1730. Saxony.

.Simultaneously, European countries, especially during the second half of the modern era, witnessed the establishment of early industries, often sponsored by royal families and catering to the upper classes. These royal factories had implications for the ownership and recognition of craftsmen. While still not achieving the same level of recognition as artists, certain factories gained renown for the quality of their production, elevating certain luxury objects to status symbols. Porcelain, tapestry, watchmaking, and glass-making were coveted goods among the upper and bourgeois classes, symbolising wealth and power (Sennet R. 2008).



Figure 11. Glassware, Royal Spanish Factory. Ca 1750. La Granja, Spain.

Access to products from royal factories was restricted to a select few based on social class, limiting public availability and fuelling demand. As the economy grew and lower-class buying power increased, the royal factories could not meet the rising need for manufactured goods. This resulted in the establishment of chartered liberal companies that produced a wider range of products for diverse buyers. Ultimately, this increased demand and need for expanded production contributed to the onset of industrialisation in Europe at the end of the modern era (Procter, A. 2020).

1.4.5. The Industrial Revolutions

The first industrial revolution, marking the transition from the modern to the contemporary era, brought significant changes in the relationship between crafted objects and mass-produced products. The increased accessibility and durability of manufactured goods led to a surge in demand across society, with furniture, cutlery, textiles, and pottery becoming everyday commodities. Craftsmanship arts integrated with emerging industries, resulting in a notable expansion of artisan labour. While some small workshops and individual makers continued to preserve their craft, the rise of factories, particularly industrialised ones, introduced the concept of branding as a means of promoting goods (Sennet, R. 2008).

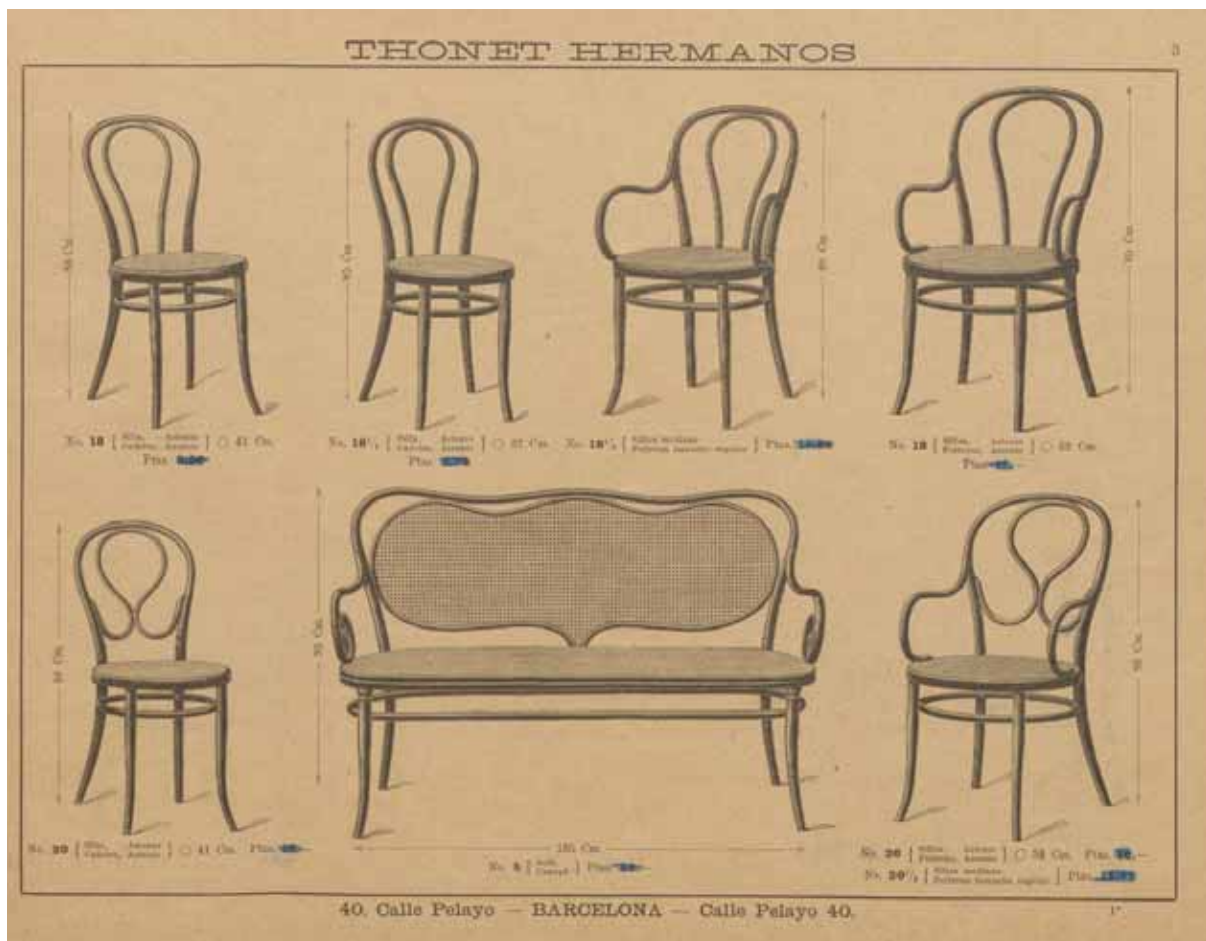


Figure 12. Thonet Chair. Licensed Production Catalogue. Circa 1901 Spain.

In this new context, crafted goods became linked to brand reputation, with the public playing a key role in recognition. Brands influenced guild structures, aligning specific styles and techniques with their processes. Regulatory entities focused more on technical aspects and quality control, while knowledge shifted to professional schools. Some guilds evolved into professional unions, separating labour rights from production regulation.

As serial production grew, a distinction emerged between exceptional handmade objects and mass-produced goods. By the early 20th century, craftsmanship perception changed, viewing serial products as less valuable due to their uniformity. This led to a renewed appreciation for handmade items and the rise of product designers as connectors between artisans and the arts (Blakesley, R. P. 2006).



Figure 13. Teapots designed by Marianne Brandt .1924.

The idea of designing common and utilitarian objects from an artistic perspective gained traction during the early 20th century with design vanguard movements. The Vanguard period witnessed the emergence of various artistic styles in Europe and America that explored new manufacturing techniques and design approaches.

Movements such as De Stijl and Bauhaus played a pivotal role in reinterpreting traditional craft practices in the context of modern manufacturing and aesthetics (Blakesley, R. P. 2006).



Figure 14.LC4 chaise longue by LoCorbusier, 1928.

From a labour and ownership standpoint, manufacturing processes and the work involved gradually assumed a secondary position as new techniques and automation came into play. Designers began to take precedence over craftsmen in terms of authorship, with workers becoming mere instruments of production. This division led to the separation of skills transmission, with design aspects primarily taught in art and design schools, while practical manufacturing skills were learned through apprenticeships and technical schools. This modern approach to object production positioned designers as the sole credited individuals, while anonymous craftsmen remained unacknowledged and unknown (Lucie-Smith, E. 1981).

1.4.6. Post Industrial Times

After the end of WWII, automation and the use of plastics revolutionised artisanry and craftsmanship, transforming the way products were manufactured. The arrival of new synthetic materials and technological advancements shifted production towards utilitarian purposes, leading to a decline in the importance of traditional manufacturing and unique designs. Industrial looks became predominant as objects were efficiently mass-produced, serialised, and stripped of their individuality. During this period, there was a prevailing belief that industrial products were superior to hand-made ones in terms of durability and quality. Consequently, the appreciation for traditional craftsmanship declined, causing a decrease in the number of new craftsmen favouring automated processes and machines (Sennet, R. 2008).



Figure 15. Panton Chair by Verner Panton.1960

The introduction of digital techniques accelerated the decline of traditional crafting processes, leading to the near disappearance of many crafts. Architecture exemplifies this trend, as prefabricated elements marginalised traditional skills

like carpentry and glassmaking, resulting in the loss of centuries-old techniques (Freidenrich, E. 2019).

However, the rise of China and other Asian manufacturing hubs in the 21st century shifted perceptions. With industrial mass production and factory delocalisation, a renewed desire for uniqueness emerged, bringing relevance back to artisans whose handcrafted products now symbolise high quality (Harrod, T. 1999). Technologies like 3D printing facilitated this revival, allowing for cost-effective production.

This renewed interest has fostered a hybrid approach where mass-produced and handmade items coexist. Craftsmanship now includes the crafter as an artist influenced by automation, with traditional techniques taught through a more regulated school-based system.

1.4.7. The Role of Craftmanship in the Making

The preservation of craftsmanship today is driven by the unique qualities and sentimental value attached to handmade objects. The emotional connection and the use of local materials and labour give these goods a souvenir-like character that resonates with people's experiences and memories. However, challenges persist, including the demands of the post-industrial economy for efficiency and speed, the concentration of populations in urban areas, and the limited access to new labour in the artisanry field.

To ensure the future of craftsmanship, it is necessary to embrace new technologies and methods of recording and transmitting knowledge. Collaboration between artisans and new technologies like 3D printing, CNC manufacturing, and Augmented Manufacturing is vital. Incorporating these technologies and the involvement of younger, more digitally savvy individuals will help preserve craftsmanship as an invaluable heritage for societies.



Figure 16. Robotica Chair by Rose Lovegrove & Nagami, 2018

1.5. Library 2: The Concept of Automation.

The concept of an artificial entity capable of performing things in an autonomous way has been with human society since its dawn. It is believed that automata were created from gods' statues during the Egyptian civilisation to enhance religious celebrations and ceremonies. That, as a concept, is intrinsically joined to human evolution. Our society, as a whole, has always had the idea of a utopian future where soulless engines would provide all the hard work, resources, and support to the population while, at the same time, humans enjoy a hedonistic life of abundance. From this perspective, it is then easy to understand why the myths and stories about this sort of machinery exist in almost every culture.

1.5.1. Ancient and Classic Times

From a common perspective, the pursuit of efficiency and task delegation has greatly influenced the development of machinery, ultimately facilitating human progress throughout civilisations. Various machines, which are automated to varying degrees, have played crucial roles in manufacturing and other sectors, supporting the growth and expansion of human societies (Lucie-Smith, E. 1981).

Historical records suggest that the concept of programmed autonomous machines dates back to ancient Greece, although the authenticity of these claims remains uncertain. However, there is substantial evidence indicating the presence of engines primarily powered by water or steam that were capable of performing simple movements, largely for entertainment or scientific purposes (Diels, H. 1903).

A notable figure from this era was Ktesibios, an influential inventor known for developing several prototypes of such machines (Landels, 1978). His most famous creation was a clock designed to resemble an owl, which would emit a whistle at regular intervals, powered by a water-driven system

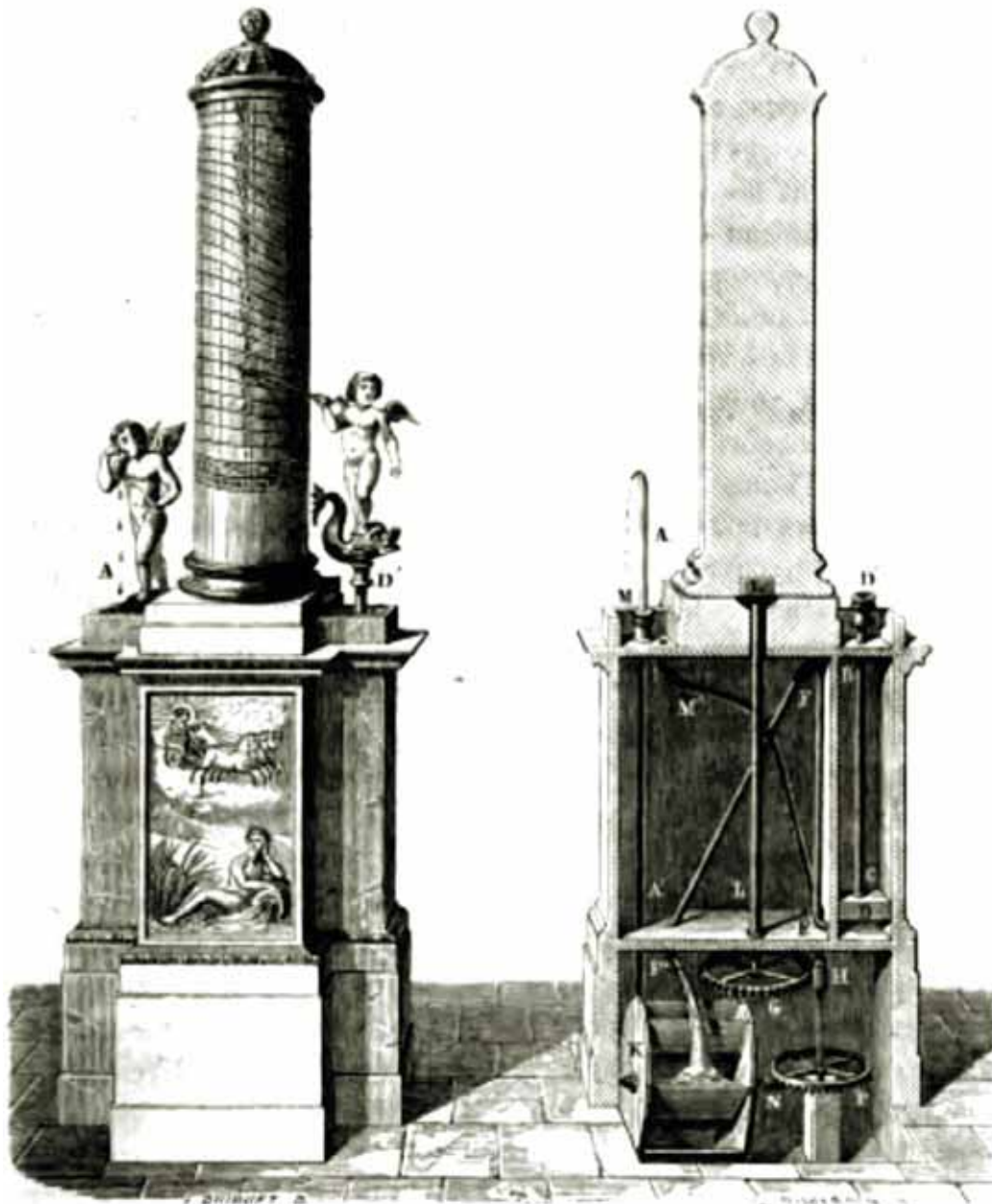


Figure 17. Ctesibius' water clock, as visualised by Claude Perrault. Circa 1670.

Another prominent Greek scientist, Archimedes, contributed significantly to machinery designed to amplify human strength and working capabilities. Archimedes is widely acknowledged for his invention of steam-driven machines, which facilitated the operation of heavy doors and the movement of bulky loads with minimal human interaction (Dijksterhuis, E. 1987). These inventions epitomise early innovations in enhancing human productivity and potential through machinery.

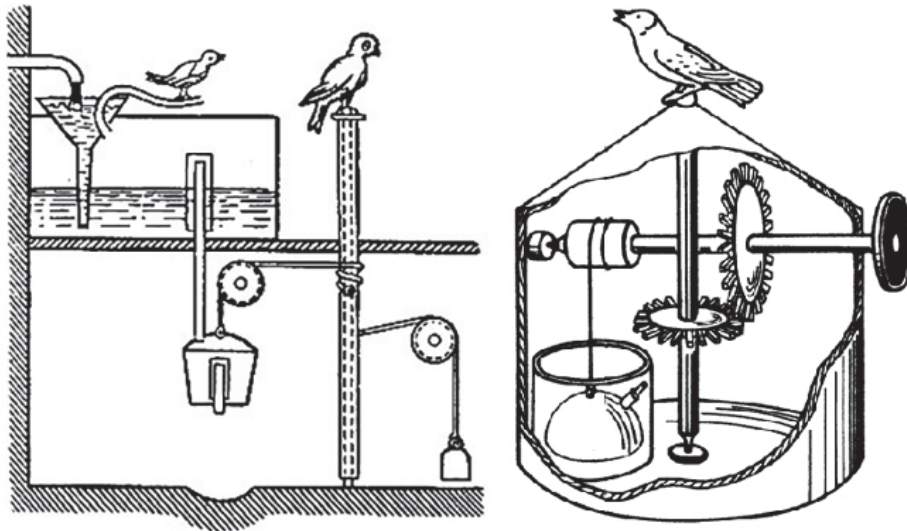


Figure 18. Example of an Archimedean Machine.

In terms of computational development, evidence from this historical period indicates the existence of programmable machines. For instance, the Antikythera mechanism was employed to calculate astronomical cycles, including eclipses (Freeth et al., 2006).



Figure 19. The Antikythera mechanism. Circa 200 B.C.

When considering the development of anthropomorphic automata, historical records suggest that Yan Shi, an inventor from ancient China, crafted a human-

sized figure capable of mimicking human movements to entertain the King circa 950 BCE (Needham, J. 1965).

These pioneering examples of automation underscore a persistent trend that has not only endured but also evolved beyond these ancient civilizations, setting the stage for automated machinery's continuous development and refinement (Mumford, L. 1961).

1.5.2. Middle Age Times

During the medieval period, the construction of automata and intricate machines designed to perform monotonous tasks flourished, especially within the Byzantine Empire. This technology became popular for entertainment and spread to cultures such as the Muslim Empire and medieval India (White, L. 1966).

These devices primarily served decorative or religious purposes, although some had practical applications (Sabra, A.1998). A significant example is the water clock constructed by Su Song in 1022, which illustrates the integration of timekeeping and automation (Needham et al., 1965). Another notable creation by Al-Jazari was an anthropomorphic device that dispensed soap and towels in restrooms (Hill, D. 1998).

Despite these advancements, the use of automation in manufacturing and construction remained limited, with basic tools like cranes and early mills being more common (Gies, F. & Gies, J. 1994). However, notable progress was made in computational devices for navigation, such as complex astrolabes, marking a significant step in technological development (King, B. 2016).

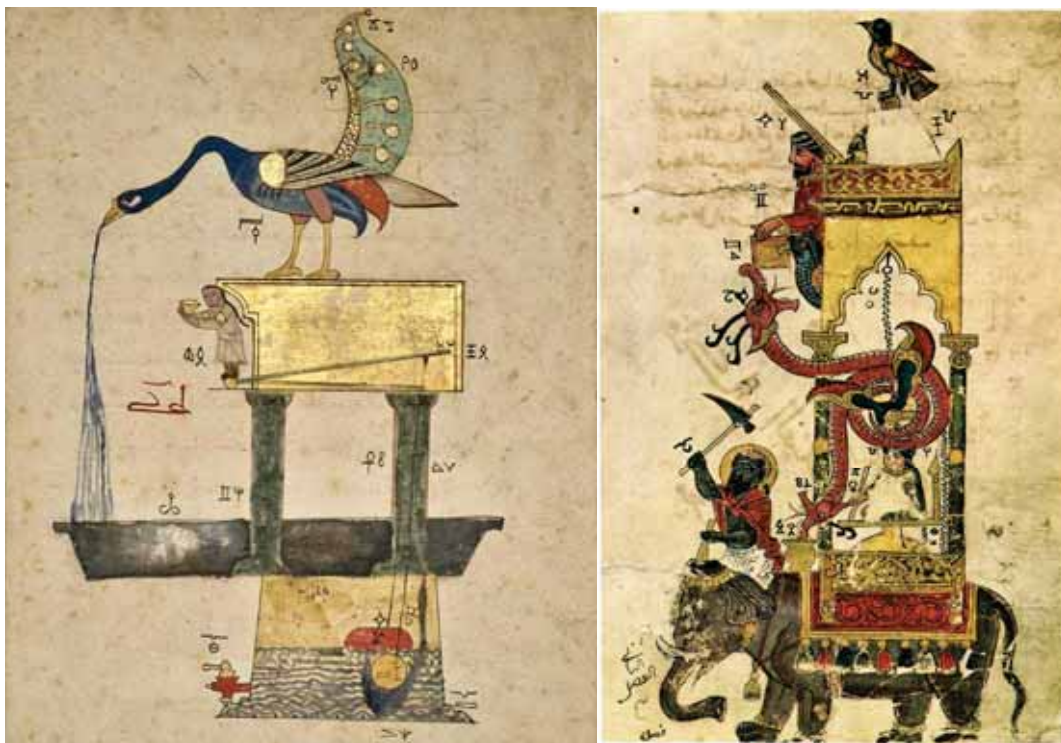


Figure 20. Al-Jazari Automatas. Circa 1135 A.C.

1.5.3. Modern-Era Times

The Modern era's revival of classical principles sparked renewed interest in automata, driven by advances in the scientific method and mechanical engineering (Riello, 2013). Initially focused on entertainment, inventors like Leonardo da Vinci explored practical applications. A notable development was the rise of mechanical and cuckoo clocks in the 15th century, commonly found in towers and public buildings across Europe (Landes, D. 2000). The Prague Astronomical Clock and the Strasbourg Tower clock exemplify this trend, combining functionality and decoration with timekeeping and ornamental automaton figures (Pacey, A. 1991).



Figure 21. Astronomical Clock. Prague. 1410.

During this period, computational advancements were limited, with improvements in astrological tools and calculation rulers but no notable inventions. The stocking frame, though not directly linked to computing, was one of the earliest programmable machines (Campbell-Kelly et al., 2004). In manufacturing, complex

machinery continued to develop, including advanced hydraulic and wind-powered machines that marked progress in mechanical engineering (Hill, D. 1991). Two key inventions, the mechanical printing press and the blast furnace, significantly impacted technology. The printing press improved the spread of technical knowledge, while the blast furnace advanced metal casting methods (Febvre & Martin, 2010; Landes, 1969). These innovations laid the groundwork for future technological revolutions.

1.5.4. Industrial Revolutions

The late 17th century marked a significant turning point in automation with the invention of the first commercial steam pump by Thomas Savery and the steam engine by Thomas Newcomen. These innovations allowed mechanical devices to surpass human capabilities in speed and strength (Cardwell, D. 1971).

Prior to this, automation largely consisted of novelty devices powered by rudimentary sources like water or weights, limiting their practical use (Hills, D. 1989). Heavy-lifting machines relied on natural power sources, making them vulnerable to environmental conditions. The introduction of the steam engine changed this dynamic, enabling engines to operate anywhere, regardless of weather, by converting water into steam. This initiated a period of practical thermodynamics and precision engineering (Nuvolari, A. 2006).

Steam technology significantly boosted industrial productivity, leading to faster production by integrating steam engines with existing machinery. This innovation spurred new ideas and advancements in manufacturing, resulting in the growth of factories (Mokyr, J. 2009). A major impact of automation was the shift in the human workforce, allowing workers to move away from monotonous tasks and focus on more creative and complex processes.

A notable outcome of this automation evolution was the gradual elimination of animal labour. With steam engines being faster, more consistent, and resistant to fatigue, their adoption rendered the use of animals redundant. Industries such as mining and shipbuilding, which heavily relied on animal power for operating cranes or pumps, replaced this inefficient labour force with steam-powered devices, leading to increased production efficiency and cost reduction (Clark, G. 2007). In essence, it was the animal workforce, more than the human one, that was profoundly affected by the First Industrial Revolution

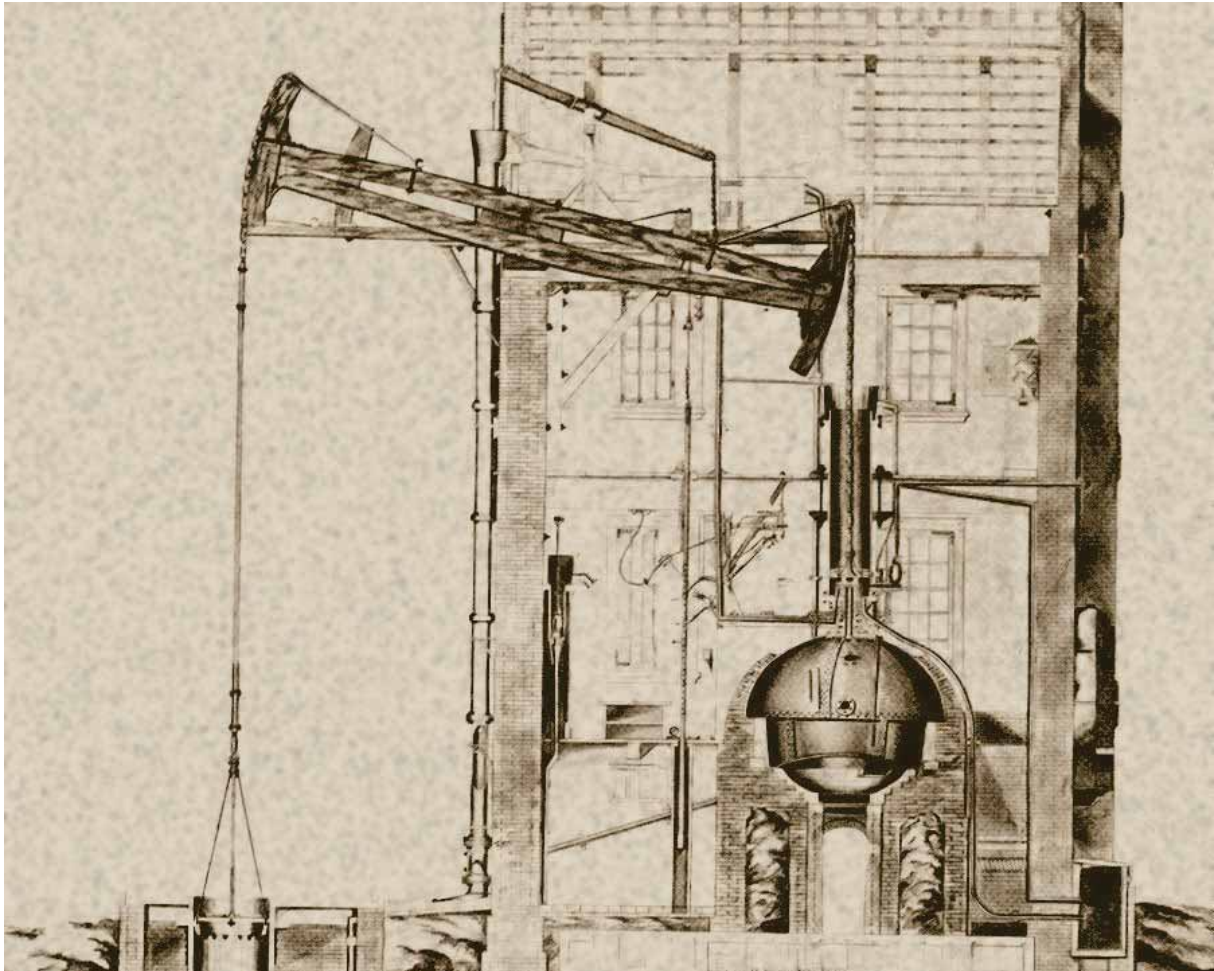


Figure 22. Newcomen Steam Engine. Thomas Newcomen. 1712

The expansion of steam-powered devices in the 18th century created a foundation for automated tools, enhancing manufacturing processes with greater precision and efficiency. The quality of iron and brass fabrication improved, shifting the focus of automatons from entertainment to production, which spurred the invention of motorised machines.

Steam and pneumatic machinery, such as textile mills and pumps, became widely adopted, necessitating the development of sensors to improve machine operation and efficiency (Bennett, S. 1986). The Centrifugal Governor, developed by Christiaan Huygens in the late 17th century, was one of the earliest automated feedback sensors, showcasing machinery's potential to enhance human perception in manufacturing.

By the early 18th century, additional feedback sensors emerged, further automating manufacturing processes (Mayr, O. 1971). The demand for precise metal components fostered the advancement of precision tools and manufacturing equipment, initially used in clocks and navigation, which were later adapted for engine and industrial machinery production (Rosenberg, N. 1963).

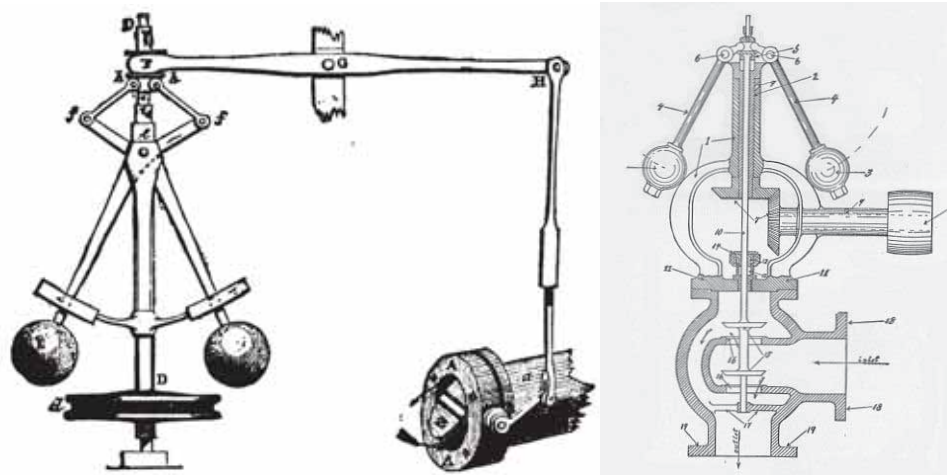


Figure 23. Centrifugal Governor. Christiaan Huygens. 17th Century.

Significant examples of such machines include the milling machine developed by Samuel Rehe in 1783 and the Lateral Lathe devised by Jacques de Vaucanson around 1760. These machines were instrumental in supplying high-quality metal parts on a wider scale.

From a computational perspective, sensors' refinement and widespread use greatly influenced early computer and computational tool development. During this period, rudimentary calculating machines were also developed, notable examples being the Poleni clock calculator in 1707 and the automatic writer crafted by Jaques Droz in 1770 (Swade, D. 2002).



Figure 24. Automatic Writer. Pierre Jaquet Droz. 1770.

However, the most determining invention of this period was arguably the automatic loom, invented by Joseph Marie Jacquard in the late 18th century and patented in 1804. The Jacquard loom, the first programmable automatic machine employing punched cards, profoundly influenced Charles Babbage and his development of the computer (Essinger, J. 2004).

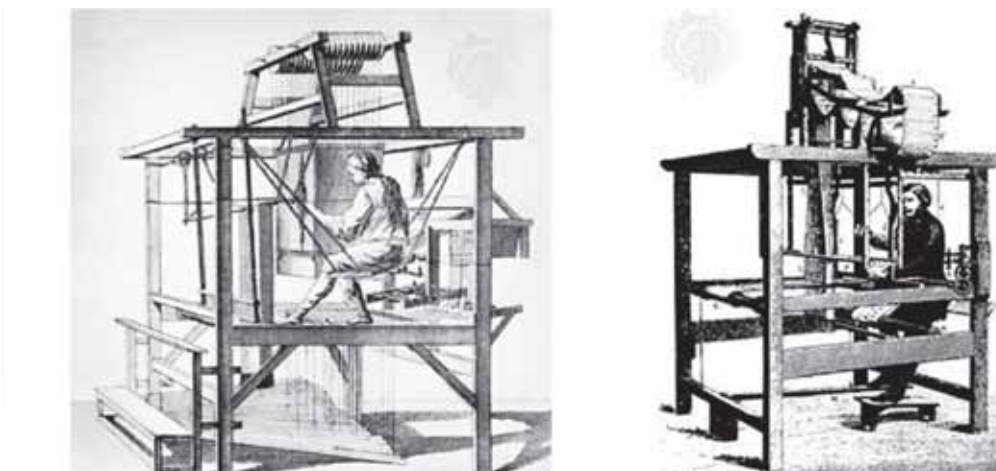


Figure 25. The Jacquard loom. Joseph Marie Jacquard. 18th Century.

The construction industry saw a major transformation during this period, largely due to the rise of the cast iron industry, which set the stage for future advancements. Notably, the introduction of machines, particularly the steam crane developed by English engineer Mr. Bunce in 1784, marked a significant leap in construction mechanisation (Buchanan, R. 1992).

The 18th century laid the groundwork for technologies essential to the 19th century, including advancements in component quality, metal parts, and the integration of engines and sensors, which contributed to automated machines. Similarly, rapid progress in physics and calculus influenced computational concepts, further developed during the second industrial revolution and leading to the invention of the computer in the 20th century (Williams, M. 1997).

The first half of the 19th century marked the consolidation and expansion of industrial machinery for manufacturing purposes. Steam engines and pneumatic mechanisms became common fixtures in the new, high-capacity factories emerging across Western countries. It is worth noting the advancement in complex mechanisms and mechanical devices, particularly in the watchmaking industry, which led to improvements in time measurement and, by extension, increased complexity in other engines and devices (David, P. 1990).

Widespread access to industrial manufacturing machines, especially in the textile and mining industries, initiated a significant shift toward automation. Machines began to replace humans on a large scale, increasing productivity and reducing costs but also leading to a decline in workforce numbers. While this trend became less visible due to the growing demand for factories in the following century, it was during this time that many manual jobs were first replaced by automation.

The most significant changes during this period occurred in computation and calculus. The perpetual calendar, created by Giovanni Plana in 1835, advanced the concept of computation for predicting information (Dubbey, J. 2002). Another key invention was the analogue computer designed by Charles Babbage in 1833, which used punched cards for differential calculations in navigation. Although it was never fully operational due to its complexity, it introduced modern concepts like loops and conditional branching, marking it as the first "Turing Complete" device (Swade, D. 2000).

In the field of architecture, automation progressed with the introduction of steam-powered and pneumatic machines, as well as more precise and capable tools. The widespread use of screw and rivet technology also facilitated the development of

prefabricated architecture. The concept of factory-made architecture emerged, particularly driven by the demand for portable houses in Australia during the first half of the century.

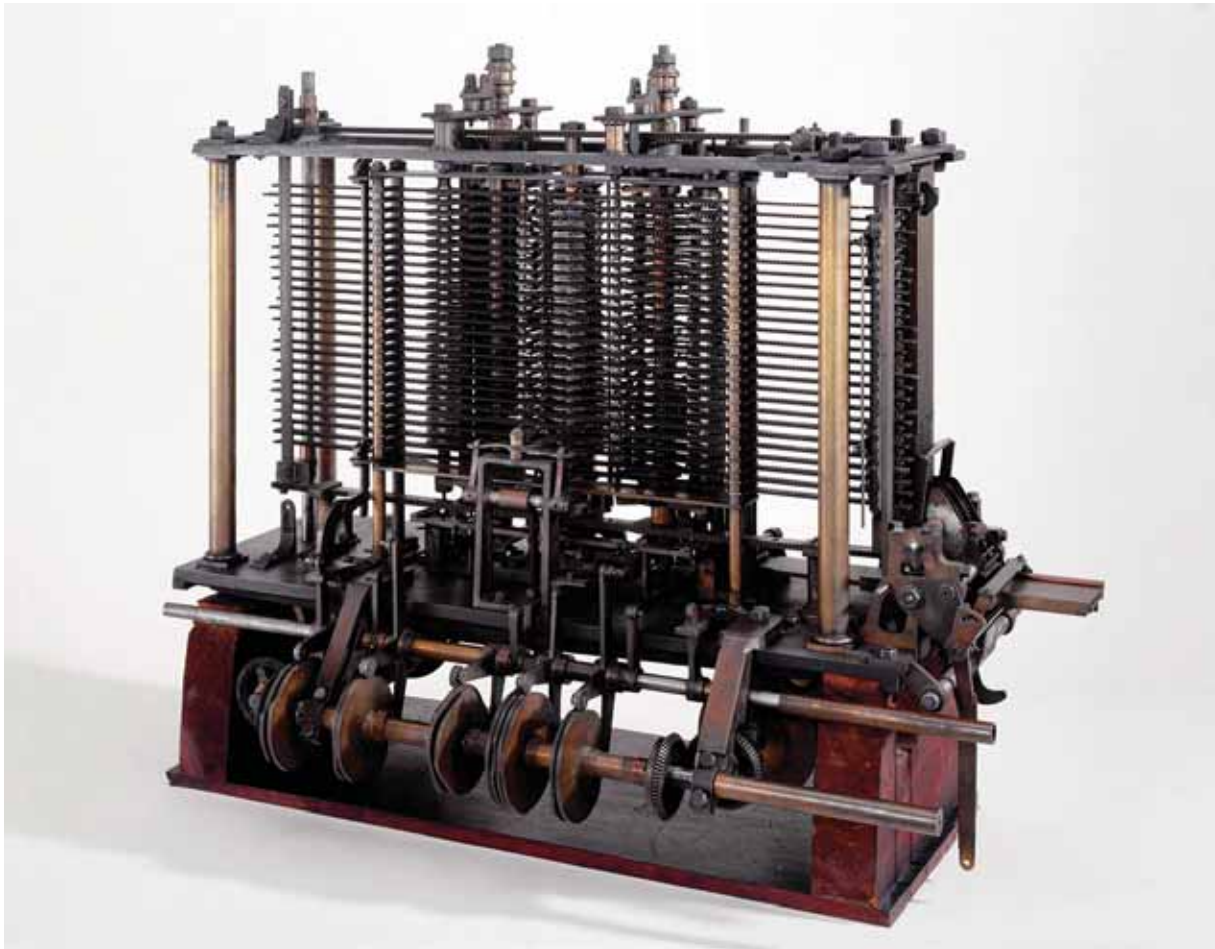


Figure 26. Analog computer. Charles Babbage. 1833.

Concurrently, numerous inventions with substantial implications for automation and computation were made. Notably, various components were invented in the second quarter of the century, accompanied by significant advancements in electrical theory. Among these inventions, the DC electric motor, developed by Joseph Henry in 1831, has played a fundamental role in various automation applications (Rigby, B. 1974). Additionally, the electrical relay, invented by Edward Davy, emerged as a critical device that greatly influenced the industry and laid the foundation for the electronics industry of the late 19th century (Rigby, B. 1974).

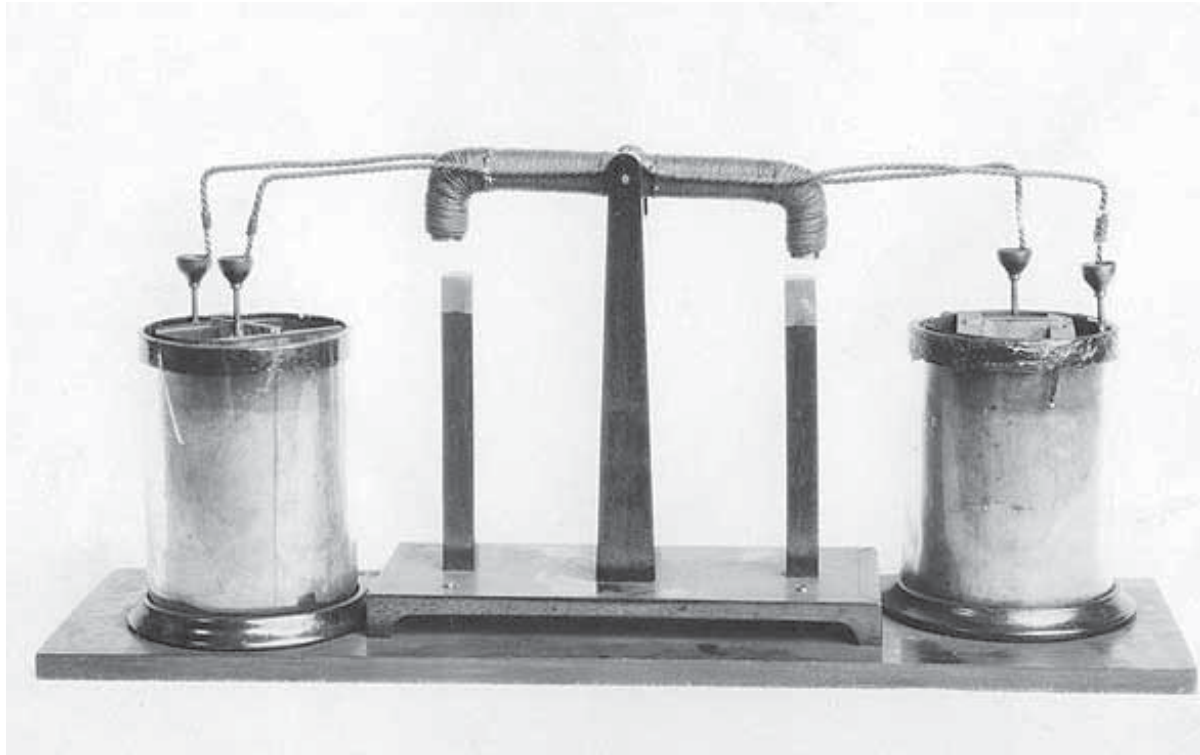


Figure 27. DC Electric Motor. Joseph Henry. 1831.

These inventions and developments marked the beginning of the Second Industrial Revolution, which profoundly shaped the landscape of automation and computation in the latter half of the 19th century.

The rise of electricity in the late 19th century was a key turning point for automation. The introduction of electrical components like motors and generators revolutionised factories, offering cleaner and more portable power than steam technology. This led to redesigned factories and more efficient devices, paving the way for powerful factory power tools (Cowan, R. 1997).

The automaton industry experienced a "Golden Era" as these devices became popular entertainment attractions at events and fairs. The introduction of electricity improved their capabilities, leading to intriguing creations like music players and drawing machines. While initially for entertainment, automata significantly influenced the future of robotics (Deutsch, A. et al. 2017).

Simultaneously, significant advancements were made in the field of computation. Devices such as the tide-predicting machine, developed by Sir William Thomson in 1872, extended the concept of "intelligent machines" beyond horology and contributed to navigation (MacLennan, B. 2007). Henry Babbage, son of Charles

Babbage, continued his father's research and successfully created a simplified prototype of the first analogue computer in 1888. Although these early devices were limited in capability, they laid the foundation for the development of more advanced machines in the early 20th century (Hyman, A. 1982).

Furthermore, notable progress was made in the electrical field during this period. Inventions like the light bulb by Joseph Swan in 1878 and the fuse by Thomas Alva Edison in 1890 played crucial roles in shaping modern electronics (Graf, R. 2002). Additionally, the construction industry experienced advancements in machinery, further contributing to the overall development of automation.

The introduction of electric components during the late 19th century not only revolutionised automation but also facilitated advancements in pneumatic and hydraulic mechanisms. Machinery such as cranes and forklifts became commonplace, and the use of electrically powered tools greatly enhanced work with materials like metals and wood (Bowers, B. 1992).



Figure 28. Electric Bulb. Joseph Swan. 1878

The introduction of electric components during the late 19th century not only revolutionised automation but also facilitated advancements in pneumatic and

hydraulic mechanisms. Machinery such as cranes and forklifts became commonplace, and the use of electrically powered tools greatly enhanced work with materials like metals and wood (Bowers, B. 1992). Moreover, the evolution of the prefabrication industry led to the development of modular and transportable systems, as seen in the Renkioi Hospital in 1855. These advancements in automation and construction had a significant impact on various industries and furthered the progress of human productivity (Silver, C. 2007).

In parallel to the automation and computation advancements, the field of communications also experienced notable developments. The expansion of the telegraph and the invention of the telephone in the late 19th century fostered an interconnected society, setting the stage for the future transmission of knowledge and the emergence of electronic communications (Gleick, 2011). Although not directly linked to automation, the ease of remote communication and the technologies developed for its functionality had a profound influence on the subsequent evolution of electronics and computation during the 20th century.

These new additions formed the foundation for a critical transformation in the fields of automation and computing. Ideas that once seemed like distant dreams, such as tools to enhance human performance, automated machinery for heavy-duty or hazardous tasks, and the use of computers to augment human calculation capabilities, became tangible and attainable (Chandler, A. 1977). This marked the beginning of what is commonly referred to as the Second Industrial Revolution.

1.5.5. Post-Industrial Times

The transition between the 19th and 20th centuries heralded several remarkable discoveries that would shape the fields of programming, computing, and automation. Pivotal milestones included the invention of radio control and the formulation of the photoelectric effect, both of which significantly deepened our understanding of electricity and communication waves (Einstein, A. 1905). Concurrently, technology in the electric realm was developing at a rapid pace, thus becoming the cornerstone of the evolving automata technology. This led to the birth of a new generation of interactive automata.

One of the pioneering examples of an electric and programmable android automaton is the device conceived by W.H. Richards in 1928, fondly named Eric. Many experts consider this device to be the first instance of a modern robot. However, when discussing interactive robots, the title of the inaugural device likely goes to the robot developed by Westinghouse Electric Corporation in 1939, called Elektro. This robot had the capacity to perform basic movements and speech tasks and interact through voice commands (Carlson, W. 1991).

Notably, the manufacturing industry did not remain untouched by the advancements in automation. A prime example is the first known programmable robot designed for construction tasks in 1938. This device, known as Gargantua and developed by Griffith P. Taylor, was a crane-like robot with five axes and was designed to stack bricks in pre-defined patterns. The program was designed around a series of bands dictating the motor's revolutions. Despite being a promising prototype, it lacked a commercial impact due to its construction from Mecanoo parts and was eventually dismantled after its exhibition (Scheinman, V. 1969).

The first truly programmable robot intended for commercial use was developed by George Devol in 1954, and was named Unimate (Devol, G. 1954). This machine was designed for object transfer tasks, though its abilities were limited to four axes and a pneumatic gripper. Initially tested in a General Electric factory for bulb palletising, it was subsequently implemented in General Motors factories for various stages of car manufacturing.

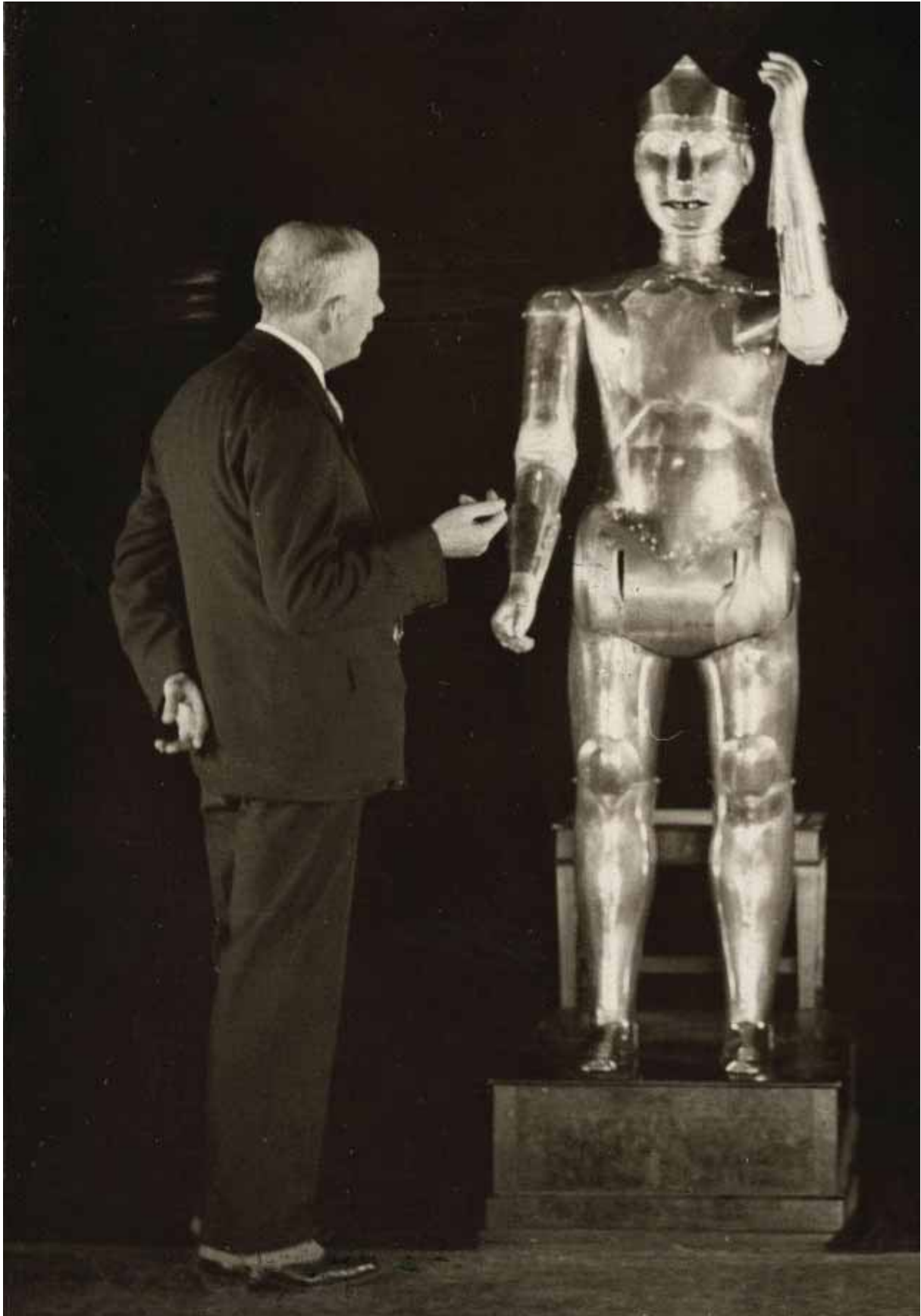


Figure 29. Eric the Automata. W.H. Richards. 1928.

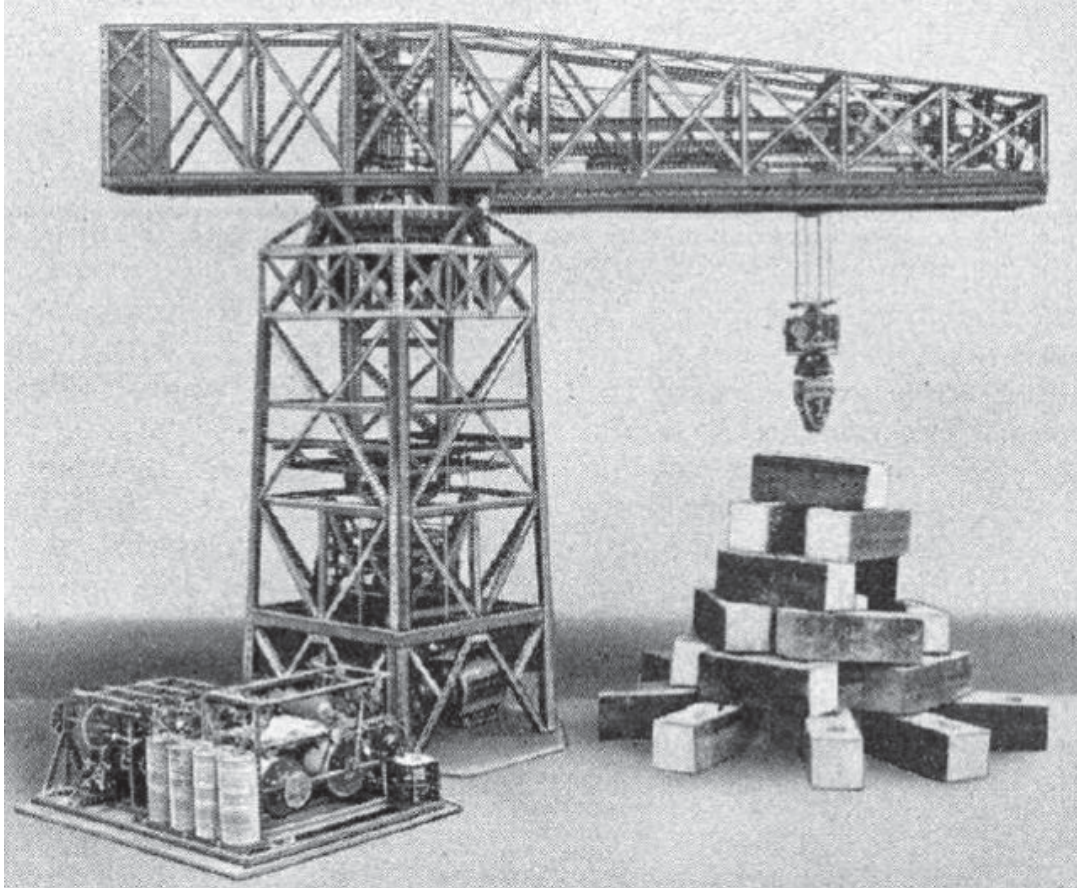


Figure 30. Gargantua. Griffith P. Taylor. 1938.

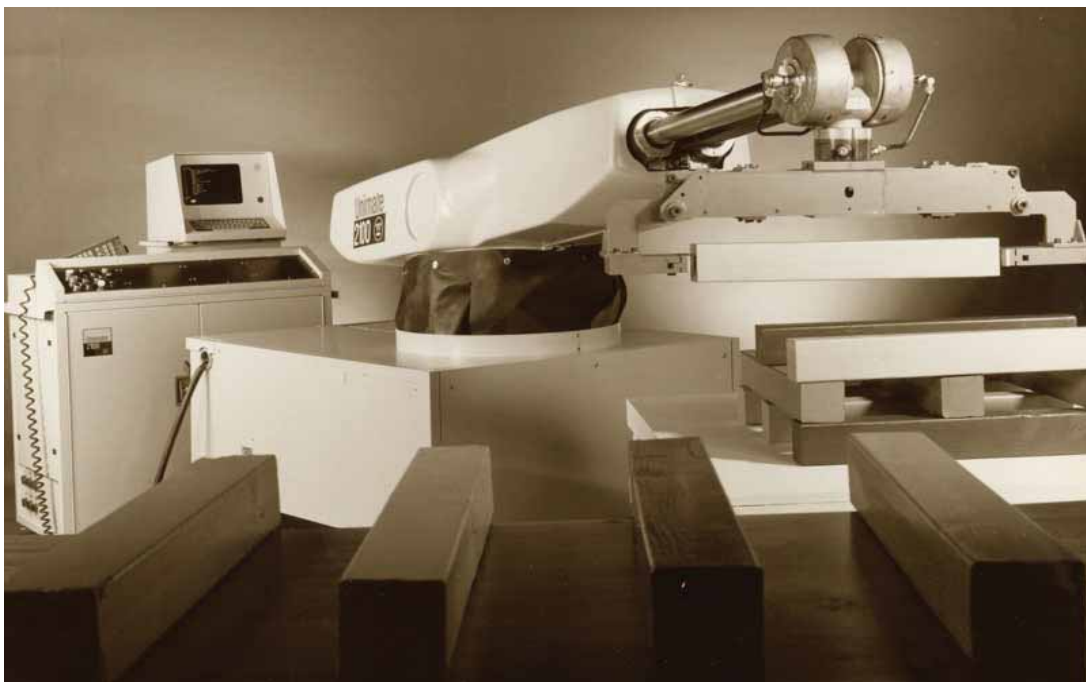


Figure 31. Unimate. George Devol. 1954.

A significant leap in automation occurred at Stanford University's robotics lab in 1969 when Victor Scheinman developed the first all-electric 6-axis robot (Scheinman, V. 1969). This device was quickly adopted by General Motors, a primary funding partner for the project, offering more freedom and flexibility in their car manufacturing processes. The advent of this type of robot revolutionised the industry, leading numerous companies to rush the development of their own versions. ABB and KUKA, two of the most important automation companies, emerged in 1973 as a response to this shift (Moravec, H. 1983).

The swift popularisation of robotics, particularly in countries like Japan and the United States, marked a crucial shift in various industries. While initial applications were primarily centred on manufacturing lines, the late 1970s witnessed the advent of robotics in a broader array of sectors (Nof, S. 1999). The pioneering experiment of introducing and developing robots for on-site construction took place in Japan, where robots were initially delegated to hazardous and toxic tasks such as polymer spraying. The 1980s saw the continued utilisation of robotics in architecture, with more than 200 prototypes developed until the 1990s.



Figure 32. First 6 Axis Robot. Victor Scheinman. 1969.

Internationally, Georgia Tech University initiated a groundbreaking research project in the early 80s exploring the potential of collaborative robots in

construction. This project introduced the concept of 'swarm' robots in construction (Werfel et al., 2014).

During the 1990s, research into robotic applications for the building industry intensified, and such technologies began to be commercially available. Concurrently, prefabricated elements in architecture, which gained popularity during the 1980s, saw an integration of robotics in their manufacturing lines.

A significant technological advancement in the building manufacturing industry was the advent of CNC routing machines. Although manual mechanical milling machines had long been integral to the industry, it was in 1949 that John T. Parsons developed the first automated CNC machine at MIT. This development marked a pivotal breakthrough, paving the way for more precise and efficient manufacturing of a diverse range of materials and parts. The impact of this innovation on the manufacturing industry was far-reaching, with a particularly significant influence on the prefabricated architecture industry from the 1990s onwards.

Simultaneously, automation also extended beyond manufacturing to encompass household appliances designed to ease day-to-day tasks. From the first automated washing machine in 1904, this market sector blossomed during the first half of the century. Post World War II, industrial producers pivoted to civilian production, which boosted the domestic appliance industry due to favourable economic conditions. As a result, these automated appliances found their way into mainstream culture and became commonplace in households by the latter part of the 20th century. Devices such as the Thermomix robot are typical examples of this trend (King, B. 2016)

In the sphere of android or human-like robots, the tradition of automata continued into the 80s, with the increasing ability of these robots to interact with and respond to their environment (Schodt, F. 1988).

Honda Motor Company initiated an advanced robotics program in 1983 to produce a bipedal robot that could emulate human movement (Hirose & Oda, 2006). By the year 2000, despite the limitations of several prototypes of walking robots like the P3, they provided invaluable insights into the intricacies of programming and hardware (Vukobratovic & Borovac, 2004).

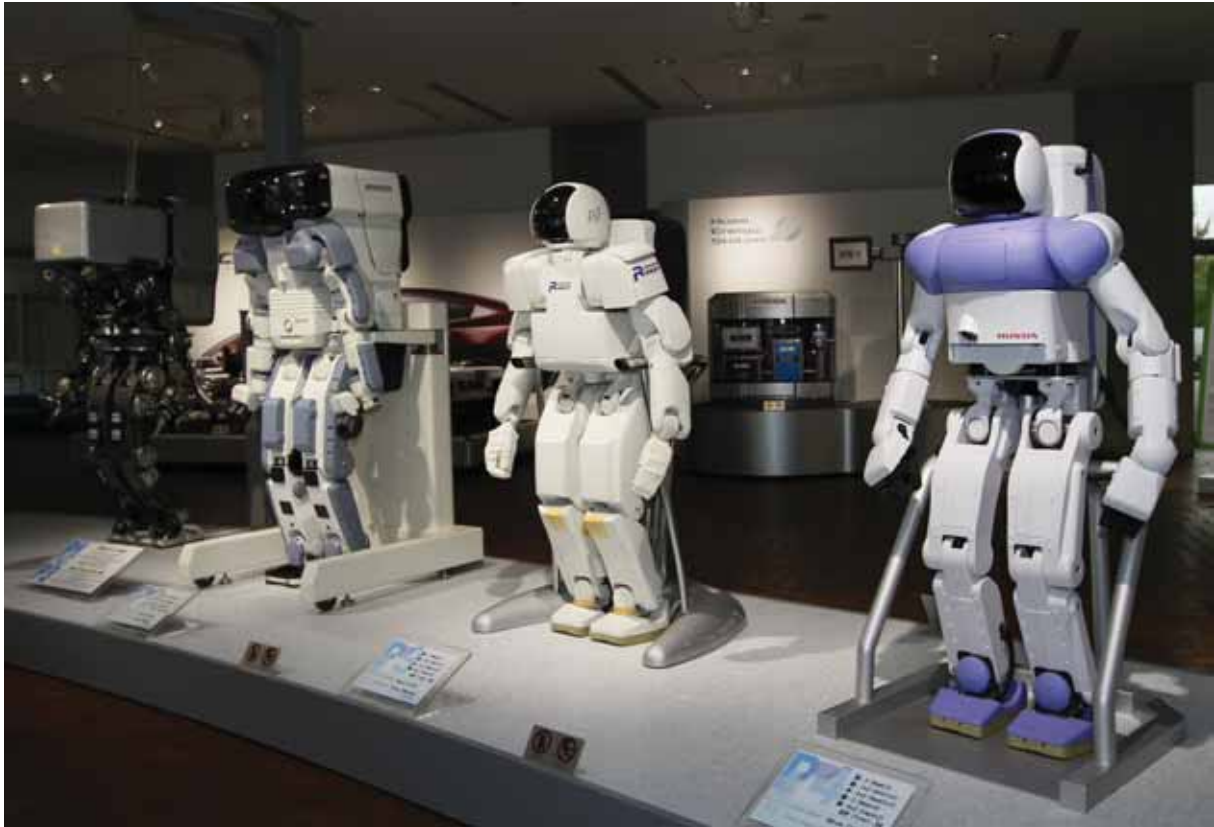


Figure 33. Honda Humanoid robots.

The late 1990s marked a significant turning point as the general applicability of robotics and their potential for domestic use began to shift from the realm of science fiction to reality. This era saw a growing mainstream recognition of robotics as an accessible and beneficial tool, setting the stage for explosive growth in the field during the 2000s (Cohen et al., 1997).

At the same time, the rapid advancement of programming and computing power played a pivotal role in the technological leap of the 20th century. Early computing experiments in the late 19th century sowed the seeds for rapid evolution and, ultimately, a profound impact on the enhancement and progression of electromechanical components (Campbell-Kelly & Aspray, 1996). While the first half of the century saw the development of advanced and sophisticated mechanical computers, the introduction of the first electromechanical computers in the late 1930s revolutionised the understanding and function of computing machines (Cortada, J. 1993).



Figure 34 . Z1 Computer. Konrad Zuse. 1938

A German civil engineer, Konrad Zuse, is often credited with developing the first functional electromechanical computer in 1938 (Rojas & Hashagen, 2000). Although this early iteration was rudimentary and non-digital, Zuse quickly replaced it with the Z3, the second generation that utilised the binary system for coding and computing. This marked the birth of the first digital computer, now recognised as Turing-complete.

Alan Turing's inspiring contribution to this field cannot be understated. Turing conceptualised the modern idea of stored-program computers and the universal computing device, which later evolved into the computer processor module (Hodges, A. 1992).

During the Second World War and up to the 1950s, numerous electromechanical computers were developed. One such significant development was the Manchester Baby, developed in 1948, which became the first stored-program computer in history (Enticknap, N. 1998). This invention marked a paradigm shift in computing technology and introduced a completely new approach to this rapidly evolving field.



Figure 35. First Transistor device. 1947

The latter half of the 20th century heralded remarkable innovations that forever changed the landscape of computer technology. One such groundbreaking invention was the transistor. This device, significantly smaller, faster, and more precise than the preceding electromechanical relays, revolutionised the field of electronics, facilitating the creation of more powerful and compact devices (Hoddeson et al., 1994). William Shockley, John Bardeen, and Walter Brattain invented the transistor in 1947, and its commercial application from the early 1950s played a crucial role in the ensuing hardware revolution (Riordan & Hoddeson, 1998). Notably, this invention paved the way for the development of the microprocessor in 1952, which later became a fundamental component of modern computers.

Almost simultaneously, the second key innovation in electronics, the integrated circuit, was developed. This component significantly simplified the construction of circuits, concentrating on specific functions within modules, which facilitated the assembly of computers while reducing their size and complexity (Moore, G. 1965). In 1971, the third and arguably the most significant invention of this era, the microprocessor, was developed by Intel (Faggin et al., 1971). This component essentially became the 'brain' of computers and the core of all modern computer systems.

These three inventions collectively shaped modern computing and aided the transition of computers from prohibitively expensive laboratory devices to compact, affordable general-use devices, eventually giving rise to the Personal Computer. The Kenbak-1, though not commercially successful, established the model for subsequent devices such as the Altair 8800 and the IBM 5100 (Ceruzzi, P. 2003). In 1977, the market saw the introduction of several personal computers, referred to as the "1977 Trinity" (Apple II, Commodore PET 2001, and TRS 80 Model 1), marking the beginning of Consumer Electronics (Freiberger & Swaine, 2000). This widespread accessibility of computers triggered a technological revolution that continues to this day.

By the end of the 20th century, it became commonplace to find computers in households and schools, further expanding their use and necessity. Moreover, a significant advancement in communication occurred during this period - the advent of networking, which revolutionised knowledge sharing and creation (Abbate, J. 2000). It facilitated an immense database, accelerating technological progress. In fact, the internet and networks created a framework for gathering and storing what later became known as "Big Data," which played a pivotal role in the evolution of automation technology in the 21st century (Beyer & Laney, 2012).



Figure 36 . Kembak 1. 1973.



Figure 37. Altair 8800. 1974



Figure 38. IBM 5100. 1975.

1.5.6. The Role of Automation in the Making

The dawn of the 21st century marked the consolidation of automation in society. Whereas the 20th century witnessed the mainstream implementation of automated systems primarily in manufacturing, the 21st century is experiencing a shift towards domestic or alternative areas (Zuboff, S. 2018). This transition was facilitated by the increased accessibility to technology driven by cost reductions and enhanced user accessibility. The consequential transformation in businesses and households was profound. Computers and automated machines have evolved from being mere curiosities to indispensable tools in professional settings and commonplace items in households (Brynjolfsson & McAfee, 2014).

The development and adoption of automation in the domestic sphere have continued apace. Concepts such as 'domotics' or home automation emerged, and it has become increasingly commonplace for households to feature numerous automated devices (Aloisi & De Stefano, 2018). For instance, robots have been reimagined as vacuum cleaners, window cleaners, or lawnmowers. Even the houses themselves have become automated; through the integration of sensors and automated systems, residences can autonomously manage aspects such as lighting, heating, security, and cleanliness (King, B. 2016)

Automation has also been found to have applications in other areas. Autonomous vehicles have begun to feature in urban and rural spaces, and robotics has extended its reach into diverse fields such as medicine, transportation, and leisure. However, the standardisation of automation in society has not only altered the manufacturing paradigm but has also triggered changes in various sectors of the economy.

The 21st century ushered in a form of automation that is prepared to redefine the nature of work in the foreseeable future - Artificial Intelligence (AI). The development of AI began as early as 1954 but truly took off during the early 2010s with the advent of deep learning and big data (Schmidhuber, J. 2015). These two concepts marked the transition from a theoretical approach to a practical, applicable technique. Subsequent research has led to the development of self-learning AI that is capable of not just data computation but also learning from and critically analysing data. While such capabilities were mooted during the 1980s and 1990s, their actual realisation was technically unfeasible until the first decade of the 21st century (LeCun, Bengio, & Hinton, 2015).

The initiation of self-training artificial intelligence (AI) marked a significant turning point that was shaping an ongoing revolution at the time of this writing. Organisations such as OpenAI have demonstrated the remarkable potential of AI and its potential impact on numerous sectors of society (Hassabis et al., 2017). Contemporary computational systems have evolved to perform calculations and engage in thinking and creative tasks. Historically, notions such as creativity were exclusively attributed to humans. However, the advent of advanced diffusion models capable of translating text into images shattered this paradigm (del Campo, M. et al. 2016). It is now widely acknowledged that every sphere of human cognitive activity is susceptible to transformation by this ongoing revolution. The future implications of automation extend beyond labour, potentially encroaching on the domain of human thought itself.

The notion of automation is far from novel. Humans have speculated about the prospect of artificial entities emulating human actions and cognition since ancient times (McCorduck, P. 2004). The vision of a hedonistic society in which strenuous labour and its associated responsibilities are shouldered by artificial agents, thereby enabling humans to enjoy abundance, has been a pervasive aspiration across historical societies. However, our contemporary society operates on a labour exchange for goods model, the structure of which could be substantially disrupted by automation.

Although the impact of automation on the workforce is relatively recent, it is gradually becoming more noticeable. Within less than two centuries of intensive labour automation, the workforce's composition and market dynamics have undergone considerable change, catalysing a rapid acceleration of societal evolution (Chui et al., 2016). Humans have transitioned from active participants to supervisors in manufacturing. Yet, even these supervisory roles are now being automated by advanced technologies such as computer vision and AI (Huang et al., 2008).

In light of a future scenario dominated by automation and AI, critical questions arise concerning the role and relevance of humans in the workforce. Will humans become passive observers, or can human labour maintain its relevance? Is there even a necessity for human labour to persist? These questions remain unanswered. Society is undeniably on the brink of significant changes, and the outcome of the automation revolution remains uncertain. While some projections are feasible, unexpected phenomena are likely to occur. If human labour does not retain its intrinsic value, its existence could potentially become redundant. Therefore, the

pressing issue arises of how to preserve the relevance of human labour and craftsmanship in an increasingly automated world.

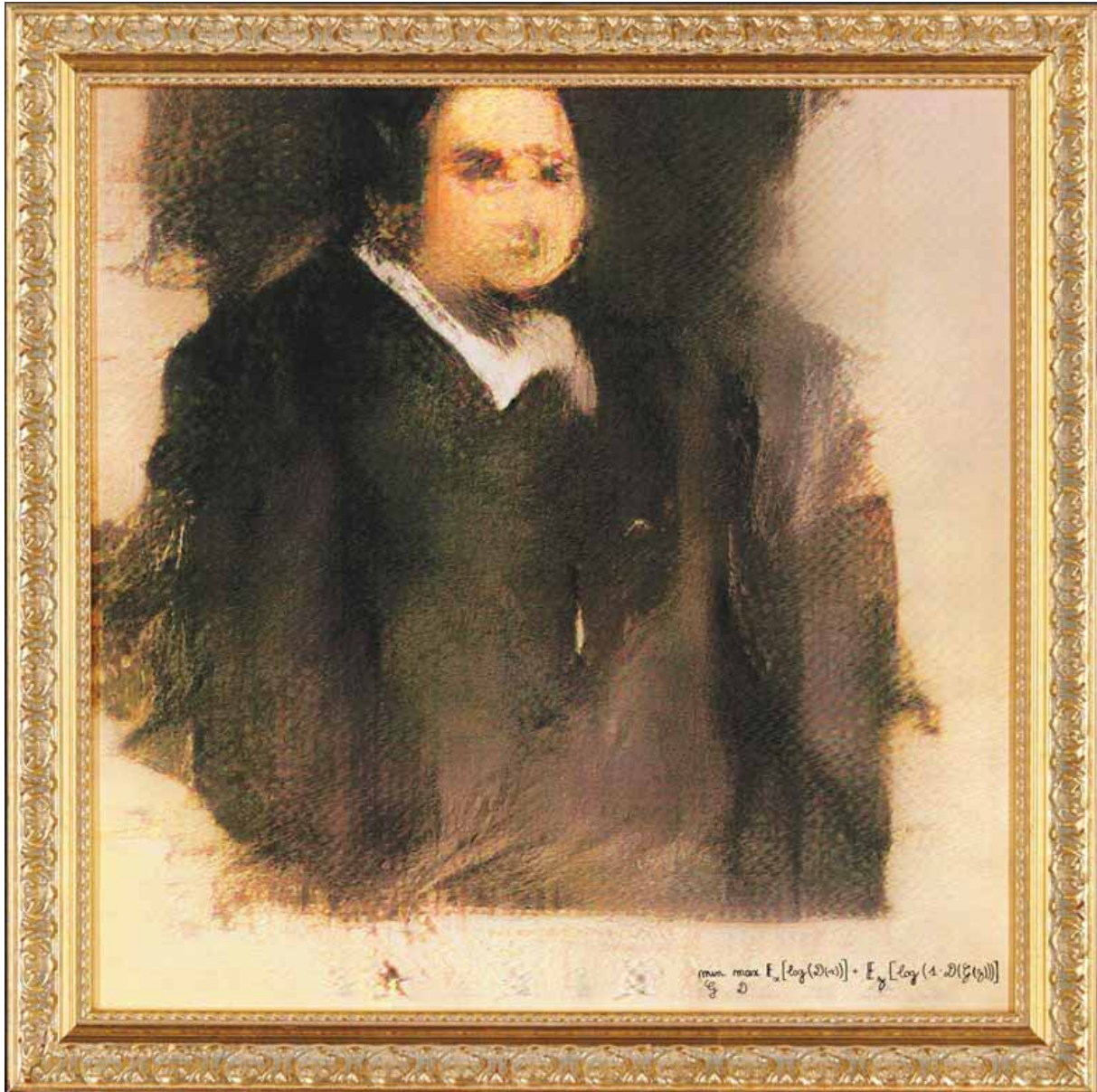


Figure 39. First AI Generated Image. Obvious. 2018.

1.6. Library 3: The Concept of Augmentation.

One of the signs of complex thinking in living beings in nature is using tools to perform tasks that would help them succeed. We can observe several species, like apes, or crows, that use different tools for particular needs. This, in essence, enhances their capabilities and allows them to manage situations that otherwise, by only natural means, were impossible.

Human beings have differentiated themselves from most animals since their dawn in terms of augmentation. The use of tools as part of everyday tasks can be traced to even before the Homo Sapiens time. Our capabilities as a species to achieve goals like hunting or farming accelerated our development, making us capable of things not defined by our DNA, unlike most of the animals of the time. This advantage was the reason humans progressed as a society and developed the current technology.

Throughout history, there are already well-known leaps in technology that have accelerated its development rate. Achievements like fire control, the wheel, and the cutting tools initiated the evolution of the machines and devices we use today. The history of technology is the history of how humans have enhanced their performance at all levels. If we define Augmentation as every external means to a body that will enhance the performance or the experience of a specific task, augmentation, in reality, covers all the means, from tools to visualisation devices up to Artificial Intelligence.

In terms of manufacturing, augmentation can be analysed in two categories. The first category is mechanical performance augmenting devices or physical augmentation. This would cover all sorts of tools, machines, and devices that make humans stronger, faster, or more precise when developing a task. The second category is the informative augmenting devices or Knowledge Augmentation. These are the ones that add information, whether visual, acoustic, or tactile, to the user. This enhances performance by increasing the knowledge of a task. These categories can also combine for further augmentation and, nowadays, even combine with automation to expand manufacturing capabilities.

1.6.1. Physical Augmentation

The origins of augmentative devices can be traced back to the Paleolithic era when early humans used basic stone tools for tasks like hunting and crafting (Rapp & Hill, 2010). As they mastered fire and developed more complex tools, significant breakthroughs occurred, including the invention of the wheel and transportation devices (von Sivers, Desnoyers & Stow, 2012).

By the end of the Stone Age, advancements in tools led to craftsmanship, decorative elements, and the first clothing (Bogucki, P. 1999). This evolution involved diversifying materials, such as wood, bone, and fur.

The Neolithic period saw further tool development, enabling carpentry, advanced textiles, and the emergence of musical instruments (Bogucki, P. 1999). Complex tools like the bow and arrow allowed for manipulating other objects, leading to navigation aids like canoes and shelters (Mithen, S. 1999). This era also marked the start of quarrying and wood exploitation, supported by stronger and higher-quality tools.



Figure 40. Prehistoric Human with Bow.

The discovery and mastery of metals marked a significant technological leap, enhancing toolmaking with superior durability and precision (Tylecote, R. 1992). This advancement allowed for more complex devices and early engines, establishing the foundation for tool manufacturing that persisted until the

Industrial Revolution. While tools evolved in quality during the ancient world and Middle Ages, the fundamental techniques remained largely unchanged (Ashton, T. 2004). The Industrial Revolution transformed tool utilisation and manufacturing with non-animal power sources and advanced scientific knowledge, leading to rapid developments in high-strength metals, glass, and ceramics and the evolution of physical augmentation devices (Pomeranz, K. 2001).

The latter half of the Industrial Revolution marked the mastery of electricity, which transformed power tools by making them smaller and more portable for the average worker (Hughes, T. 2004). This era distinguished between human-operated tools and autonomous machines, with the latter operating independently and having distinct purposes (Schwab, K. 2016). As steam and electrical power consolidated, portable tools evolved into affordable domestic appliances, leading to the widespread adoption of physical augmentation in the 20th century. This shift influenced both artisanal workshops and large factories as increased automation transitioned human labour from physical tasks to knowledge-based work, prompting a change in tool focus from physical to human enhancement (Mokyr, J. 2002).

The arrival of mechatronics and robotics transformed the concept of devices designed to directly improve human performance in terms of both strength and precision (Siciliano & Khatib, 2016). While the powered electric chair, invented in the 1930s, is considered the first such device, the development of advanced powered exoskeletons did not commence until the 1960s by the US military (Garcia, E. 2008). These devices aimed to augment soldiers' capacity to carry heavier loads. Several civilian applications have since been developed to increase worker performance and safety in heavy-duty tasks. In the medical field, exoskeletons are now designed to compensate for mobility impairments in patients.

These devices have pushed the boundaries of human capability, challenging our conception of humanity and evoking ideas of cyborgs. Although not prevalent in the manufacturing sector, the medical field provides numerous examples of early cyborgs in patients with electrical devices implanted to enhance their abilities, such as powered prostheses, heart control devices, or insulin-infusing devices (Clark, A. 2003). The human enhancement paradigm is now shifting from using external tools to integrating physical augmentation devices within the human body.

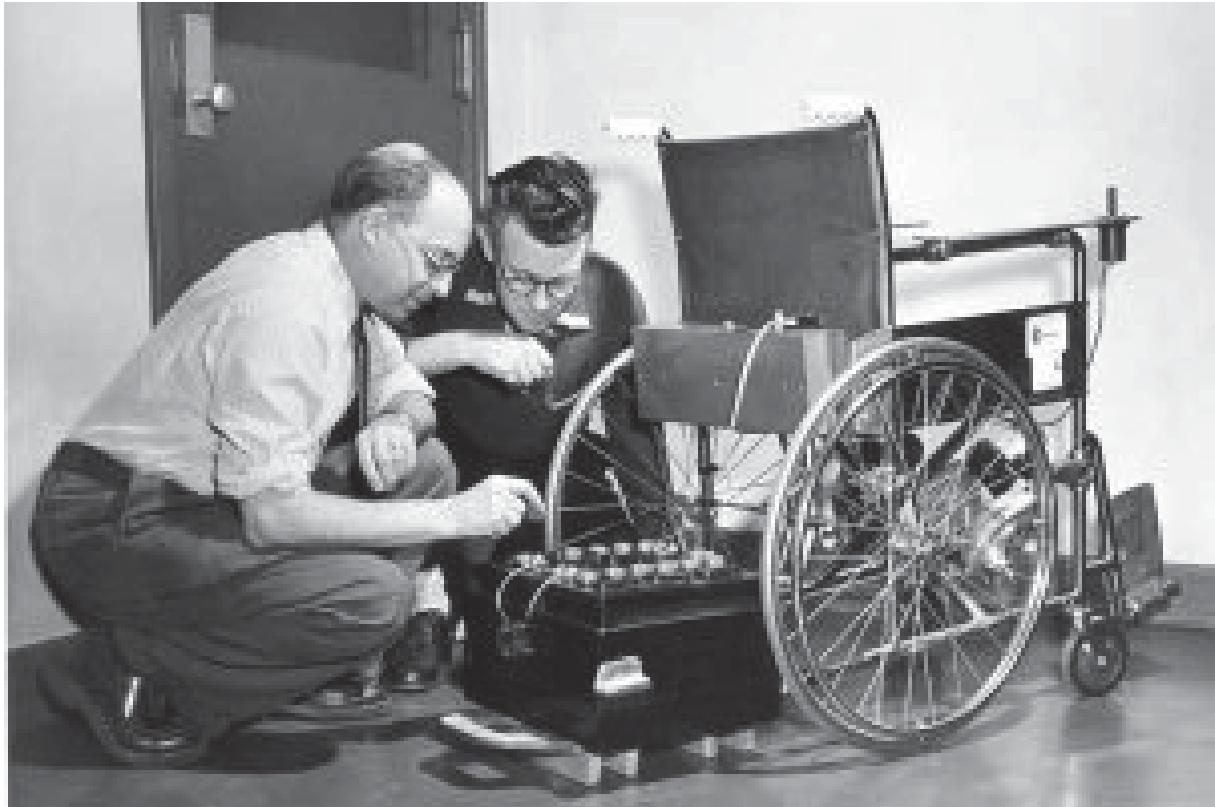


Figure 41. First Electric Wheelchair.1930.



Figure 42.Mechanical Exoskeleton.

1.6.2. Cognitive Augmentation

Identifying the earliest examples of cognitive augmentation is complex due to its various forms. Broadly defined as tools providing previously inaccessible information, rudimentary devices like solar clocks and astronomical calendars from the Neolithic period can be seen as early instances of cognitive augmentation (McLuhan, 1964). Additionally, tools like the plummet, used in construction, also fit this context.

As we approach the end of the metals period, the invention of the compass marked a revolutionary advancement in navigation, allowing for more accurate travel independent of the sun (Gies & Gies, 1994). Similarly, the astrolabe, created around the second century BCE, significantly improved maritime navigation (Kanas, 2007). Together, these inventions made long-distance sea travel practical, fostering societal development at the time.

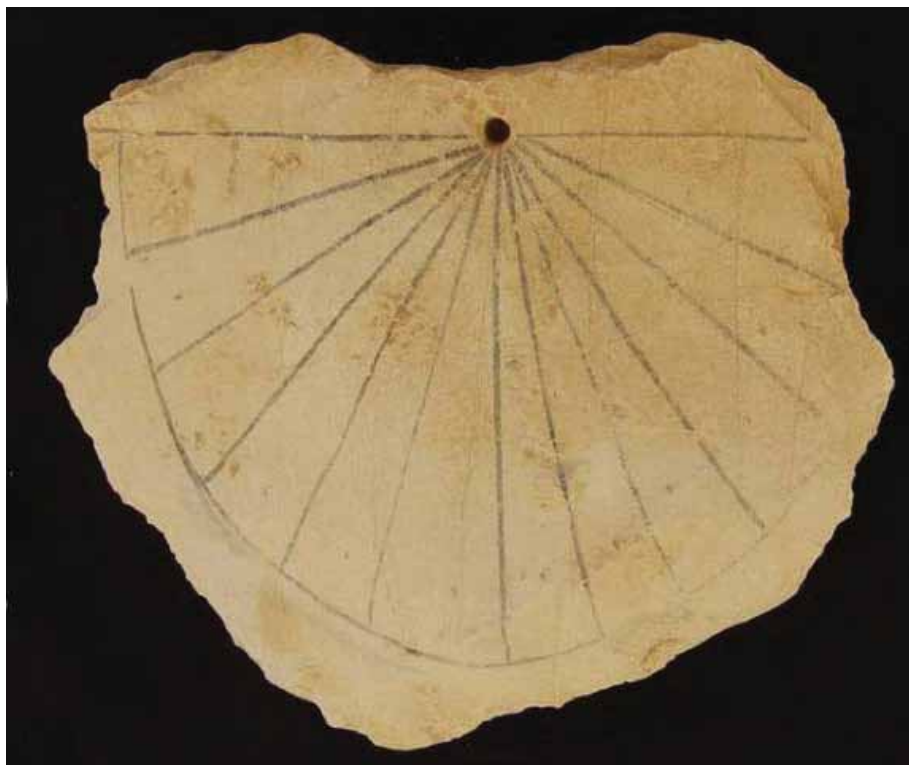


Figure 43. Prehistoric sun Clock

During the Middle Ages, cognitive augmentation technology evolved, particularly with navigation and construction tools becoming more precise and user-friendly. A notable invention was the eyeglasses, introduced in the 13th century to correct visual impairments (Ilardi, V. 2007).

The Modern Age saw the invention of the telescope by Hans Lippershey in 1608, which transformed our understanding of the universe (Van Helden, A. 1977). Around the 1620s, the microscope was developed, allowing humans to explore both long distances and microscopic levels (Wilson, C. 1997). This advancement in optics laid the groundwork for future developments in Augmented Reality.



Figure 44. First Telescope. Hans Lippershey. 1608.

The period marked significant advancements in measuring instruments, with the introduction of the mechanical clock, thermometer, and barometer (Golinski, J. 2007). These tools enabled real-time data verification and decision-making, paving the way for the Industrial Revolution in the late 18th century. As the 18th and 19th centuries progressed, advancements in precision measuring tools and vision

augmentation became crucial for cognitive enhancement and complex task execution (Norman, D. 2013).

In the late 19th century, the discovery of electricity and early mechanical computers, along with artificial lighting, set the stage for a revolution in augmentation in the 20th century. Additionally, inventions like the phonograph and cinema, while not directly augmentative, highlighted the possibilities of recording and creating synthetic realities (Benjamin, W. 1969).

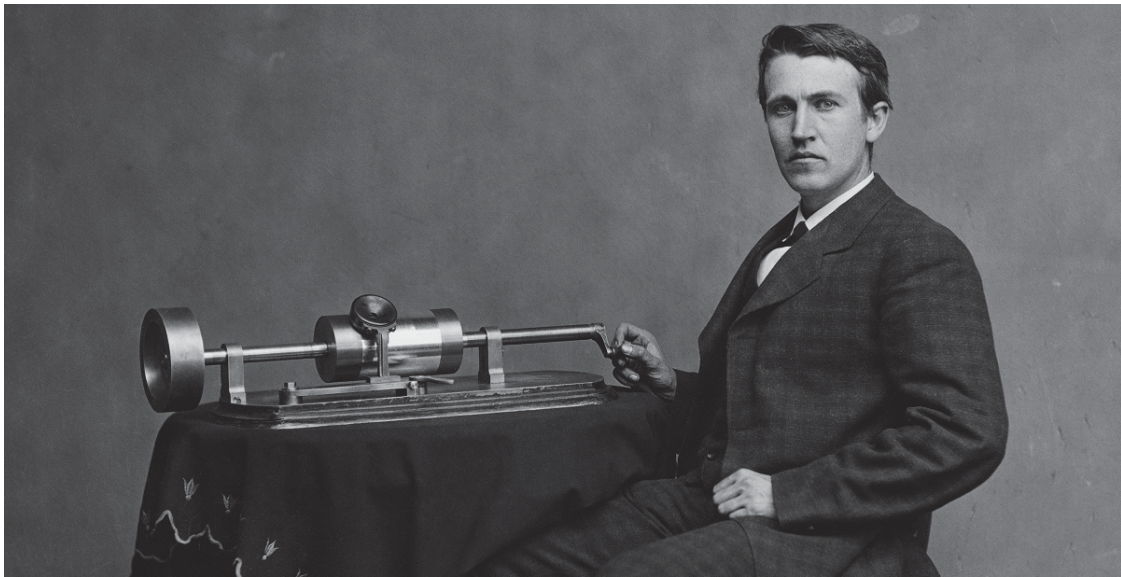


Figure 45. Edison with his Phonograph. 1878.

The beginning of the XX century and significant advancements in optics and lighting technologies heralded the birth of the first Augmented Reality device. As envisioned by noted telescope maker Howard Grubb in 1900, the reflector sight served as the pioneering AR device capable of superimposing real-time information over actual reality (Azuma, R. 1997). Initially, the reflector sight functioned as a targeting mechanism for cage rifles, enabling unparalleled precision for homing in on moving targets. Given its intrinsic features and capabilities, the reflector sight found swift adoption and underwent further refinement within the ambit of military technology. By the onset of World War I, it had seen significant enhancements, making it a critical part of aircraft and other artillery weaponry.



Figure 46. The Reflector Sight. Howard Grubb. 1900.

In 1897, Karl Ferdinand Braun invented the cathode tube, leading to the first electroluminescent screen in 1907, which enabled the visualisation of live information and laid the groundwork for future AR devices (Rheingold, 1991). In 1942, the UK Army developed what could be considered the first Heads Up Display, allowing pilots to view crucial tactical data on a transparent screen, enhancing their cognitive functioning and performance (Bowen, J. et al. 2020). Early science fiction, like Frank Baum's "The Master Key," envisioned electronic goggles for displaying information (Baum, 1901). Building on this, Morton Heilig created the Sensorama in 1958, an immersive device that provided sensory experiences through visuals and sounds, highlighting the potential of augmented reality (Heilig, 1962).

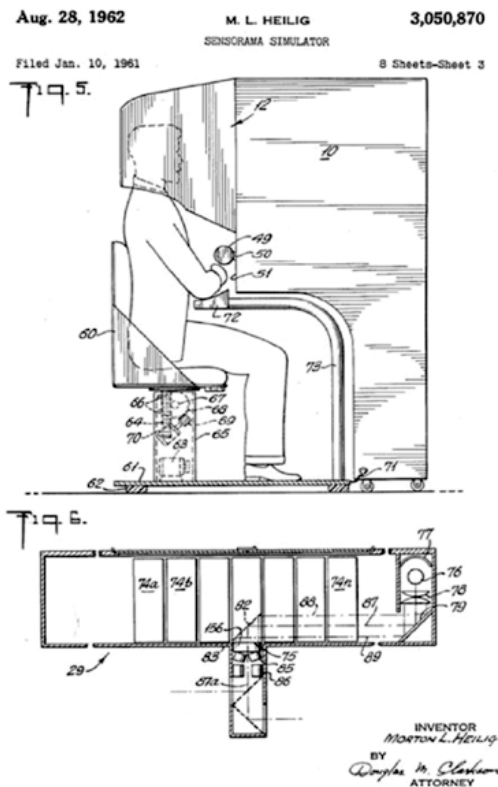


Figure 47. Sensorama. Morton Heilig. 1958.

The initial applications of AR technology in military scenarios and the Sensorama experiment established the potential value of AR as a tool to enhance human performance and experience in the future. However, the fact that these early devices were bulky and non-portable constrained their applicability. It wasn't until 1968, with the advent of the Damocles Sword device by Ivan Sutherland, that a portable AR device was tested (Sutherland, I. 1968). Recognised as the first Head-Mounted Display, Sutherland's device could present stereoscopic projection information to the user via two individual eye screens, overlaying digital images onto the real world. This innovative capability of the HMD garnered significant attention from the aviation industry, leading to the development of similar devices aimed at enhancing pilots' performance (Sutherland, I. 1968).



Figure 48. Damocles Sword. Ivan Sutherland. 1968.

In 1975, Myron Krueger, a computer scientist from the University of Wisconsin-Madison, conceptualised an experimental setup called Videoplace (Krueger, M. 1985). This space, equipped with an array of cameras and computers, allowed users to interact with digital objects and remotely control rooms by visualising a recording of the remote space. Although it was in its nascent stages, this experiment underscored the potential of AR in facilitating real-time human-computer interaction (Krueger, M. 1985).



Figure 49. Videoplace. Myron Krueger. 1975.

The notion of using AR for skills transmission and augmentation was further developed in 1980 when a researcher from the University of Illinois published a paper highlighting the advantages of using AR devices for teaching and learning technical skills (Feiner, S. 2002). This concept was later adopted by Boeing in the late 80s to assist electricians in assembling intricate electrical components using an AR screen that provided step-by-step guidance (Caudell & Mizell, 1992). During the same period, the first real-time information overlay for weather forecasting debuted on television. A significant milestone was also marked with the development of the EyeTap by Steve Mann in 1980, the first portable computer vision display, a technology that has become integral to contemporary AR (Mann, S. 1997).

While the foundation for Augmented Reality technology had been laid over the years, it was not until 1990 that this term was coined by engineer Thomas Caudell from Boeing (Caudell & Mizell, 1992). He created the term to characterise the company's system for intricate electrical and mechanical assemblies.

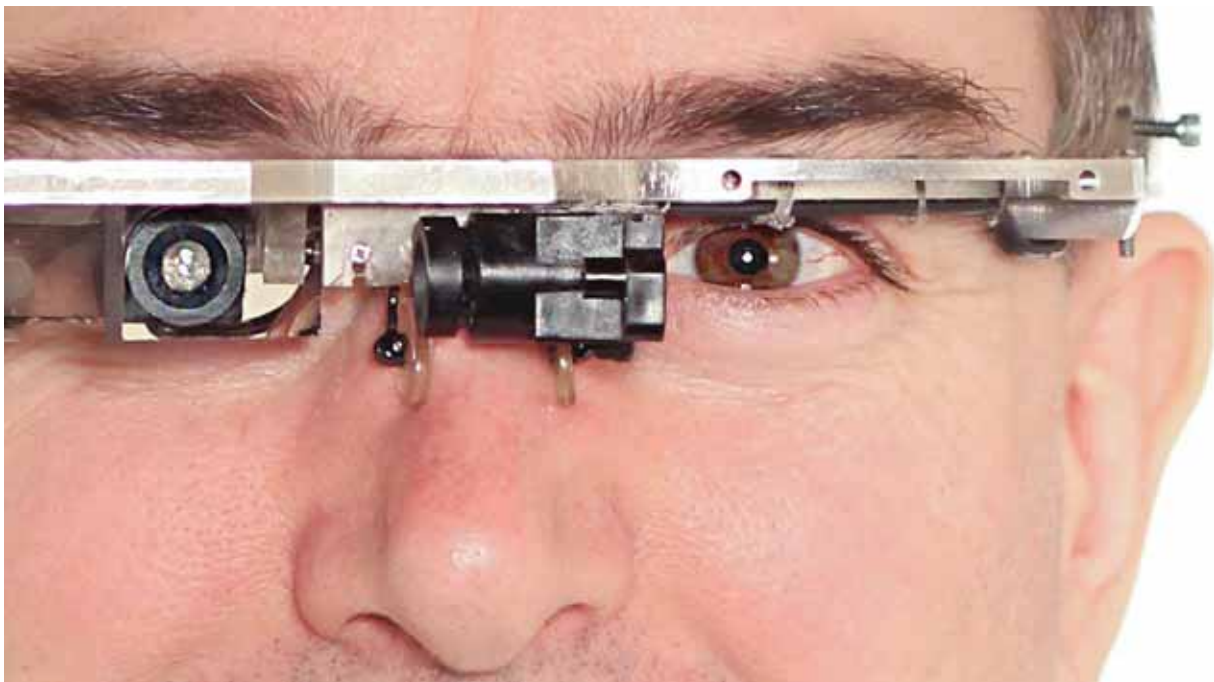


Figure 50. EyeTap. Steve Mann. 1980.

In 1992, researcher Louis Rosenberg developed a functional AR device during his tenure at the United States Air Force (USAF). The device was designed to assist a visual aid operator in operating a robot, and it included safety information areas

that helped the operator to stay within certain boundaries, thereby replacing traditional physical barriers with digital overlays (Rosenberg, L. 1992). Notably, Rosenberg continued his groundbreaking research after leaving the USAF, contributing significantly to the development of AR and the Mixed Reality Continuum Theory.

The introduction of Complementary Metal-Oxide-Semiconductor (CMOS) sensors for video and digital image recording in 1993 made digital cameras more portable and accessible (Nixon & Aguado, 2008). This technological innovation had a profound impact on the evolution of computer vision, a field essential for the advancement of AR.

In the wake of technological advancements in computing and computer vision throughout the late 80s and 90s, AR technology gained momentum across diverse sectors. For instance, the Heads-Up Display began to find commercial applications with its integration into the Oldsmobile Cutlass Supreme in 1988 (Bowen, J. et al. 2020). In addition, the video art scene also embraced the use of AR technology, a notable example being Julie Martin's 1994 project "Dancing in Cyberspace". The project consisted of a choreographed dance performance featuring live dancers interacting with digital objects projected on stage (Martin, J. 1994).



Figure 51. Cutlass Supreme Heads-Up Display. 1988.

This widespread adoption of AR technology across various fields during the late 90s stimulated the development of new portable devices and applications. Furthermore, several industries, including General Electric, began to test AR technologies in complex manufacturing processes to improve worker performance by integrating Computer-Aided Design models with real-world objects (Boud et al., 1999).

The dawn of the new millennium brought a flurry of significant breakthroughs in AR technology. In 2000, Rockwell Technology developed the first autonomous portable AR device (Milgram & Kishino, 1994). A year later, the Archeoguide project demonstrated the potential of AR in enhancing the understanding of ancient ruins through the use of digital model overlays on site (Vlahakis et al., 2001). In 2004, Trimble Navigation further developed this concept by creating the first standalone on-site visualisation device for the building industry (Trimble Navigation, 2004). This technological progression continued throughout the decade until 2008 when Android released the G1, the first smartphone operating system with AR capabilities. This development revolutionised the notion of ubiquitous and easily accessible AR technology, greatly influencing the creation of mass consumer devices throughout the 2010s (Schmalstieg & Hollerer, 2016).



Figure 52. Paranormal Activity gameplay. Ogmento. 2010.

The arrival of Augmented Reality (AR) technology in smartphones initiated a paradigm shift in the gaming industry, with various companies commencing exploration into the potential of this novel format. Notably, Ogmento's "Paranormal Activity: Sanctuary" was one of the pioneering efforts in this sphere, illustrating an AR interface that intricately linked GPS technology, thereby integrating the actual geographical location as an integral part of the gameplay (Ogmento, 2010).

Google X, a subsidiary of Google Inc., further contributed to the mainstream incorporation of AR by launching the first commercially available AR device - the Google Glasses, in 2013 (Google, 2013). These portable glasses could project augmented information to the user, record their environment, and display sounds. Although the product didn't meet the expected commercial success, it provided pivotal proof of concept that the development of autonomous portable devices for everyday use was within reach and carried profound potential for the mainstream market.



Figure 53. Google Glass. Google. 2013.

The impact of Google Glasses on the tech industry was substantial, inducing other companies to pursue the development of mainstream, multipurpose AR devices. A significant milestone was Microsoft's launch of HoloLens 1 in 2015, arguably the first fully immersive, autonomous stereoscopic AR device (Microsoft, 2015). Evolving significantly from the Google Glasses, the HoloLens boasted an extended

field of vision, enhanced interactive capabilities, and advanced environment recognition.

The introduction of the HoloLens marked a crucial evolution in AR technology, primarily because it was the first instance where AR became environment-interactive. This marked improvement implied that the HoloLens could be used for visualisation and direct interaction with the environment, thereby enabling the execution of complex tasks (Microsoft, 2015). The device proved vital in highlighting the potential of AR technology beyond mere visualisation and demonstrated the interactive capacity of the environment with computer vision technologies to influence the user's experience in real-time.



Figure 54. Hololense. Microsoft. 2015.

However, the watershed moment in the adoption of AR technology by the general public was arguably the release of "Pokemon Go", a smartphone game developed by Niantic in 2016 (Niantic, 2016). This application generated a worldwide phenomenon, introducing AR technology to millions of users for the first time. Consequently, the mainstream perception of AR experienced a radical transformation from being associated with science fiction to becoming a tangible, accessible reality.

The evolution of AR continues unabated, with consistent efforts toward creating and developing more immersive and comprehensive applications and devices.

Furthermore, its application has transitioned from the realm of the experimental to professional fields, with multiple industries adopting AR as a primary tool for executing complex tasks (Billinghurst, Clark, & Lee, 2015)



Figure 55. Pokemon Go. Niantic. 2016.

1.6.3. The Role of Augmentation in the Making

The history and evolution of augmentation technologies have had an essential impact throughout human history. Their use, from rudimentary tools to Augmented Reality, has marked several breakthrough moments, changing the understanding of the possibilities for humans to perform tasks and understand their environment. The typical limitations humans have due to their physiological composition have been long overpassed. As a technological species, we now rely on all sorts of augmentation forms to perform daily life and tasks. Humans have made augmentation their way to success as the dominant being on the planet Earth and even for exploring further territories. In this sense, as predicted by Michio Kaku, humans will be even more embedded in the near future with all sorts of augmentation devices that will entwine our capabilities with artificial intelligence and other technological means.

In terms of augmentation in the building industry, the scenario will be similar to the rest of society, and soon, we will be seeing more and better integration of cognitive augmentation technologies. The future of craftmanship and manufacturing will be balancing the idea of automation and computational design and digital manufacturing with human-made augmented work. Future workers will then be more versatile and capable of performing different tasks within a project, facilitating a wider pool and a more capable and precise workforce that will potentially be augmented in its performance, cognition, and potentially even intelligence by using AI. However, augmented technology will not replace the workforce or human intelligence in the same form as automation. The augmented craftsmen and workers will combine human intuition and rapid reaction to events with their aesthetical views and enhance them using the technology. The “Human Touch” will not be lost but integrated with digital means to achieve better and more optimised results. Augmented technologies have the potential to connect tradition and the digital future to ensure that human machines coexist in a productive manner that will eventually expand and improve the results, being the sum of the factors bigger than the value of the isolated elements.

1.7. Entwining Libraries.

The art of manufacturing has served humans since its early beginnings as a forward species from the rest of the big apes. Its ability to fabricate tools and weapons to enhance hunting and gathering gave them a clear competitive advantage over the rest of the animal species of the time. However, the impact of manufacturing is not only based on the tool performance skills. Through manufacturing, humans have also developed the idea of arts and the idea of artificial entities. These two artificial concepts show how powerful the idea of creation can be and how things like travel space or artificial intelligence are now possible by evolving these techniques.

From the perspective of the thesis, the three libraries explain the synergy between living beings and artificial objects. Craftmanship is the human ability to fabricate artificial objects, Automation is the capability of artificial machines to perform human tasks, and Augmentation is the bridge between humans and machines, bringing together all the parts to assemble the technology. The entwining of these three concepts is also the base for all architectural and artistic creation. They have been instrumental in the creation of useful and aesthetic buildings that are also functional, as well as other objects or furniture.

To completely understand this thesis, these three libraries serve as the technical knowledge base to evaluate and comprehend the impact of automation, augmentation and craftmanship within the manufacturing environment. The relationship between them is also capital as these concepts can compete or collaborate, and their balance is determinant in how the making ideals can evolve in a digital society. For example, the evolution and implementation of tools and technologies have influenced the fluctuation of perceived value in crafted goods. This particular industry tends to be conservative and reluctant to include any new technologies, as it positions the human as the centre of the composition, giving, in many cases, an artist recognition to the makers and their objects. This idea represents a primary issue as it defines automation as the antagonist instead of an ally. Similar approaches can also be seen with digital design and augmented technologies. They are seen as dehumanised, and their use tends to be rejected as a crafted product. In that sense, it is essential to see and understand how the

evolution of these three technologies is actually connected, and as this thesis postulates, their collaboration can only be productive and maybe necessary for their future and complete integration with the digital world. Craftmanship will need to accept and integrate digital technologies, while digital technologies will then need to create solutions that will cater to craftmanship. Also, automation should be part of this entwining as it will help and improve production, allowing for more decentralised and flexible manufacturing. Its use together will also help to make craftmanship more affordable and accessible to new artisans, and together with the augmentation, they can facilitate the preservation and transmission of artisanry traditions. Finally, augmentation, whether for making or for designing, can play a fundamental role as the medium to preserve and transmit knowledge, connecting it with new users, places, and automation techniques. The reality is that these three concepts should not be seen as competitors anymore. They need to be understood as part of the same idea, which is the idea of making for the future.

2. State of the art

The thesis focuses on exploring the current state of the industry and its relationship with automation, augmentation, and digital technologies. It aims to understand how the integration of architecture and digital media is transforming the way we learn, design, produce, and build architecture. Comprehending the current situation is crucial, as it impacts not only the building industry but society as a whole. In this context, Daniel Bell's work serves as a fundamental analytical framework to evaluate areas such as society, knowledge, skills, and education.

Daniel Bell predicted significant societal and economic changes that continue to shape our world today. The industry has undergone notable transformations, reflecting key aspects of Bell's insights, such as the shift towards a knowledge-based economy, the rise of the service sector, the importance of information and innovation, flexibility, and adaptability, as well as cultural and social considerations.

One of Bell's central ideas was the transition from an industrial economy to a knowledge-based economy, which is evident in the architectural and design industry. Design professionals have moved from manual drafting to using sophisticated computer-aided design software and building information modelling tools. Architects and designers now rely on data-driven insights, 3D modelling, and virtual reality to create and visualise designs. The emphasis has shifted from craftsmanship to knowledge-intensive practices, prioritising research, analysis, and the integration of information into design processes.

Bell also highlighted the growing importance of the service sector, which is particularly pronounced in the architectural and design industry. While the creation of physical spaces remains crucial, design professionals now offer services related to planning, project management, sustainability consulting, and user-centric design. Clients seek comprehensive solutions that go beyond aesthetics, requiring architects and designers to provide services encompassing functionality, environmental considerations, and user experience.

The centrality of knowledge and innovation in post-industrial society was emphasized by Bell. Architects and designers play a critical role in driving innovation within the built environment. They are responsible for incorporating

sustainable practices, smart technologies, and adaptable designs that respond to rapidly evolving user needs. The architectural and design industry is at the forefront of research and development, continually exploring new materials, construction techniques, and design philosophies to meet the demands of the information age.

Bell's concept of flexibility and adaptability aligns with the evolving nature of the architectural and design industry. Professionals in this field must be agile and responsive to changing client preferences, emerging technologies, and evolving regulatory environments. The ability to pivot, embrace new information, and adapt to emerging trends is essential for success.

Bell's insights into cultural and social changes are mirrored in the architectural and design industry's evolution. Design professionals now place a stronger emphasis on inclusivity, sustainability, and cultural relevance. Architects and designers are creating spaces that reflect cultural diversity, address environmental concerns, and respond to changing social dynamics. This focus on social and cultural considerations is reshaping the industry's practices and priorities.

Bell's ideas have also influenced architectural and design education and training. Design schools and programs have adapted to the changing demands of the post-industrial era by integrating technology, interdisciplinary learning, and research-driven design into their curricula. Graduates are equipped with the skills and knowledge needed to thrive in a knowledge-based industry.

The architectural industry has shifted towards a knowledge-based economy, with a rise in the service sector and a focus on information, innovation, flexibility, adaptability, and cultural and social factors. These changes reflect the broader societal shifts that Bell predicted, demonstrating how knowledge, information, and adaptability have become paramount in our post-industrial world. Architects and designers play a crucial role in shaping the future of our societies by creating a built environment that is in keeping with the principles of the post-industrial era.

This section of the thesis will, therefore, use this framework to define the state of the art and establish a theoretical background in connection with the hypotheses presented in this text. Five primary areas are studied based on the concepts proposed by Bell: Socioeconomic context, the value of skills, the influence of automation, new digital service-based environments, and the distribution of knowledge.

2.1. The Augmented Society

The second half of the 20th century marked the beginning of two very influential social changes: the transition from traditional production-based capitalism to financial-based capitalism and the rise of digital technologies. These shifts mark the onset of the post-industrial era (Castells, 1996). These changes in the socioeconomic fabric had a profound impact on human relationships and societal dynamics. The expansion of mass media and communications revolutionised access to information and its dissemination, connecting society to knowledge in a globalised manner (Giddens, 1990).

One significant element that heavily promoted this transformation is the Internet. It has played a decisive role in shaping post-industrial society and is now the primary medium through which social trends and interactions are driven. This creates a fluid environment for communications, information exchange, and human interactions (Manovich, 2001). As digital technologies become increasingly integrated into our daily lives, our reliance on them grows. Technology is now not only a tool to enhance or perform tasks but also a medium that completes and defines various aspects of our society and lives (Turkle, 2011).

As a result, traditional analogue experiences are gradually being displaced by digital alternatives. From games to news, socialising to artistic expression, there is a clear trend towards a digital-centric existence, often at the expense of authentic, real-world engagement.

The increasing integration of digital technologies and artificial content into society aligns with Baudrillard's concept of simulation as described in "Simulacra and Simulation" (Baudrillard, 1988). Contemporary society is becoming increasingly dependent on digital hardware and content, shifting the form of human interactions and relationships. Likewise, advances in computer-generated images and artificial intelligence contribute to the creation of a hyperrealistic world where the line between reality and simulations is completely blurred (Manovich, 2001).

The question of what reality is and what simulation is—essentially what is true and what is fake—has become more unclear than ever, defining a new stage in the digital age. Concepts like digital edition, public validation, or the value of aesthetics over content are promoting a change in the creative discourse. The

digital sphere now dominates society, with its influence overreaching every aspect of our lives (Turkle, 2011).

While technology has the potential to improve and enhance our lives, it also carries significant risks if we fail to acknowledge and address the implications of a fully simulated society. Understanding the distinction between reality and virtuality is crucial for comprehending the truth and intrinsic value of things. Allowing everything to be a simulation poses the risk of devaluing reality itself, undermining its importance, and neglecting the need for its existence. It is paramount to exercise caution and control over the phenomenon of simulation, as the consequences of unchecked simulation can be rhizomatic and unpredictable (Baudrillard, 1988). The proliferation of digital media has created a world of hyperreal images and narratives, often disconnected from their original referents. Social networks, with their emphasis on self-presentation and curated identities, contribute to the construction of hyperreal selves, leading to the fragmentation of individual identities (Turkle, 2011).

As digital technologies become increasingly integral to our society, the need for a balanced coexistence with their presence becomes paramount. As a society, we must carefully consider the implications of these technologies and their implementation in the future while ensuring that we maintain control over how they influence our world. It will be essential to ensure a balance of coexistence between the digital and physical realms. Governance will be key in creating a fair and humanistic future (Castells, 1996). In fact, a correct balance will not only be positive but could enhance our society, helping us preserve the value of the authenticity of the human experience while moving towards a fully interconnected and integrated society.

The hypermodern society is characterised by individualism, constant change, and media dominance (Lipovetsky & Serroy, 2013). Mass media and social networks play significant roles in shaping consumer preferences and behaviours, thereby influencing society's values and norms. Individuals seek validation and recognition by consuming and promoting media-driven trends (Couldry, 2012). These platforms contribute to the liquid modernity of our society, facilitating the creation and dissolution of connections and enabling the rapid dissemination of information. However, these platforms can also perpetuate superficial interactions and shallow relationships, hindering the formation of deep and meaningful social bonds (Turkle, 2011).

The impact of mass media and social networks on the design environment has significant implications for how it is being reshaped. Design is no longer limited by physicality but extends to the digital world. The influence of interfaces, information, and user experiences is now part of the equation. Overall, its impact is already visible and expected to progress in the near future (Carpo, 2011).

Firstly, the attention economy fuelled by social media platforms has shaped design practices. Designers must now create visually captivating and attention-grabbing content to compete for the limited attention spans of users (Couldry, 2012). This emphasis on visual appeal and instant gratification has influenced the aesthetics and functionality of digital interfaces and the design of advertisements and marketing materials.

Secondly, social networks have democratised the creation and distribution of design. Individuals can now easily share and promote their design work, bypassing traditional gatekeepers. This has led to a proliferation of user-generated content, challenging traditional notions of authorship and expertise (Turkle, 2011). However, it has also raised concerns about the quality and ethical implications of design, as misinformation and fake news can spread rapidly through these channels.

Furthermore, the hyperreality state produced by mass media and social networks has impacted the design of physical spaces and objects. The desire for immersive experiences and "Instagrammable" moments has influenced the design of retail spaces, art installations, and public environments (Lipovetsky & Serroy, 2013). Designers must now consider how their creations will be perceived and shared through social media, leading to an increased focus on creating visually striking and shareable experiences. Designers must navigate the challenges and opportunities presented by these platforms, considering the ethical implications and the need to create meaningful and authentic experiences in a hyperreal world.

Moreover, the rise of digital platforms and augmented reality applications is redefining social interactions. Platforms like Facebook, Instagram, and TikTok, alongside AR tools such as Snapchat filters and Pokémon Go, are not only altering how people connect but also how they perceive reality. These technologies enable users to overlay digital information onto the physical world, creating a hybrid environment where digital and physical realities coexist. This blending of realities is further pushing society towards a state where the distinction between real and virtual becomes increasingly irrelevant.

However, this shift is not without its challenges. The continuous engagement with these augmented environments can lead to a disconnection from the physical world and real human interactions. Researchers like Sherry Turkle have argued that while technology offers new forms of connection, it often leads to shallow interactions and a sense of isolation, as people increasingly prefer digital communication over face-to-face conversations (Turkle, 2011).

The implications of augmented and virtual realities extend beyond social interactions to cultural identity and preservation. As these technologies allow for the creation of hyperreal environments, they also enable the digital preservation of cultural heritage. Through AR and VR, historical sites and artefacts can be experienced in new ways, providing educational opportunities and promoting cultural awareness. However, there is a concern that these digital recreations might overshadow the importance of preserving the physical, tangible aspects of culture.

For instance, while a virtual tour of a historic site can provide accessibility to those who cannot visit in person, it cannot fully replicate the experience of being physically present in that space. The risk is that as society becomes more accustomed to digital experiences, the value placed on preserving physical heritage might diminish. This highlights the need for a balanced approach that leverages digital technologies to enhance cultural preservation without undermining the importance of the physical artefacts and sites themselves.

As digital and augmented realities continue to permeate every aspect of life, ethical considerations become increasingly important. Issues such as data privacy, digital surveillance, and the manipulation of digital content are critical areas that require careful attention. The creation and dissemination of digital content that blurs the line between reality and fiction pose significant challenges in determining what is authentic and trustworthy.

Moreover, the use of augmented reality in public spaces raises questions about consent and the potential for intrusive experiences. For example, AR applications that overlay information onto the physical world can alter an individual's experience of that space, potentially infringing on their personal autonomy and privacy. As these technologies evolve, it is essential to establish ethical guidelines and regulatory frameworks that protect individuals' rights while fostering innovation.

The augmented society, shaped by digital technologies and augmented realities, presents both opportunities and challenges. While these technologies have the potential to enhance social interactions, cultural preservation, and education, they also raise significant ethical questions and risks related to the devaluation of physical reality and the erosion of authentic human experiences. As society continues to navigate this digital transformation, it is crucial to find a balance that embraces the benefits of these technologies while safeguarding the core values of human interaction, cultural heritage, and personal privacy.

2.1.1. Extending Realities.

The emergence of Mixed Reality could become a significant factor in shaping the future of society. Mixed Reality, as defined in the glossary, is a technology that blends virtuality and reality in a gradual continuum, encompassing elements of Augmented Reality and Virtual Reality (Milgram & Kishino, 1993). It creates an immersive experience that has the potential to impact society profoundly. As a digital environment, MR aligns with the concept of a "Liquid Society" because it represents an ever-evolving medium that eschews permanence. Zygmunt Bauman's framework of the Liquid Society offers valuable insights into understanding the upcoming changes that MR could bring (Bauman, 2000).

MR also fits with this notion of a Liquid Society as it exemplifies the fluidity and flexibility of technology. As MR bridges reality and virtuality, it allows individuals to perceive and interact with both worlds seamlessly. This facilitates real-time engagement with the digital world, creating a sense of immediacy. In this context, MR encapsulates some of the paradigms of the Liquid Society. Therefore, understanding MR within this framework is fundamental to analysing its potential social impact.

Furthermore, the duality of Mixed Reality closely aligns with Jean Baudrillard's idea of Hyperreality. By intertwining the virtual world (simulation) with the real world, MR blurs the line between these states. This interconnection results in a hyperreal condition where the distinction between what is real and what is

simulated becomes irrelevant, as the new reality is the simulation itself (Baudrillard, 1994). These simulated experiences can potentially change human interactions and the way we perceive reality. There is also a risk that the virtual could overtake the real, which, according to Baudrillard, could lead to the collapse of society as the concept of truth becomes obsolete. Accordingly, a careful study of these factors and their ramifications is essential to ensure the sensible implementation of MR in our daily lives.

The impact of MR on society within the framework of Liquid Society and Hyperreality can be observed across various fields. In entertainment and media, MR offers hyperreal experiences that captivate and engage users in unprecedented ways. For example, MR applications in gaming can create immersive virtual worlds that offer an intensified sense of presence and interaction. These experiences have the capacity to transcend the limits of mainstream media, potentially redefining the boundaries of reality. As a result, MR could contribute to a new form of Hyperreal immersive entertainment and social interaction.

Similarly, Mixed Reality could reshape communication, altering how people engage and connect with one another. With MR technologies, individuals can participate in shared virtual experiences, regardless of physical distance. This fluidity of presence and interaction challenges traditional notions of social connectedness and expands the possibilities for communication in a Liquid Society. However, the prevalence of MR-mediated communication may also contribute to a sense of Hyperreality, where the distinction between authentic human interaction and simulated experiences becomes increasingly blurred.

In education and learning, MR could revolutionise the way knowledge is acquired and assimilated. MR applications offer immersive and interactive learning environments, enabling learners to engage with content in novel and engaging ways. The immersive nature of MR learning experiences challenges traditional educational paradigms, providing learners with Hyperreal encounters that blur the boundaries between real-world contexts and simulated scenarios. However, it is crucial to consider the potential risks associated with Hyperreality in

educational settings, such as the loss of critical thinking and the uncritical acceptance of simulated information.

The design and architecture fields could also be significantly impacted by MR within the context of Liquid Society and Hyperreality. MR enables architects and designers to create virtual representations of physical spaces, facilitating immersive and interactive experiences for clients and stakeholders. This fluidity between virtual and physical environments challenges traditional design processes and offers new opportunities for architectural expression. However, the Hyperreal nature of MR experiences may also raise questions about the authenticity and integrity of architectural representations, necessitating critical reflection on the balance between simulation and physical reality.

Mixed Reality has the potential to transform society, particularly in the context of Hypermodernity and a fluid society. It could redefine the boundaries between physical and virtual realities, enabling seamless transitions and challenging conventional notions of space, time, and identity. While MR offers exciting possibilities in entertainment, communication, education, and design, it also raises important considerations regarding the impact of Hyperreality and the erosion of authentic experiences. As society continues to navigate the fluidity of the digital age, it is crucial to engage critically with the implications of MR and ensure that its implementation aligns with the values and aspirations of a rapidly changing world.

2.1.2. Augmentation as the solution

From the gradient defined by Mixed Reality, the technology of Augmented Reality will be marked as one of the most relevant elements in the coming years (Kaku, 2014). It has an interesting potential to transform many aspects of our society. From education to gaming up to manufacturing, AR defines a new approach where the influence of real-time virtual information becomes a pivotal factor of progress.

The futurist Brett King highlights the role of augmented reality in creating more immersive and engaging social experiences. With AR, individuals can communicate and interact in new ways, transcending geographical boundaries and

bringing people closer together (King, 2012). For instance, AR applications can facilitate remote collaboration and communication, enabling individuals to share a common augmented space and interact with virtual objects in real-time.

Moreover, AR and MR have the capacity to enhance educational practices. Michio Kaku emphasises the potential of augmented reality in creating immersive educational experiences (Kaku, 2014). AR applications can overlay interactive 3D models, simulations, and visualisations onto textbooks or real-world objects, making learning more interactive, engaging, and effective. Students can explore complex concepts and interact with virtual objects, fostering a deeper understanding and retention of knowledge.

In addition to education, Augmented Reality technologies have the potential to revolutionise the entertainment and media industries. Louis B. Rosenberg emphasises the transformative potential of mixed reality in creating interactive storytelling experiences (Rosenberg, 2024). MR can enable users to actively participate and influence the narrative, blurring the boundaries between fiction and reality. For example, AR games can allow users to interact with virtual characters and objects in the real world. Furthermore, AR can enhance live events, concerts, and sports by overlaying digital content, statistics, and information onto the physical environment, providing spectators with a more enriched and interactive experience.

The impact of augmented reality extends beyond entertainment and education; it has significant implications for healthcare and medicine. New forms of diagnosis and treatment are possible, which can help patient care and survival. For example, Augmented Reality can be used to assist doctors and surgeons, providing real-time overlays of patient data and procedure information. They can also display medical imaging as well as help in collaborative processes (Kaku, 2014).

MR can allow surgeons to visualise and manipulate virtual organs or structures during surgeries, enhancing precision and reducing risks. Additionally, AR can improve patient education and rehabilitation by providing interactive and personalised information and guidance.

However, as with any emerging technology, several challenges and considerations must be properly addressed and evaluated. Concepts like ethical concerns about privacy and security are relevant to the safe use of the technology. These technologies are capable of collecting vast amounts of data, so it is important to carefully define a reasonable frame for its use in this sense. Additionally, access to

and affordability of AR and MR technologies can create disparities, limiting their benefits to certain segments of society.

The use of augmentation technologies presents itself as a relevant actor for the upcoming future in enhancing the performance of several professions. Its implementation in areas like Education, Entertainment, and healthcare, among other industries, will soon redefine several professions and ways of interaction. It is paramount, then, to prevent future problems by creating working and legal frames that can support and facilitate the correct and productive use of the technology.

2.1.3. Augmenting the future

Preserving cultural heritage is crucial for maintaining a society's collective memory, history, and identity. Cultural heritage encompasses tangible structures, such as historic buildings and archaeological sites, as well as intangible elements, such as traditions, customs, and knowledge systems. Preserving cultural heritage is essential to maintaining diversity and allowing future generations to connect with their roots. With the emergence of digital design technologies in recent years, architects now have powerful tools to document, analyse, restore, and reconstruct cultural heritage.

Digital design technologies provide architects with precise and accurate methods to capture and document cultural heritage sites. Techniques such as 3D scanning, photogrammetry, and laser scanning enable the creation of detailed digital representations of historic structures and archaeological sites (Sanchez, 2016). These digital documentation techniques are crucial in the creation of comprehensive databases that serve as references for future preservation efforts. Digital documentation ensures accurate recording and facilitates the sharing and dissemination of knowledge among experts and the public.

Mixed Reality tools empower architects to reconstruct and visualise cultural heritage sites in a virtual environment. Virtual Reality and Augmented Reality technologies offer immersive experiences that can recreate digital twin spaces (Carpo, 2017). Through virtual reconstructions, users can gain valuable insights into heritage sites' original designs and construction, even if they have undergone

transformations over time. Interactive virtual tours and simulations provide individuals with novel ways to engage with cultural heritage, promoting a deeper understanding and appreciation of historical architecture.

Digital design technologies enable architects to engage in adaptive reuse and design interventions that breathe new life into historic structures while preserving their cultural significance. Balancing preservation and innovation is crucial in architectural practice (del Campo, 2019). Techniques such as parametric design and computational design allow for the creation of adaptive and responsive architectural interventions that respect the historical context while meeting contemporary needs. This approach ensures the sustainable use and preservation of cultural heritage sites.

Another advantage of using digital design technologies in the context of heritage preservation is their role in promoting sustainable practices. Integrating environmental analysis tools into the digital design process allows architects to simulate energy performance, daylighting, and thermal comfort (Sanchez, 2016). By doing so, architects can develop conservation strategies that minimise the environmental impact of interventions at heritage sites. Digital design also enables architects to explore innovative and sustainable materials and construction techniques that respect the historical integrity of cultural heritage while ensuring long-term preservation.

Digital design in architecture has the potential to democratise access to cultural heritage and encourage public participation. The concept of "digital heritage" enables the creation of online platforms and virtual museums where individuals can remotely access and explore cultural heritage (Carpo, 2017). Crowdsourcing initiatives allow the public to contribute to preservation by sharing personal stories, photographs, and memories of heritage sites. Social media platforms facilitate the wider dissemination of cultural heritage, creating opportunities for engagement and fostering a sense of collective ownership and responsibility.

The use of Augmented Reality as a medium to preserve cultural heritage represents an interesting opportunity that connects technology with tradition. By augmenting the environment around the user, information can be transmitted and visualised in context. It can therefore improve the user experience and facilitate a better understanding of the cultural value, contributing to its preservation.

AR applications can provide visitors with additional layers of information and context when exploring cultural heritage sites. By using mobile devices or

wearable technology and digital apps, users can access AR content that enriches their understanding of historic buildings, artifacts, or landscapes. For example, AR apps can superimpose virtual reconstructions onto physical structures, allowing visitors to see how the site might have looked in the past. This immersive experience bridges the gap between the present and the historical context, encouraging a deeper connection and appreciation for cultural heritage.

Moreover, AR can facilitate interpretation and education by delivering interactive and engaging content. Visitors can learn more about the significance and history of cultural heritage sites by accessing multimedia materials like videos, images, and audio narratives. Additionally, AR applications can offer real-time guidance and navigation, making it easier to explore the site and access relevant information efficiently.

In terms of public participation, AR can enable user-generated content and contributions. Visitors can capture and share their experiences through AR-enhanced photographs or videos, adding personal perspectives and stories to the cultural heritage narrative. This user-generated content can be incorporated into digital platforms, creating a collaborative and dynamic archive of cultural heritage.

AR technology has the potential to enhance the accessibility and inclusivity of cultural heritage, transcending physical limitations and geographical boundaries. Remote access to AR applications enables individuals who cannot physically visit the sites to engage with cultural heritage in meaningful ways. The preservation of cultural heritage is greatly enhanced by digital design in architecture, which allows people from all over the globe, including students, researchers, and enthusiasts, to explore and learn about these sites. This raises a sense of global community focused on cultural heritage preservation.

Architects can ensure the long-term preservation and appreciation of our diverse cultural heritage through digital documentation, virtual reconstruction, adaptive reuse, and sustainability-driven practices. Augmented reality further enhances these efforts by offering immersive and interactive experiences that engage visitors and promote wider accessibility. As technology advances, architects and researchers need to tap into the potential of digital design tools and augmented reality to protect and honour cultural heritage for future generations.

The convergence of digital design technologies and AR offers significant opportunities for preserving, disseminating, and celebrating cultural heritage.

Professionals from the architectural industry and academia must continue to explore the potential and values that these technologies have. This is necessary to ensure the long-term preservation and appreciation of our diverse cultural heritage. However, it is paramount to address the ethical and legal challenges that Mixed Reality, and particularly Augmented Reality, pose. Concerns regarding privacy, security, and data protection are important and necessary to address. Additionally, ensuring democratic access throughout society is of significant importance. Without it, the implementation will never be fully realised. By creating a reasonable balance between all these matters, society can benefit from Mixed Realities. The values of preserving authenticity, heritage, tradition, and knowledge are fundamental to ensuring that digital technology remains human, celebrating the past while looking towards the future.

2.2. Skills, Knowledge and Heritage in Making

One of the unique characteristics of human society is its remarkable ability to document and transfer knowledge across generations, distinguishing it from other animal societies (Tomasello et al., 1993). This ability facilitates the transfer of knowledge across time and geographical locations without the physical migration of individuals. Humans stand alone among Earth's inhabitants in their capacity to construct a global, timeless archive of knowledge. This radical capability contrasts sharply with the knowledge retention systems found in the rest of the world's species. The far-reaching implications of this unique ability have facilitated the development of sophisticated technologies over generations, significantly augmenting the overall performance of the human species.

Initially, the transmission of knowledge within human society was based on an intergenerational system. Knowledge was shared orally within small, localised groups. This method remained prevalent until the invention of the written word, a development that triggered a significant shift in the way knowledge was disseminated. The ramifications of this evolution in communication were profound. First, the discovery of durable mediums, such as the clay tablets of the Sumerians (Schmandt-Besserat, 1996) or the papyrus of the Egyptians, enabled long-term information storage. Second, the portable nature of these written materials allowed their transport to different locations, thereby broadening the dissemination of the written content. This transformation signalled a substantial change in the reach and speed of skill and technique propagation, impacting the growth and development of other cultures. Knowledge, in effect, began to globalise, precipitating an accelerated evolution of technology (Schmandt-Besserat, 1996).



Figure 56 (Left). Babylonian clay table. Figure 57 (Right). Egyptian Papyrus.

Following the invention of these written channels, their storage became a matter of crucial importance. Libraries were conceived to fulfil the need for secure spaces to archive and protect these fragile and brittle objects. These structures served as hubs where knowledge was stored and made publicly accessible for professional consultation. Although schools and other knowledge-teaching institutions predated libraries, the notion of a centralised, uniform hub was revolutionary, effectively establishing a framework for classifying and sorting knowledge. Moreover, the co-location of diverse research fields within a shared space facilitated interdisciplinary interaction, significantly influencing technological progression.

The establishment of centralised repositories for knowledge preservation and dissemination also stimulated the creation of higher education institutions, such as academies, which served society's humanistic and technical educational needs. The centralisation of knowledge encouraged homogeneity and the establishment of academic norms, making the educational system exportable and reproducible. Regardless of their geographical location, individuals could access the same knowledge in a uniform manner. The synthesis of these elements—portable materials, dedicated storage facilities, and public spaces—came to define the universal format of knowledge transmission throughout history.

During the Middle Ages, the classical academic institution transformed into the university system, a format that persists to this day (Rüegg, 2003). Over the past two millennia, modern systems have not deviated significantly from this archetype. The trinity of recording, archiving, and disseminating knowledge continues to form the essence of the educational system, serving as the primary medium for propagating and solidifying knowledge and for training professionals across diverse domains globally.

The traditional methodologies of knowledge transmission within the realm of craftsmanship and construction navigate between two divergent paths. As defined in the Craftsmanship Library, skills required for construction and object fabrication have been historically conserved and transferred through professional associations or guilds. These institutions functioned as both regulators and preservers of the craftsmanship heritage pertinent to their respective domains. Documentation in books and treatises was also a key component of this broader scope of knowledge transfer. However, unlike the academic model, the focus of training in these craft-based disciplines historically gravitated more toward an apprenticeship model until the 19th century.

The nuances of craft and construction processes have historically favoured the apprenticeship model. Human movement and intuition, quintessential elements of craftsmanship, pose complex challenges in terms of knowledge transfer. While other domains allow for recording precise data and logical sequences to carry out tasks, articulating movements, intuition, or assemblies in textual or two-dimensional formats necessitates sophisticated abstraction. Concepts like patterns or shapes may be relatively more accessible owing to their amenability to representation and description. However, the art of stone carving or wood shaping demands a level of guidance that traditional texts cannot adequately provide. Similarly, concepts such as spatial quality or textures necessitate a more empirical approach for comprehensive understanding (Dormer, 1994).

Consequently, the apprenticeship method, in essence, a hybrid form of knowledge transmission, was advanced not as a result of conscious strategising but as a response to the unique needs and requirements of craftsmanship and construction fields. This model offered the necessary hands-on experience and in-person guidance that enabled the preservation and transmission of intricate manual skills (Lave & Wenger, 1991).

Despite the merits of the apprenticeship system, including the more substantial preservation of cultural identities and heritage, the relative isolation of knowledge transmission prompted a more heterogeneous evolution of building and crafting arts worldwide. The limited nature of knowledge dissemination and the emphasis on cultural identity often restricted expertise sharing across different regions (Sennet, R. 2008).

Consequently, architectural and crafting techniques showed low permeability across various parts of the globe, resulting in distinctive design differences driven by divergent technological advancements.

For instance, Western nations historically favoured stone in their construction, attributable to superior metallurgy and construction machinery, whereas Eastern cultures predominantly used wood, which is reflective of advanced cutting and wood carving tools (Pye, 1968). This divergence exemplifies how the intersection of knowledge influences the speed of evolution and implementation across scientific disciplines, with its absence often slowing the pace of development.



Figure 58 (Left). Western stone building. Figure 59 (Right). Eastern wood building.

This trend may contribute to the conservatism observed in the manufacturing and construction industries, which have shown resistance to adopting and adapting new technologies (Eastman, Teicholz, Sacks, & Liston, 2011). The integration of new technologies and methodologies has lagged behind other technical sectors, such as aeronautical engineering or medicine.

The digital revolution had a limited impact on these industries until the 1990s. It was only with the emergence of Computer-Aided Design systems that digital technologies started to gain a stronger foothold (Sabot, 2008). Consequently, the digitisation of the industry and the adoption of digital tools and formats are gradually transforming the construction and architecture industry into a more technologically receptive practice.

2.2.1. Job Structures and How They Balance.

The stratification of labour tasks and job qualifications has been an intrinsic part of human society since the formation of the first human communities. This division of roles traces its roots back to prehistoric times, with distinct roles such as hunters, gatherers, caregivers, and spiritual leaders shaping social structures and work dynamics (Gamble, 1999). This segmentation of labour encouraged specialisation, which in turn facilitated the emergence of professionals. Through

continuous engagement in specific tasks, workers could cultivate expertise in their respective domains, thereby enhancing their performance over time (Becker, 1964). This trend of specialisation drew heavily from the tradition of apprenticeships, wherein younger individuals would attach themselves to experienced workers to learn and participate in a profession (Rosen, 1979).

The specialisation of roles significantly influenced the modalities of knowledge and skill transmission, retaining its relevance in contemporary times. Another consequential factor tied to job qualification was the bifurcation of job types. Historically, roles were differentiated based on the nature of the tasks. Broadly, roles can be categorised based on the degree of physical or mental activity required.

In ancient societies, two primary types of roles emerged: those of thinkers and providers. The role of a hunter or gatherer would exemplify the provider category, whereas tribe leaders or spiritual guides would fall under the thinker category (Durkheim, 1933). Predominantly, the majority of the population was engaged in provider roles, owing to the greater demand for resources. Thinking roles were relatively scarce and often occupied by key societal figures. Social status has played a substantial role in this dynamic from the early stages of human history (Bourdieu, 1986).

The limited number of thinkers was pivotal in balancing the demand and needs for different roles, driving an increase in providers and a scarcity of thinkers. In this context, social influence played a decisive role in ensuring that requisite roles were adequately filled. This was particularly true in the absence of a mature economic system, where close-knit communities could better plan and distribute jobs. Moreover, the relative simplicity and limited variety of roles within these societies enabled the functionality of this system (Polanyi, 1944).

The narrow number of possibilities and the fact that the general community needs were better understood in smaller groups resulted in a traditionally hereditary system where descendants would continue their predecessors' roles in the tribe. However, this system also had its drawbacks. If, for example, a generation of providers was less capable than the previous one, it could result in the tribe's failure.

With the progression of society and concurrent technological advancements, a broader range of roles within the labour structure emerged. The appearance of new social roles, including the need for artisans, artists, builders, and merchants, led to an innovative classification of jobs extending beyond the traditional binary of thinkers and providers (Bronowski, 1973). These emerging needs for manufactured products and constructed facilities fostered the development of a new professional category: the makers. Occupations within this category required both physical activity and intellectual engagement, thereby integrating the previously distinct realms of providers and thinkers.

This professional evolution led to the establishment of the tripartite division of labour that persists today: the primary sector engaged in resource extraction and production, the secondary sector focused on the transformation of resources into consumable goods and the tertiary sector dedicated to the consumption of goods and the provision of services (Fisher, 1939; Clark, 1940). This sector-based restructuring of labour marked the onset of societal liberalisation. As tribes transitioned into cities and demands became more abstract, deep-seated changes ensued, prompting the regulation of labour towards a trade-based system (Weber, 2009).

Although the hereditary nature of job selection largely prevailed, the creation of new job categories offered increased opportunities for mobility, facilitating individuals' transition across different sectors (Marshall, 1920). Nevertheless, the correlation between job classification and social status remained influential, with the introduction of more complex hierarchies reinforcing this association (Bourdieu, 1984). Consequently, some professions have historically been perceived as superior based on the societal segment they traditionally represent. Broadly, this notion can be distilled to the assertion that thinker professions have historically been accorded a higher status than provider roles, with maker occupations positioned somewhere in the middle. This stigma persists in contemporary society and continues to profoundly influence society's perceptions and valuation of labour (Collins, 1979).

2.2.2. The Skilled Worker Shortage

The labour landscape has continuously evolved, demonstrating an increasingly intricate specialisation over time. As technological advances introduced new resources and product types, job scopes have become progressively narrower, concentrating on particular tasks. This evolution significantly impacted the makers' group, as specialisation in specific product categories defined today's manufacturing chains (Mokyr, 2002). Moreover, manufacturing professions became the primary source of social and technological development, establishing the contemporary economy where product exchange forms the primary trade medium.

The secondary sector emerged as the principal driver of industrialisation and urbanisation (Chandler, 1990). This sector's significance persisted until the Industrial Revolution, a period characterised by drastic changes in goods production that entirely transformed the labour market. The secondary sector began to adopt automation, progressively diminishing the requirement for extensive factory workforces (Mokyr, 1990). The demand for makers declined during the 19th and 20th centuries, replacing this workforce with new roles within the 'thinker' sector, which required more cognitive and less manual skills (Brynjolfsson & McAfee, 2014).

These profound changes also affected the transmission of skills and the tradition of occupational heritage. The more volatile and flexible labour market that arose during this period facilitated greater job mobility, enabling faster and more accessible social and professional change (Acemoglu & Autor, 2011). The hereditary professions, once prevalent, are now waning, representing a minimal portion of contemporary professionals. Moreover, the transition from small businesses to large corporations dissolved the localised connection between industries and their regions. As a result, local production and industries have become globalised, losing their traditional identities (Schumpeter, 1943).

As with all significant societal changes, the evolution of labour and its division carries both positive and negative implications. On the one hand, the more flexible and adaptable system has favourable implications for the workforce and the potential fulfilment of workers' needs. Conversely, the globalisation of the economy and the workforce has posed significant challenges to local production industries, impacting communities (Stiglitz, 2003). Cities have become the economic epicentres, which pose risks of marginalising communities outside these environments.

The escalating digitalization of the economy and industrial systems is reshaping the usage of labour and the necessary profiles for modern jobs. In line with the trend that began during the Industrial Revolution, which saw workers transitioning from manufacturing to services, this effect has intensified with the widespread adoption of automation and the burgeoning digital economy (Brynjolfsson & McAfee, 2014). Supported by globalisation, this shift in traditional labour demands is instigating several consequential side effects, impacting both global production and traditional local manufacturing channels.

Broadly speaking, the digitalisation of labour is creating a preeminent demand for roles within the digital economy. The proliferation of digital goods production is also affecting the conventional trading economy, overshadowing the relevance of physical goods (Schwab, 2016). Consequently, a global decline in the demand for manufacturing workers can be discerned, leading to a contraction of employment opportunities in traditional manufacturing sectors (Acemoglu & Restrepo, 2017).

Another significant factor is the increased accessibility to higher education. The appeal of superior status associated with university degrees and the anticipated benefits of employment opportunities afforded by higher education is attracting an unprecedented number of individuals, thereby depleting the pool of candidates for manufacturing and industrial jobs (Goldin & Katz, 2008). This phenomenon is noticeable not only in the secondary sector but also in the primary sector, leading to a transformative effect on the existing goods production chain.

An additional issue precipitated by the shortage of prospective workers in production is the disruption of the traditional formation and apprenticeship

knowledge transmission system. Given that a substantial portion of the skills requisite for these roles is passed through physical experience and teaching, a decline in the number of students is detrimental to the continued transmission of this embodied knowledge (Lave & Wenger, 1991). Largely, it restricts access and limits the number of trainees that can be taught in a generation. This situation poses a potential risk, as a diminished pool of available trainers could result in a long-term loss of knowledge and skills if they are not adequately preserved (Lindqvist, 1994).

Beyond the confines of the professional market, yet intertwined with the situation of production and manufacturing labour, is the profound alteration society is undergoing in its conventional way of life. Traditionally, manufacturing industries and craft traditions were deeply entwined with the local culture in which they originated (Pye, 1968). Small industries often constituted the lifeblood of towns or shires, and their existence significantly shaped the identity of their respective communities. Whether these communities were centred around food products or manufactured goods, they depended on these types of small, localised identity industries to maintain and preserve the population, thus ensuring long-term survival (Thompson, 1965).

Many examples exist where a particular product or good came to symbolise a place, and consequently, the place became known due to the reputation of the good. An apt instance is the case of Switzerland, where the production of watches has ingrained itself into the identity of the country's western region, even spawning a tourist industry in its wake.

However, the cultural and identity dimensions intrinsic to goods production industries have begun to wane due to the demographic shifts instigated by new economic paradigms. The significant migration from rural to urban environments, which was initiated in the twentieth century, continues and even accelerates in the twenty-first (Sassen, 2018). Rural populations are gradually diminishing, and cities now condense more than half of the global populace's habitat (United Nations, 2018). One visible consequence of this phenomenon is the diminished diversity and availability of professionals in regions beyond urban areas.

This dilemma impacts not only the manufacturing industry but an array of professions. Yet, the ramifications for the industrial production sector are particularly significant due to the shortage of workers at the same time this line of local production factories (Autor, 2015). Concurrently, this slow industrial destruction further intensifies the natural migration effect toward job opportunities, compelling an increasing number of individuals to migrate to cities, thereby further depleting rural areas (Moretti, 2012).

Ultimately, this scenario creates an ouroboros-like situation whereby it sustains itself until an inevitable collapse. The imminent threat of losing rural communities and economies is palpable and could potentially lead to the disappearance of heritage industries, manufacturing jobs, and local building traditions (Florida, 2017). The disappearance of heritage industries, manufacturing jobs, and local building traditions poses a significant threat to preserving cultures, communities, and knowledge (Hesmondhalgh & Baker, 2011).

The final phenomenon worthy of analysis in relation to the contemporary state of manufacturing and building labour is the reliance on workers' production and construction costs. From a purely economic perspective, production via automated processes and prefabrication of building components typically leads to cost-efficient production (Agrawal, Gans, & Goldfarb, 2018). Automation is premised on ceaseless operational units that are devoid of industrial action demands or calls for improved working conditions. This context has driven manufacturing and construction companies to increasingly incorporate automation into their operations, a transition that has contributed to the erosion of traditional manufacturing labour (Acemoglu & Restrepo, 2017).

This development further promotes an impression of a dying industry, which could vanish, dissuading prospective workers from choosing it as their professional pathway. Broadly speaking, the making and building industry is losing its attraction in comparison to more dynamic sectors such as the digital or FinTech sectors (Morse, 2023). Moreover, the portrayal of human workers as costlier and less efficient hinders further investment and research into existing techniques,

limiting technological progress and reinforcing the perception of this industry as outdated (Brynjolfsson & McAfee, 2014).

The landscape fashioned by this situation is impacting access to skilled labour across multiple industries. Predominantly in the Western world but also influencing developing countries, the Skilled Labor Shortage is emerging as a significant issue that is adversely affecting the economic fabric in diverse ways (World Economic Forum, 2020). Although this issue spans all sectors and areas, this thesis will specifically focus on its impact on the crafting and construction industries.

Historically, the built environment industry has been reliant on manual labour and the accumulation of traditional expertise (Gann & Salter, 2000). It is a field dependent on workers who learn experientially, gaining proficiency and knowledge through hands-on practice. Drawing inspiration from ancient masonry lodges, this mode of knowledge transmission gives rise to a system of apprenticeship and mastery, which still resonates today. Generally, this system establishes a clear hierarchy on the building site that commands respect, directing existing workflows and internal logic. It also determines priorities and privileges within a building project.

Parallel conditions are found in the craftsmanship aspect of the industry. Professions such as carpentry, metalworking, and artisanal work also operate similarly. Consequently, the issues triggered by the skilled labour shortage can be analysed in a similar manner, with interconnected problems and solutions (World Economic Forum, 2020).

In both cases, the declining availability of a workforce has immediate ramifications for production in both sectors. On the one hand, with fewer workers, projects will likely last longer, incurring higher additional costs. This predicament is already leaving its mark on the industry, which is tackling the highest recorded delays in history (Azhar, 2011). Coupled with delays instigated by the material production sector, worker scarcity further accentuates problems not necessarily rooted in complexity or technology implementation.

These delays are critical since the building and manufacturing industries are highly time-dependent, and each additional day of work represents a significant added cost. Furthermore, longer project timelines mean a slowing down in the commencement of new projects, creating a backlog in development and hindering the general public's access to the final product.

Another direct repercussion of the skilled labour shortage in the craftsmanship and construction industries is the impact it has on trading costs, brought about by the lack of qualified and quality workers. Analogous to the goods market, the scarcity of specific skills inherently influences their market value (Bessen, 2019). As the availability of specialised workers and experienced tradespeople decreases, certain cost aspects related to specific tasks, such as scaffolding construction or woodworking, are experiencing a significant uptick.

This surge is not only limited to monetary aspects but also extends to deployment factors, given that workers possessing these skills are pivotal for most projects and, consequently, essential for even basic buildings. This situation exacerbates the costs associated with delays, compelling the building industry to grapple with increased labour expenses, thereby reducing the profitability of the completed buildings (Gruneberg & Ive, 2000).

Furthermore, the shortage of skilled labourers has a knock-on effect on project requirements and techniques. Specifically, particular techniques or manufacturing requirements are replaced with alternative options due to the scarcity of specialised skills. These alternatives often equate to cheaper, lower quality, lower value, or less environmentally friendly solutions, thereby diminishing the overall architectural quality (Eichholtz, Kok, & Quigley, 2010).

A third problematic outcome of the lack of trained and specialised workers pertains to preserving and transmitting their skills. As previously indicated, the shortage of skilled workers—particularly in areas beyond urban places—poses a significant barrier to knowledge transfer due to a reduced pool of potential instructors. In a professional context where hands-on experience and mentor-apprentice training are of substantial relevance, the scarcity of such workers hinders the grooming of fresh talent.

Simultaneously, the diminishing number of skilled tradespeople impacts how craft knowledge is conserved. If the stream of apprentices dries up, the craft risks perishing with the last practitioner (Marsden, 2013). This scenario threatens a potential loss of heritage and building traditions, with local techniques, styles, or arts being particularly vulnerable, given their often intrinsic link to local craftspeople.

These factors are often critically important as traditional knowledge and techniques often embed historical insights into dealing with local environmental conditions, resource access, or natural disaster prevention (Janda, Killip, & Fawcett, 2014). Local building traditions frequently display a high degree of climate adaptability, which mainstream, industrialised techniques may struggle to replicate appropriately. Consequently, architecture risks losing its contextualisation and relationship with the people and societies it serves.

Likewise, the lack of new builders and artisans jeopardises the conservation of the building and cultural heritage, thus posing a direct risk to the preservation of community identity (Fellows & Liu, 2012).

The final implication of the skilled labour shortage is the limitation it poses to the development of non-urban areas. The disproportionate distribution of skilled labourers, favouring urban environments, incites a 'pull effect' where the few skilled workers in rural environments feel drawn to urban work settings (Marlet & Van Woerkens, 2014). This reinforces the migration from rural to urban areas and accelerates the isolation and resource scarcity faced by developing communities.

Especially critical in developing nations, this condition stalls the progress of communities, precipitating regression as access to advanced techniques vanishes, supplanted by simpler, less efficient methods. Similarly, the scarcity of trained workers and the cost of deploying specialised labour in rural or developing areas affect the quality of output and limit the introduction of new resources like sewage treatment or electrical and telecommunication services. The impact of this situation is already observable in regions like central Africa or Southeast Asia, where surveys indicate a decline in construction quality (Narayan & Smyth, 2008).

Such trends could result in a regression in the overall quality of new constructions and potentially influence the trajectory of rural or developing communities. The skilled labour shortage thus represents a significant issue that warrants urgent attention before its effects substantially damage the building industry's fabric. Developing solutions on how knowledge is preserved and transmitted and expanding the labour pool is imperative to ensure the preservation and continuation of craftsmanship and building arts for future generations (Fellows & Liu, 2012).

2.2.3. The media society and skills

The transformation from analogue to digital technology stands as a breakthrough in the latter half of the 20th century. The dawn of the digital computer and global communication networks has revolutionised public interactions (Castells, 2011). Digital media has bridged the gap between international entities, paving the way for globalisation that has extensively influenced commerce and knowledge acquisition (Waters, 2011). Platforms such as the Internet have given birth to a new form of universal archiving, making information accessible to everyone, anywhere (Duff, Craig, & Cherry, 2004). This newfound accessibility to vast amounts of information has catalysed the development of smaller, remote communities, enabling them to connect with broader global networks and resources (Warschauer, 2003).

Once perceived as professional technical tools, computers have transitioned into ordinary household items and have infiltrated most of our devices (Ceruzzi, 2003). Society has adopted and adapted to these digital computing tools, deeming them indispensable for daily use. They serve as platforms for communication, work, leisure, learning, and play. Fundamentally, they now form an integral part of our lives, acting as principal tools for documenting our experiences and memories (Turkle, 2011).

While knowledge has progressed and expanded over the years, our modes of education and learning have largely maintained their traditional form since the inception of educational institutions (Cuban, 2001). This model is predominantly

characterised by a mentor imparting knowledge to students, who then strive to understand and commit this information to memory. Typically, theoretical instruction is provided first, followed by practical application and an apprenticeship, depending on the profession (Collins, Brown, & Newman, 1989). In essence, education requires a venue for the transmission of knowledge and practices to consolidate it. This model adheres to a memory-based system that emphasises learning through repetition and assimilation. In the context of this thesis, the conventional model parallels the way we archive architecture and aligns with the linear method of sorting (Davies & Talbot, 2008). In general, traditional pedagogy strives to deliver knowledge in an organised manner. Although functional, this approach may not fully harness the potential of existing technology (Prensky, 2001).

Nonetheless, the realm of education has not remained unaffected by digital technologies and their accompanying hardware. Throughout the final decade of the 20th century and into the 21st century, an incremental revolution in the distribution of knowledge has unfolded (Otto, P. 2000). Various modes of education have emerged in diverse formats, leveraging the Internet as a platform (Siemens, 2005).

This shift traces its roots back to 1982 at the University of Illinois, where the first online courses were offered (Harasim, 2000). These courses initially took the form of step-by-step manuals. Although rudimentary at the outset, they quickly evolved in tandem with advancing technology, integrating sound recordings and, subsequently, video recordings. Despite adhering to a traditional linear teaching model, the virtual nature of these courses broke down the initial barrier—the physical presence of students (Anderson, 2008).

The elimination of spatial constraints brought about a change in the temporal aspect of classes as well. Utilising pre-recorded online resources divorced the learning process from being tethered to a specific location or time, thus broadening the accessibility of education for more students (Bonk & Zhang, 2006). While the impact of these novel formats was substantial, leading to the establishment of the first entirely online universities and colleges (Allen & Seaman, 2013), the true revolution commenced in 2005 with the arrival of the YouTube platform (Burgess & Green, 2018).

The arrival of online video platforms has substantially impacted the field of education. Despite their initial non-educational intent, these platforms have

become integral components of both physical and digital educational processes (Khan, 2012). Although YouTube was not the first platform of its kind—Vimeo launched in 2004—it has since become the foremost site for video tutorials on the internet, marking it as a highly influential tool in modern education (Burgess & Green, 2018).

In the early days, educational videos were largely produced by amateurs, but the platform has since experienced significant growth in official institutions uploading their educational content (Burgess & Green, 2018). Today, the site is teeming with tutorials and courses, spanning the spectrum from everyday household advice to comprehensive university degrees (Maynard, 2020).

In terms of format, traditional linear methodologies continue to dominate, although advancements in production and assembly techniques are enabling a shift toward a more rhizomatic system of learning (Deleuze & Guattari, 1987). A recent trend exemplifying this shift is the compartmentalisation of courses into shorter clips, each embodying a unitary concept. This method enables targeted information retrieval, negating the need to view an entire course. The accessibility and brevity of these segments further encourage a search-centric approach to learning rather than a traditional sort-based one, thereby promoting a more streamlined process (Downes, 2012).

In this context, the learner can personalise their education, gaining nearly instantaneous access to tutorials for the specific knowledge they seek or the task they aim to perform. Consequently, the traditional emphasis on memorisation and assimilation diminishes as knowledge transforms into an instantly accessible resource housed within our hardware devices (Kop & Hill, 2008).

However, this emerging model of education has a significant shortfall: its lack of tangible connection to reality. Online video and education platforms can disseminate knowledge, but their absence of direct physicality renders them incomplete (Anderson & Dron, 2011). The requirement for practical, hands-on experience is paramount, particularly for manufacturing processes. Thus, purely visual online training constitutes an incomplete educational process.

The need for an interface bridging the divide between virtual content and the physical world provides an ideal context for incorporating Mixed Reality (MR) and Augmented Reality into the educational landscape. These technologies are well-suited to resolving the existing disconnect between the digital and physical realms of learning (Milgram & Kishino, 1994).

The initial applications of AR technology beyond the military sphere centred on instructing users in model assembly (Azuma et al., 2001). Numerous corporations, including Boeing, have since explored the use of AR as a medium for executing complex tasks (Rosenberg, 1992). Holographic projections of procedural steps have proven to be both practical and effective in facilitating 3D assembly processes (Wagner & Schmalstieg, 2007).

Moreover, AR is increasingly being used in industries such as architecture for quality control and geometry review, demonstrating its broad applicability (Kipper & Rampolla, 2012). The Archeoguide project from the early 2000s showcased the ability of AR to fully contextualise on-site model displays, demonstrating the technology's flexibility and potential for varied and comprehensive information display (Vlahakis et al., 2002). These features make it highly adaptable for guiding a wide array of assembly processes.

In fact, not just assembly but also traditional techniques like weaving, forging, clay pottery, and carving can benefit from AR technology, as illustrated by the work of Fologram and RC9 (Dorta et al., 2016). Additionally, the integration of computer vision and Artificial Intelligence can expand the capabilities of AR, enabling the processing of more information and updating it in the system in real-time (Siciliano & Khatib, 2016).

The incorporation of Mixed Reality into the learning process thus signifies the emergence of a novel knowledge model (Billinghurst et al., 2002). By harnessing this technology, digital skills can be demonstrated in real-time, empowering individuals with limited training or experience to undertake complex manufacturing tasks.

The metamorphosis of education into a 'search, not sort' paradigm has the potential to transform the transmission of skills into a more accessible, adaptable system capable of swiftly responding to emerging needs (Bell & Gemmell, 2009). Another characteristic of this novel model is the ability to record skills, not merely display them. Utilising an appropriate array of sensors, practitioners can digitalise their craftsmanship and archive it in the cloud, allowing future generations to witness the artistry of past artisans and builders (Billinghurst & Kato, 2002).

In this context, Mixed Reality presents an opportunity to simultaneously enhance the capabilities of experienced artisans in complex tasks, train novice workers in intricate techniques, temporarily augment the skills of untrained workers for specific tasks, and account for craft knowledge for posterity (Milgram & Kishino,

1994). It embodies a timeless model of knowledge preservation that could facilitate the digital archiving and transmission of local knowledge, thus safeguarding cultural identities rooted in manufacturing.

A direct consequence of employing such an interface is the potential expansion of the labour pool that is eligible to participate in manufacturing processes. If tailored training or expertise can be delivered through augmentation, workers could become more flexible and adaptable (Wagner et al., 2006). This not only reduces the diversity of necessary workers, thus requiring fewer people to be involved, but it also addresses the scarcity of labour issue.

Finally, this technology has the potential to strengthen smaller communities. Enhanced skills and the integration of new technologies facilitated by AR can improve design and construction quality in areas with limited resources or workforce (Wu et al., 2013). Communities can benefit from better-designed environments and play more participatory roles in the development process. Self-management emerges as one of the advantages of this technology, as it allows for the participation of individuals with diverse profiles (Azuma et al., 2001).

Preserving and transmitting knowledge, particularly human skills, poses a formidable challenge that must be addressed to prevent future cultural heritage loss. Traditional knowledge models are becoming antiquated due to societal shifts and demographic changes (Lave & Wenger, 1991). Linear, time-consuming methods that follow a progressive trajectory appear discordant in a fluid society that exists in the present, becoming increasingly accustomed to the 'search, not sort' paradigm that the internet encourages (Bell & Gemmell, 2009). The capacity to access immediate skills and digitally enhance them represents a promising adaptation strategy.

Mixed Reality technology emerges as a potential solution in the short term that can integrate virtual information into reality, thereby facilitating a novel model of knowledge access for individuals (Milgram & Kishino, 1994). Digital skills can still be amalgamated with human interaction due to its interactive nature. This allows for the preservation of intuitive processes and the appreciation of unexpected beauty, key facets of traditional knowledge and skills (Billinghurst & Kato, 2002).

Fields such as architecture and craftsmanship have an opportunity to incorporate this technology, combining digital design with manual manufacturing in a seamless fashion. This facilitates access to new entrants into the industry and preserves a series of building traditions that span millennia (Wu et al., 2013). By

integrating traditional knowledge systems with emerging technologies, we can create a more inclusive and sustainable model of education and practice, thereby preserving our rich cultural heritage (Azuma et al., 2001).

2.3. Automation vs Craftmanship

The consolidation of the digital age has brought important transformations in several disciplines, such as medicine, media, and the built environment. As architects increasingly adopt these technologies, tools like Computer-Aided Design, computer-aided manufacturing and automated manufacturing techniques are impacting the traditional methods of architectural practice, transforming the profession in an irreversible manner. These technological advancements have undoubtedly enhanced the industry, augmenting the projects' precision, efficiency and complexity. However, they have also sparked a controversy, as in several ways, these new technologies are causing the disappearance of traditional craftsmanship and artisanry in architecture.

Craftsmanship, with its emphasis on manual skill, understanding of materials, and aesthetic sensibility, has long been a cornerstone of architectural heritage. Crafted elements within architectural structures serve a functional purpose and carry deep cultural, historical, and artistic significance. As such, the increasing automation of architectural design and production raises important questions about the preservation of these craft traditions.

Looking towards the complex relationship between automation and craftsmanship in contemporary architecture, the various ways in which these seemingly contradictory forces intersect, overlap, and conflict are paramount to consider. They can be antagonists but also collaborate to create a future where this duality could subliminate into a more wholesome practice that embeds both approaches' advantages.

Mass production and automation, borne out of the Industrial Revolution and the progressive technological advancement of the XX and XXI centuries, have permeated the manufacturing sector largely due to their capacity for producing large volumes of identical products efficiently and at a reduced cost (Ford & Crowther, 1922). At the same time, the spread and enhancement of automation technologies have further exacerbated the replacement of human labour, rendering human hands obsolete in various aspects of production (Bessen, 2019). In fact, the dominance of brands like Ford over objectively better cars like Mercedes was due mostly to the mass and cheap production of their cars in a manufacturing line. A

direct offshoot of mass production is automation, a phenomenon that has been witnessed.

Machinery and technology replace human labour for certain tasks, further enhancing productivity while also reducing labour costs (Bessen, 2019). The implications of these industrial developments on a global scale are far-reaching, both positively and negatively.

On the one hand, automated mass production had the positive effect of democratising access to goods and products, making them more affordable and accessible, increasing the segment of the population capable of consuming these goods. On the other hand, these two phenomena, especially automation, severely impacted the preservation of traditional making techniques and the traditional workforce. Generational knowledge was, for the first time, interrupted (Kreps, 2009).

The significance of these traditional techniques extends beyond mere methods of manufacturing; they are profound cultural expressions deeply embedded in the cultural fabric of societies, reflecting the diversity and richness of human creativity (UNESCO, 2017). Therefore, the loss of these techniques is synonymous with the erosion of cultural heritage, posing a grave threat to cultural diversity.

A closer look at specific case studies sheds light on the scale and severity of this cultural erosion. For instance, in Japan, the 'Kutani-yaki' ceramics industry, which has a proud tradition dating back to the 17th century, is under severe threat from automation. In India, the renowned handweaving industry, celebrated for its intricate designs and exceptional quality, is being rapidly replaced by power looms, endangering the livelihoods of artisans and the survival of traditional techniques.



Figure 60 & Figure 61. Examples of the Kutani Yaki Porcelain Ware.

A complex interplay of socioeconomic factors drives this trend. Globalisation, which promotes the mass consumption of goods, has put pressure on industries to increase production volumes and reduce costs, thus paving the way for mass production and automation (Kaplinsky, 2013). Additionally, the rising cost of living in many regions of the world forces artisans to abandon their traditional crafts in search of more lucrative occupations, further contributing to the decline of traditional making techniques (Pye, 1968).

Given this situation, the role of governments and educational institutions in safeguarding cultural heritage becomes paramount. They can provide the necessary policy support for traditional crafts, integrate the recognition of craftsmanship into the educational curriculum, and promote the concept of sustainable consumption among their citizenry (Throsby, 2002).

Craftsmanship, often characterised by skill, care, and a deeply ingrained knowledge of materials, techniques and traditions, stands as a connection between cultural heritage and arts worldwide. It weaves itself into the fabric of society, preserving histories, stories, and local distinctiveness, demonstrating the richness and diversity of human creativity (UNESCO, 2013). Despite the surge in technological advancements and the popularity of mass production methods, the value of craftsmanship remains indispensable, demanding attention and fostering academic discussions.

At its core, craftsmanship represents the essence of humans, showcasing skills and creativity to create unique objects. It is essential to our traditions and human values. Craftmanship is more than the physical execution of a task; it is an expression of a personal being (Sennett, 2008). It encapsulates the relationship between problem-solving and skill, head and hand, embedding knowledge in practical activity. Craftmanship is a conduit for innovation, often leading to the creation of objects that are not only aesthetically pleasing but also functional, thereby blurring the lines between art and utility (Pye, 1968).

Moreover, craftsmanship serves as a tangible link to our past. It offers a unique window into understanding cultural traditions and histories, as it often embodies traditional knowledge passed down through generations. This cultural continuity is seen in the precision of Japanese ceramics and other local traditions around the globe. Through the persistence of these traditional crafts, we maintain a living connection to our heritage and foster a sense of identity and belonging (Jones, 2010).

Craftsmanship also plays a pivotal role in preserving cultural diversity, thereby fortifying cultural resilience. Each region or community often has its unique crafting techniques, materials, and aesthetics reflecting its geography, cultural beliefs, and historical narratives (Kreps, 2009). In a world increasingly dominated by globalisation, preserving these traditional crafts acts as a safeguard against cultural homogenisation, thereby contributing to cultural diversity (Kaplinsky, 2013).

Furthermore, craftsmanship aids in adopting sustainable development. Traditional making techniques often rely on locally sourced materials and employ environmentally friendly processes, contrary to many mass production methods, which often involve high energy consumption and pollution (Walker, 2006). Thus, investing in craftsmanship could significantly contribute towards achieving sustainable development goals (Throsby, 2002).

The value of craftsmanship, however, faces challenges in contemporary society. The advent of mass production and automation has contributed to the erosion of traditional crafts and skills (Bessant, 2019). It is, therefore, crucial to advocate for policies that support traditional crafts and provide the necessary infrastructure and education to encourage and nurture craftsmanship (UNESCO, 2017).

The importance of craftsmanship in preserving cultural heritage and arts cannot be overstated. Its ability to represent human creativity, link to the past, preserve cultural diversity, and foster sustainable development makes it invaluable. The continuous recognition, understanding, and support for craftsmanship are critical for the cultural sustainability of our societies, calling for a combined effort from governments, educational institutions, and individuals.

The introduction of Prefabrication and Computer-Aided Manufacturing has significantly altered the outlook of architectural aesthetics. The architectural profession is facing growing demands for speed, efficiency, and precision, and these technological advancements have provided effective solutions. The transition from traditional craftsmanship to the mass production of buildings has not only revolutionised construction techniques but has also started to redefine the aesthetic and formal potential of architecture (Kieran & Timberlake, 2004).

Prefabrication, a technique that involves manufacturing standard building components in a factory setting, rose to prominence in the 20th century as a response to the urgent need for efficient, cost-effective housing solutions. Its arrival led to an era of standardisation and modularity, affecting the visual

language of architecture. In the past, this method's aesthetic uniformity and repetition were often critiqued as a threat to individuality and diversity.

However, with Computer-Aided Manufacturing integration, prefabrication has emerged from the shadow of homogeneity. CAM technology enables architects to use digital design tools to create intricate, precise designs translated directly into physical forms through automated manufacturing processes such as 3D printing, CNC milling, and robotic fabrication (Kolarevic, 2003). The result is an expanding aesthetic vocabulary that encompasses the potential for unique, innovative architectural forms and spaces.

A relevant example of this is the DFAB House in Switzerland, the first fully inhabited building to be planned and built using predominantly digital processes (Gramazio & Kohler, 2018). Here, the aesthetic is characterised by a distinctive curvilinear form that could only be achieved with the precision and intricacy that CAM and prefabrication allow. The innovative use of these technologies has enabled the creation of a structure that showcases a new level of geometric complexity and detail, thus demonstrating the evolving aesthetic paradigm facilitated by these techniques.



Figure 62. DFAB House. VVAA. 2018.

Similarly, the serpentine curves of Zaha Hadid's Heydar Aliyev Centre in Azerbaijan illustrate the transformative impact of CAM technologies on architectural aesthetics. With its continuous, flowing forms, this building embodies the move away from the orthogonal limitations of traditional construction methods and the shift towards an architectural language that embraces fluidity and dynamism (Schumacher, 2019).

On a smaller scale, the OneShot.MGX Stool by designer Patrick Jouin is an exemplar of the potential for aesthetic innovation using these technologies. Manufactured using 3D printing technology, the stool begins as a compact, bud-like form that expands into a fully functional piece of furniture. This design would be impossible to achieve using traditional manufacturing processes, thus highlighting the aesthetic possibilities inherent in the use of CAM (Carpo, 2017).



Figure 63. Heydar Aliyev Centre. Zaha Hadid Architects. 2012.

However, while CAM and prefabrication can create opportunities for aesthetic innovation, they also present challenges. The capacity to generate intricate, unique forms can lead to a certain level of complexity and even excess in design, often at

the cost of practical considerations. Additionally, the increased reliance on these technologies can potentially erode traditional building craft and homogenise architectural forms and styles across different contexts and cultures (Kieran & Timberlake, 2004).



Figure 64. OneShot MGX Stool. Patrick Jouin. 2006.

Prefabrication and CAM manufacturing have significantly influenced architectural aesthetics, expanding the range of possible forms and spatial configurations. However, as the field continues to evolve, architects must also grapple with the challenges posed by these technologies, balancing the push for innovation with respect for craft, context, and the human scale.

In contemporary architecture, the quality that comes from creating with passion, precision, and attention to detail, often termed craftsmanship, tends to be overlooked. The global shift towards mass production in architecture has led to a landscape characterised by uniformity, frequently compromising the quality and distinctiveness associated with craftsmanship (Sennett, 2008). The aesthetic value of craftsmanship in architecture is one of its most notable aspects. Each structure resulting from craftsmanship carries an individualistic essence, reflecting the artisan's personal touch (Adamson, G. 2013). With their detail-oriented approach and artistic expression, craftsmen contribute to buildings that radiate authenticity

and individuality. Every crafted building is a unique piece of art, bearing the artisan's signature, making it incomparable to any other.

On the other hand, mass-produced buildings often resemble each other strikingly due to standardised designs and techniques. While such uniformity brings with it certain benefits, such as cost-effectiveness and speed of construction, it often results in a lack of uniqueness and authenticity. The absence of the artisan's personal touch leads to buildings that lack the charm and character often associated with crafted structures.

Craftsmanship in architecture plays a significant role in preserving and continuing cultural heritage. Traditional techniques and locally inspired designs are often employed by craftsmen, ensuring that the local context and cultural history are well reflected in the architectural landscape (Glassie, 1999). In a rapidly global world, such a role of craftsmanship becomes increasingly crucial.

Mass production, while providing the advantage of speed and efficiency, tends to overlook the cultural aspect of architecture. It opens the access of goods to a broader audience, but as a result, designs tend to be generic and completely disconnected from the local traditions or culture. Likewise, the homogeneity of the products and their globalisation also enhance the disconnection with the people's lore and, in the case of architecture, the resonance with local identities (Zukin, 1991).

Besides offering aesthetic and cultural benefits, craftsmanship presents a sustainable architectural approach. Crafted buildings frequently make use of locally sourced materials, thereby reducing the environmental impact associated with long-distance transportation of building materials. Further, traditional construction techniques that craftsmen employ are often more eco-friendly than modern, mass-production techniques that rely heavily on energy-intensive processes.

In contrast, mass production in architecture is often associated with substantial environmental impact. The energy-intensive processes involved and the extensive use of non-local materials contribute significantly to carbon emissions. Furthermore, the short lifespan of mass-produced buildings results in a frequent need for reconstruction, thereby further escalating the environmental cost (Reiser & Umemoto 2001).

Although mass production has relevant positive factors, the lack of uniqueness, cultural disconnect, and substantial environmental impact can make it a less

desirable approach when compared to craftsmanship and its intrinsic value. With its attention to detail, cultural relevance, and environmental friendliness, craftsmanship proves to be an interesting alternative, albeit often more time-consuming and costly. However, the cost associated with craftsmanship should not be viewed purely in economic terms. The aesthetic appeal, cultural relevance, and environmental benefits that craftsmanship brings about are invaluable.

Although mass-produced industrial architecture might seem more economical and efficient, the long-term benefits that elements like craftsmanship offer, like sustainability, can better them, making them a more valuable investment. The craftsmanship in architecture is still very present in contemporary architecture and is still essential for many projects. That was the case for the new Edinburgh Parliament, where the work of a series of expert crafters was essential to achieve the intricate and unique details of the building. The building, designed by Enric Miralles, showcases remarkable woodwork with complete bespoke interiors, exteriors, and comprehensive, integrated furniture. The refinement and integration of the different architectural materials and components were only possible through the work of highly skilled makers and crafters.



Figure 65. Edinburgh Parliament. EMBT. 1999.

Another notable example is the Centro Botín in Santander, Spain, designed by Renzo Piano. Completed in 2017, this waterfront cultural centre exemplifies the integration of craftsmanship and contemporary design. The building's facade features thousands of ceramic discs, individually handcrafted and meticulously arranged to create a dynamic play of light and shadow. The attention to craftsmanship extends to the interior spaces, where bespoke furnishings and carefully crafted architectural elements enhance the visitor experience (Piano, 2016).



Figure 66. Botin Center. Renzo Piano. 2017.

The third example is the Liyuan Library in Beijing, China, designed by Li Xiaodong. Completed in 2011, this small-scale library showcases the fusion of traditional craftsmanship and modern design. The building's exterior is clad in a lattice of locally sourced twigs, meticulously arranged to form a delicate and intricate screen. The craftsmanship extends to the interior, where handmade furniture and carefully crafted details create a serene and contemplative environment.

The value of craftsmanship in architecture is still essential to achieve quality architecture. As the previous examples showcase, precision and unique details are

needed, which still require the skills and ability of an expert maker. The individuality and differentiation in architecture are factors that aggregate variety in the field, adding value to the practice. At the end of the day, the small details in architecture add the personality that a human unique architecture needs to resonate with the users and their perception of the space.



Figure 67. Liyuan Library. Li Xiaodong. 2011.

While advantageous in certain respects, the shift towards mass production in architecture has undermined the importance of craftsmanship. Acknowledging the aesthetic, cultural, and environmental advantages of craftsmanship is crucial.

Industrial manufacturing and artisanry should be able to live together and combine to converge into a position that could achieve efficiency, quality and uniqueness. In a time when the built environment has an essential role in shaping society, it is important not to ignore the relevance of craftsmanship in preserving architecture's heritage and historical values. By striking a balance between these two contrasting approaches, the architectural realm can ensure that our built

environment is functional, aesthetically pleasing, culturally relevant, and environmentally friendly.

The introduction of Computer-Aided Manufacturing and digital manufacturing has undoubtedly augmented the transformative wave, pushing boundaries and facilitating the rise of complex architectural designs (Kolarevic, 2003). Nevertheless, whilst acknowledging their undeniable significance, it is critical to recognize the integral role of traditional craftsmanship and the emerging potential of Augmented Reality for preserving historical values and steering architecture towards a resilient and inclusive future.

Craftsmanship encapsulates a complex blend of manual skill, judgment, and a profound understanding of materials and tools, with significant architectural value embedded in each crafted element (Pye, 1968). In architectural heritage, craftsmanship preserves and embodies local identity, tradition, and culture. As such, it provides an essential counterbalance to the impersonal precision and homogeneity that can characterise digitally-produced architecture. Thus, despite the efficiencies of digital manufacturing, it is critical to retain the human element in the architectural process, emphasising the value of hand-crafted elements and detailing in juxtaposition to digitally fabricated components (Adamson, G. 2013).

AR can provide a platform to understand, appreciate, and engage with the craftsmanship involved in the architectural process, making it a perfect ally for preserving historical values. By creating digital holographic instructions or real-time overlays, AR could also be used to aid in the learning and execution of complex craft techniques, enhancing the scope and sustainability of craftsmanship within contemporary architectural practice (Wang et al., 2018). The intersection of CAM, craftsmanship, and AR technologies offers promising opportunities for the future of architecture. While the efficiencies of digital manufacturing processes should be harnessed, it is essential not to overlook the value of traditional craftsmanship for preserving historical values. Augmented Reality can serve as the necessary bridge, merging the digital and the tangible, enhancing the understanding and practice of craftsmanship, and bringing the public closer to the architectural process. In the trajectory towards the future, the coexistence and interaction of these elements will enable a more holistic, inclusive, and culturally vibrant architectural landscape.

AR can be instrumental in education and skills training. Traditional craftsmanship is a repository of intricate skills and techniques, many of which risk

being lost in the digital age (Adamson, G. 2013). AR can guide individuals in learning and executing these complex craft techniques by providing holographic instructions or real-time overlays. For example, AR applications can demonstrate traditional stone masonry or woodwork methods, allowing students to closely observe, understand, and imitate these processes (Bower et al., 2014).

The use of AR can also facilitate the restoration and preservation of historic buildings. Understanding the original craft techniques is often crucial in such efforts (De la Fuente et al., 2018). AR technology can overlay this information on physical sites, providing conservators with real-time, hands-on insights into traditional craftsmanship.

AR manufacturing can raise creativity and collaboration in architectural design while still valuing craftsmanship. By overlaying digital information onto physical spaces, AR allows architects and craftsmen to visualise design iterations and experiment with different materials, forms, and embellishments (Huang et al., 2019). This collaborative environment encourages the exploration of innovative design solutions while integrating and preserving traditional craft sensibilities.

The future survival of architecture as an artistic practice lies not in the supremacy of one approach over another but in the thoughtful amalgamation of digital design, architecture, mixed reality technologies, and traditional craftsmanship. The accelerated advancements in digital design and architecture have fundamentally revolutionised the landscape of architectural practice, pushing the limits of what can be conceived and constructed.

Craftsmanship, as an embodiment of cultural, historical, and artistic legacies, holds profound significance. Its preservation and incorporation into modern architectural practices enrich contemporary designs with a sense of heritage and contextual relevance. In a similar vein, mixed reality technologies such as Augmented and Virtual Reality offer unprecedented possibilities for the seamless integration of the digital and physical world, presenting novel avenues for design visualisation, interaction, and public engagement.

The progression of architecture, therefore, hinges on the careful merging of these diverse elements. It necessitates an architectural practice that marries digital design's computational efficiency and complex geometric capabilities with traditional craftsmanship's intricate, tactile richness, all while harnessing the transformative potential of mixed reality technologies. This synergy can propel a

new architectural discourse that combines the precision and scalability of digital methods with the unique narrative and aesthetic value of craftsmanship.

Such integration can raise a more inclusive, innovative, and culturally resonant architectural future, embracing the versatility of digital technologies without compromising the authenticity of traditional practices. Bridging these domains also promotes a more holistic understanding and appreciation of architecture, from its conception to its realisation, thereby forging a stronger connection between people and the built environment. In this sense, the convergence of digital design, architecture, mixed reality, and craftsmanship is not merely a theoretical proposition but a practical necessity, laying the groundwork for a resilient, sustainable, and enriched architectural legacy.

2.4. Digital Platforms and Distributed Manufacturing

The digital revolution is leading in a new era across all domains, especially in the field of architecture. As we progress into the 21st century, the incorporation of digital technologies is no longer optional but essential to improve industry efficiency, encourage innovation, and address sustainability issues (Kieran & Timberlake, 2004). This transformation is driven by various digital technologies such as Augmented Reality, digital platforms, and distributed manufacturing, each with the potential to revolutionise the architectural process and its results. The integration of these digital technologies in architecture also presents challenges, including the need for interoperability among platforms, acceptance and adaptation to AR technology, and crucial concerns about data privacy and security. However, the promise of digital technology's transformative potential for the architectural industry outweighs these obstacles. It requires a thorough exploration, understanding, and strategic integration of these technologies to fully utilise their potential.

2.4.1. The Platform Society

Digital platforms are fundamentally altering the socioeconomic fabric of our contemporary society. This digital environment, enabled by the internet and the remarkable progress in computing, creates a framework for users that allows for all sorts of interactions, such as social, economic, legal, or affective (Parker, Van Alstyne, & Choudary, 2016). These apps take the role of mediators in connecting individuals or entities, thus facilitating all sorts of transactions in a very efficient, straightforward manner. They set up a new, very flexible frame of communication.

If we take a closer look at digital platforms' impact on society, we can see how diverse and multilayered they are. Economically, they have revolutionised traditional business models by capitalising on network effects, where the value of the platform increases as more users join (Halaruda et al., 2024). The increased access to markets and reduced transaction costs have democratised economic opportunities, leading to the growth of the sharing economy and the gig economy.

Digital platforms have influenced how people connect, communicate, and interact socially. These platforms serve as a means for socialisation, learning, and cultural exchange, thus enhancing societal inclusiveness (Van Dijck, 2013). However, they also raise issues related to privacy, the digital divide, and misinformation, which warrant comprehensive governance strategies.

A practical example of the transformative power of digital platforms is Amazon. It started as an online bookstore and evolved into a global retail behemoth. Amazon's platform allows sellers to reach customers worldwide while consumers enjoy access to a wide variety of products and competitive prices.

Uber, a ride-hailing platform, is another example. It has disrupted the traditional taxi industry by enabling freelance drivers to offer rides to users, demonstrating the shift to a gig economy (Cramer & Krueger, 2016). However, it also raises questions about labour rights and regulations.

Facebook, as one of the most widespread digital platforms, has noticeably impacted society. Connecting billions of users worldwide allows them to engage in social interactions and commercial exchanges. At the same time, the app is surrounded by controversy as its current business model thrives on data collection from users, which represents a challenge to people's privacy. Also, it is being criticised for its inability to prevent fake news and misinformation. In that sense, the app represents most of the challenges that the new internet society proposes (Tufekci, 2017).

Digital platforms are very interesting and promising tools. They have the capacity to redefine our society completely, and we engage in our daily social interactions. They are poised to reshape traditional dynamics, so society has the need to adapt. Policymakers, scholars, and society at large must consider how they will fit in our society now and in the future.

2.4.2. The distributed society

The concept of distributed manufacturing described in the glossary refers to a production model based on decentralisation. It uses a network of separated locations to produce individual components and assemble them in the last location before delivery or even on-site. This model has evolved with technology, embracing

all sorts of automated manufacturing processes such as 3D printing. Also, cloud-based technologies reinforce the model and facilitate distribution at all levels, from design to manufacturing up to consumption (Rifkin, 2011).

Distributed manufacturing allows for increased flexibility, decreased transport costs, reduced carbon footprint, and potential for customisation. It enables firms to respond more swiftly to local market demands and reduces the vulnerability of supply chains to disruption (Holmström, Holweg, Khajavi, & Partanen, 2016).

These platforms allow products to be created closer to their intended use, reducing logistical challenges and environmental harm. An excellent example of this is e-NABLE's implementation of distributed manufacturing in the prosthetics industry.

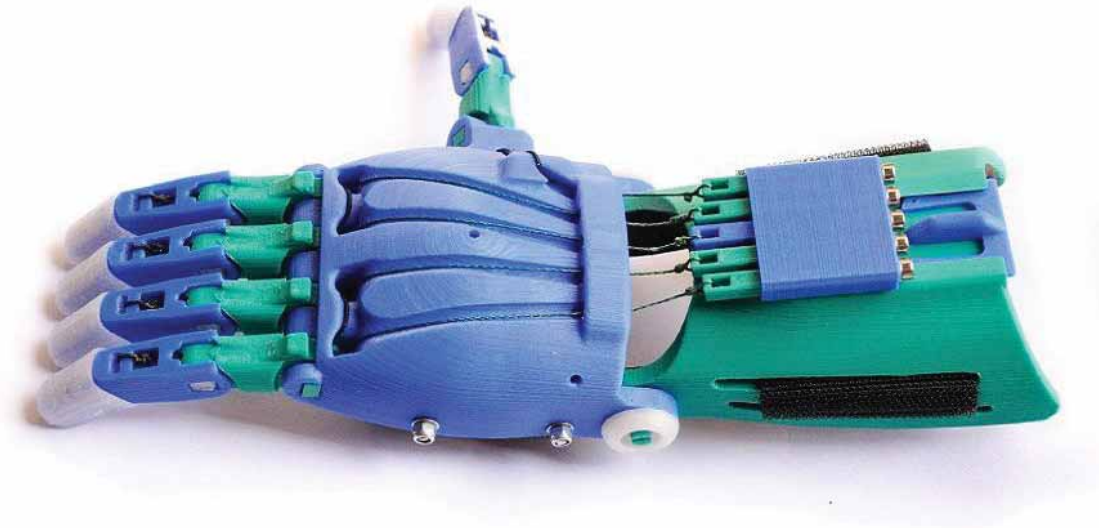


Figure 68. 3D printed prosthetic hand. E-NABLE. 2015.

e-NABLE is an international network of volunteers employing 3D printing technology to create personalised, affordable prosthetic limbs (Zuniga et al., 2015). Leveraging the power of distributed manufacturing, the organisation has an open-source model that permits anyone with a 3D printer to access, download, and print prosthetic parts at their location. This initiative is particularly outstanding for several reasons. Firstly, it democratises the production process, making it feasible for individuals and communities to contribute directly to manufacturing (Zuniga et al., 2015). It removes the need for large-scale, centralised factories and specialist labour, utilising the capabilities of common 3D printers and community collaboration (Birtchnell & Urry, 2013) instead.

The application of distributed manufacturing by e-NABLE significantly brings down costs, making prosthetics more accessible to those in underprivileged conditions (Zuniga et al., 2015). Traditional prosthetics could run into thousands of dollars, but e-NABLE's designs can be manufactured and assembled at a fraction of this cost, thereby increasing the reach of such essential technology. This model allows for a quick, localised response to needs that arise. For example, in the aftermath of a natural disaster, local makers can rapidly increase production, negating the requirement for extensive logistical organisation (Ford & Despeisse, 2024).



Figure 69. 3D printed prosthetic kit. E-NABLE. 2015.

This example embodies the transformative potential of distributed manufacturing, where advanced technology and a decentralised production model are combined to make significant societal impacts.

Also, in response to the COVID-19 pandemic, various entities across the globe leveraged distributed manufacturing to address shortages in personal protective equipment (PPE) and ventilators. Makers and hobbyists used 3D printers at home or in local workshops to produce these critical items, illustrating the model's responsiveness and resilience in times of crisis.

Distributed manufacturing represents a production model that facilitates the democratisation of access to produce worldwide. Its evolution towards platforms establishes a promising framework for a more efficient manufacturing industry. Together with cloud-based technologies and digital platforms, it has the potential to shift the way we produce goods noticeably.

2.4.3. Distributed Architecture

The built environment transformation into an industrial manufacturing-based practice promotes concepts like prefabrication and serial manufacturing. Likewise, the idea of implementing distributed manufacturing is growing and becoming a relevant topic in architecture. This production model leverages technologies such as 3D printing, digital fabrication, and cloud computing to generate architectural elements closer to their point of use (Holmström, Holweg, Khajavi, & Partanen, 2016). This shift from centralised to distributed production presents both advantages and challenges, fundamentally altering how we conceive and execute architectural projects.

One major advantage of distributed manufacturing in architecture is the potential for customisation. By utilising digital fabrication technologies like 3D printing, architects can design and manufacture unique, complex, and tailored building components without significantly increasing costs. This enhances design flexibility and allows for a more nuanced response to site-specific conditions and client requirements (Ratto & Ree, 2012).

Secondly, distributed manufacturing can reduce transportation costs and associated environmental impacts. Manufacturing components closer to the construction site minimises the need for long-haul shipping, contributing to lower carbon emissions. Furthermore, localised production allows for more effective use of local materials, further reducing the environmental footprint.

Thirdly, distributed manufacturing in architecture can lead to more resilient supply chains. Decentralising production diminishes the risk of disruption due to issues at a single factory. This can be particularly beneficial in times of crisis or when responding to rapidly changing demands.

However, distributed manufacturing in architecture also presents certain challenges. One primary concern is quality control. Ensuring consistent standards across multiple production sites can be complex and challenging. Misalignments in production quality can lead to structural issues or delays in construction (Gibb, 2001).

Another concern relates to economic feasibility. The initial investment in advanced fabrication technologies can be substantial. While this may be offset by long-term savings, it does present a significant barrier for smaller architectural practices or in regions where such technologies are not yet widely accessible (Berman, 2012).

Furthermore, the reliance on advanced technologies also raises concerns related to cyber security. With designs and manufacturing instructions transmitted digitally, there is a risk of data breaches or cyber-attacks, which could have serious consequences (Romanosky, Telang, & Acquisti, 2011).



Figure 70. Wiki House. Alastair Parvin. 2011.

Practical examples of distributed manufacturing in architecture provide insights into its potential and challenges. The WikiHouse project, an open-source platform for designing and building houses, exemplifies the advantages. Users can customise designs and then manufacture components at a local fabrication shop, enabling personalised and locally produced architecture (Parvin, 2013).

On the other hand, the experience of the Sagrada Familia in Barcelona illustrates some challenges. While digital fabrication technologies have been instrumental in

advancing construction, ensuring quality and precision across highly complex, uniquely fabricated components has required rigorous processes and controls (Krieg, O. et al. 2012).

While distributed manufacturing presents a promising paradigm for architecture, offering increased design flexibility, reduced environmental impact, and supply chain resilience, it poses significant challenges related to quality control, economic feasibility, and cyber security. As with any paradigm shift, navigating these opportunities and challenges will require adaptive thinking, innovative solutions, and robust regulatory frameworks.

2.4.4. Platform Architecture

Digital platforms, as the backbone of our internet-powered world, are reshaping many industries, including architecture and manufacturing. Their transformative impact extends to distributed manufacturing (Holmström, Holweg, Khajavi, & Partanen, 2016). When these digital platforms are combined effectively, they can greatly enhance the distributed manufacturing process in the architectural domain.

The integration of various digital platforms like design software, cloud computing, and the Internet of Things, as well as manufacturing platforms such as computer-aided manufacturing software, can streamline and optimise the entire production pipeline. Design platforms like AutoCAD, Rhino, and Revit enable architects to design complex building components. These designs can then be shared and modified via cloud platforms, promoting collaboration and flexibility. IoT devices can then track the production process in real-time, allowing for on-the-fly adjustments. Finally, CAM platforms translate digital designs into instructions for manufacturing machines such as 3D printers or CNC routers (Kuusk, Kruusimägi, & Mägi, 2019).

Moreover, digital platforms can enhance data exchange and standardisation, which is essential for efficient distributed manufacturing. Platforms like Autodesk's Fusion 360 enable the seamless sharing of digital design files across different software, adopting interoperability and easing coordination between design and manufacturing processes (Ford, Despeisse, & Moilanen, 2020).

Furthermore, digital platforms support the management of distributed production processes. For example, platforms like 3DPrinterOS allow for the remote management of 3D printers across multiple locations, streamlining production scheduling, quality control, and troubleshooting, all crucial aspects of distributed manufacturing (Hannibal & Knight, 2018).

One other way digital platforms enhance distributed manufacturing in architecture is by facilitating collaboration. Architects, engineers, and manufacturers can collaboratively develop, modify, and improve digital designs through platforms like GitHub. Such platforms enable real-time design evolution, informed by inputs from various stakeholders, fostering a more iterative and integrated design process (Briscoe & Mulligan, 2014).

In addition to enhancing the process, the integration of digital platforms can also improve the product. The combination of design and analytical platforms can lead to better-performing, customised building components. For example, environmental simulation software can be used in conjunction with design platforms to optimise a building component's performance, such as its thermal or structural properties. These tailored designs can then be manufactured locally using digital fabrication tools, resulting in a building that is better adapted to its specific environmental context and user needs (Kensek, 2014).

Despite the promise of digital platforms in enhancing distributed manufacturing in architecture, there are several challenges that need to be overcome. The need for interoperability between different platforms is one major hurdle. With a myriad of design, analysis, and manufacturing software available, ensuring that they can effectively communicate and exchange information is a substantial technical challenge. Open standards and protocols can help address this issue (Beetz et al., 2010).

Companies like Facit Homes are using integrated digital platforms to streamline their production process. They use digital design tools to create tailored designs, which are then manufactured in a local workshop using digital fabrication tools. The components are flat-packed and assembled on-site, reducing waste and transport costs (Brell-Cokcan & Braumann, 2013).

Similarly, the Building on Demand project explores how digital platforms can enhance distributed manufacturing in architecture. This project uses a digital platform to manage a network of mobile 3D printers, demonstrating how such

platforms can support the coordination of distributed production processes (Negroponte, 1976).

Finally, the Global Village Construction Set project provides an example of a digital platform facilitating the sharing of modular designs for various machines and structures necessary for setting up a small civilisation. Users can download, customise, and locally produce these designs, demonstrating how digital platforms can enhance data exchange and customisation in distributed manufacturing (Jakubowski, 2013).

Digital platforms have the potential to enhance distributed manufacturing in architecture significantly. By integrating design, collaboration, analysis, and manufacturing platforms, architects can streamline their production process, produce customised and optimised building components, and overcome geographic constraints. However, challenges related to interoperability and standardisation must be overcome to unlock this potential fully.

2.4.5. Augmented Distributed.

In the context of distributed manufacturing, AR can significantly enhance the workflow by providing real-time, context-aware instructions and feedback, facilitating remote collaboration and support, and enabling advanced visualisation and simulation. AR overlays digital information directly onto the physical environment, thereby offering workers intuitive and interactive instructions for machine operations and assembly tasks (Jahn, 2022). These AR-guided procedures can reduce errors, increase efficiency, and improve product quality. Furthermore, AR can help bridge the geographical gaps inherent in distributed manufacturing. Through AR, team members can collaborate in real-time, regardless of their location. They can share their view of the physical world, overlaid with digital information, to discuss issues, propose changes, or guide processes. This can increase efficiency, reduce the need for travel, and foster a more collaborative culture (Rosa, 2015).

Additionally, AR can enhance the quality control process in distributed manufacturing. By comparing the physical product with the digital design in real-

time, AR can help identify deviations or defects. This can lead to more consistent products despite the disparate locations of production (Jahn, 2022).

Finally, AR can help companies offer innovative services. For example, AR can provide remote assistance, where an expert guides a customer or technician through a process, such as maintenance or repair. AR can also be used to visualise products in the customer's environment before they are manufactured and delivered, helping customers make more informed decisions (Porter & Heppelmann, 2014).

When it comes to architecture, AR can play an instrumental role in enhancing distributed manufacturing. One significant application of AR in architectural distributed manufacturing is in the assembly of building components. Complex, customised components produced through distributed manufacturing can be difficult to assemble correctly. However, AR can guide construction workers through the assembly process, displaying digital instructions on how to connect the components. This can result in faster construction times, fewer errors, and safer worksites (Jahn, 2022). AR can foster remote collaboration and support in distributed manufacturing through digital platforms. Workers in different production sites can collaborate through shared AR experiences, allowing them to view and interact with the same digital information overlaid on their respective physical environments. Experts can provide remote support to less experienced workers through AR, guiding them through complex tasks by overlaying instructions or annotations onto the workers' field of view. These AR-facilitated collaborations can bridge geographic barriers, leverage expertise more effectively, and enhance the agility and resilience of distributed manufacturing systems (Porter & Heppelmann, 2017). Advanced visualisation and simulation capabilities enabled by AR can also significantly benefit distributed manufacturing. Workers can visualise and interact with digital prototypes or simulations overlaid with the physical environment, enabling them to assess and optimise design and manufacturing processes more effectively and intuitively. Manufacturers can also leverage these AR capabilities to offer customers unique customisation options.

AR can also help architects and clients visualise and modify designs before they are manufactured. By overlaying digital building models onto the physical site, AR can help participants better understand the design, its relationship with the site, and its performance parameters. This can lead to more informed design decisions and fewer costly changes later in the process (Jahn, 2022).

Moreover, AR can support the inspection and maintenance of buildings produced through distributed manufacturing. By overlaying digital information, such as construction details or maintenance instructions, onto the physical building, AR can help identify construction errors or guide maintenance tasks. This can lead to better-quality buildings and a more efficient facility management process (Wang et al. 2018).



Figure 71. 3D printed bridge.MX3D. 2021.

A relevant first example comes from the company MX3D, which used AR to assist in the construction of a 3D-printed steel bridge in Amsterdam. AR was used to guide the assembly of the bridge, resulting in a faster and safer construction process (MX3D, 2018). They created a cloud-based system so both teams could seamlessly communicate and interact during the process.

The second example involves the company Trimble, which developed an AR system to visualise and modify architectural designs in real-time. Their digital platform, combined with industrial BIM software packages, allows for straightforward communication between the design and onsite teams. That has been proven efficient to survey and assess sites and make relevant design decisions prior to and during construction (BIM+, 2018).



Figure 72. Trimble Navigation. Trimble. 2019.

AR holds significant potential in enhancing distributed manufacturing combined with digital platforms, both generally and specifically in the field of architecture. By assisting in manufacturing tasks, fostering collaboration, enhancing quality control, and offering innovative services, AR can help distributed manufacturing companies improve their operations, products, and services. However, technology, user acceptance, and regulation challenges must be addressed to leverage AR's benefits fully.

The integration of AR, digital platforms, and distributed manufacturing in architecture is not without challenges. These include interoperability among different platforms, technological maturity, and user acceptance of AR, as well as privacy and security concerns. However, despite these challenges, the potential benefits of this technological trifecta in the architectural domain are substantial.

AR, digital platforms, and distributed manufacturing represent transformative forces reshaping the architecture industry. They enhance design capabilities, improve manufacturing efficiency, enable localised customisation, and provide unprecedented collaboration opportunities. The challenges in implementing these technologies are significant, but so too are the potential rewards for architecture, offering a more innovative, sustainable, and user-centric future.

2.5. Search Don't Sort

Traditional knowledge acquisition and management have largely operated on the principle of sorting information in a linear and hierarchical fashion, a methodology often associated with the concept of a "knowledge tree" (Bloom, 1956). Such organisational structures provide a clear sequence for learning and understanding, illustrating a logical and progressive relationship between various elements of information.

The common use of the linear sorting approach can be seen in the structure of textbooks. These educational resources are often organised in a highly structured, sequential manner, where information is compartmentalised into chapters, sections, and sub-sections, each flowing logically from one to the next, building on prior knowledge to facilitate understanding of new concepts (Meyer & Freedle, 1984).

On a larger scale, this same strategy defines the library's Dewey Decimal System and exemplifies the linear sorting paradigm. This system categorises books and other resources into ten main classes, each of which can be further divided into ten divisions and sections, thereby creating a structured and predictable pattern for locating specific information (Dewey, 1876).

The traditional academic curricula in schools typically follow a linear pattern of organising knowledge. Students advance through grade levels, with each successive grade building upon the knowledge gained in the previous one. This incremental model is designed to help students acquire a broad base of knowledge and gradually deepen and expand their understanding over time (Krathwohl, 2002).

However, while linear sorting has its merits, it also has limitations. It assumes a standardised pace and sequence of learning that may not align with all student's individual learning needs and styles (Gardner, 1983). Additionally, it may not be suitable for the complex, interconnected nature of knowledge in the digital age, where non-linear, networked information access, such as through hyperlinking and keyword searching, has become more prevalent (Bush, 1945).

However, with the appearance of new technologies and communication methods, the traditional linear method has been challenged, and alternative approaches have been proposed. As an example, the concept of "search, don't sort" is an

emerging paradigm in the field of information management, signalling a shift away from traditionally structured databases towards more flexible and adaptive search-oriented systems. This paradigm asserts the idea that it is more efficient and productive to actively search for relevant information rather than spending resources on categorising, sorting, and storing data in a specific order (Agichtein, Brill & Dumais, 2006).

The origins of this paradigm can be traced back to the rise of Internet search engines. The massive scale of information available online has rendered traditional sorting methods not only obsolete but also counterproductive. Instead, search engines like Google employ sophisticated algorithms to crawl, index, and retrieve information as needed, thereby embodying the "search, don't sort" ideology (Page & Brin, 1998).

The evolution of email platforms like Gmail showcases this paradigm effectively. Unlike traditional filing systems that require users to sort emails into distinct folders manually, Gmail encourages users to archive their emails simply. When specific information is needed, users can then utilise the search function, which is backed by efficient algorithms, making the retrieval of information from large data sets swift and precise (Whittaker & Sidner, 1996).

Additionally, the rise of NoSQL databases, such as MongoDB, exemplifies data management's "search, don't sort" principle. Traditional relational databases necessitate a structured schema, requiring data to be sorted and classified before storage. In contrast, NoSQL databases are schema-less, allowing for the storage of unsorted data, which can then be effectively retrieved through dynamic search queries (Han, Haihong, Le & Du, 2011).

Consider the growth of digital libraries such as JSTOR. These platforms have adopted the "search, don't sort" strategy by providing powerful search engines that can sift through millions of scholarly articles instead of requiring users to navigate through sorted categories. This enables researchers to quickly find the precise information they need (Schonfeld & Housewright, 2010).

Additionally, AI has transformed how we interact with information and data by promoting the "search, don't sort" approach. AI algorithms, powered by machine learning and natural language processing, can quickly analyse massive amounts of data in real-time. They can recognise patterns, understand context, and infer user intent, enabling them to provide the most relevant results and insights without requiring manual organisation. This capability is particularly evident in

AI-driven search engines, recommendation systems, and virtual assistants, which can offer tailored responses or suggestions almost instantly.

By eliminating the need for users to sort data themselves, AI enhances productivity and allows individuals to focus on higher-level tasks, such as decision-making, innovation, and problem-solving. This paradigm shift also enables more personalised and efficient experiences, as AI can continuously learn from interactions to improve the accuracy and relevance of future searches. Overall, the "search, don't sort" approach reflects AI's ability to make complex information more accessible and manageable, transforming how we navigate the digital world.

However, while the "search, don't sort" paradigm offers advantages in terms of flexibility and efficiency, it also presents challenges, such as ensuring accurate and efficient search algorithms and protecting user privacy during data retrieval. Further research is necessary to overcome these issues and fully leverage the potential of this paradigm.

When it comes to the transfer of knowledge and the acquisition of new skills, this paradigm offers several advantages in relation to new technologies such as the internet and augmented reality. The ability to instantly and remotely access vast databases like YouTube for resource searches and access to a wide range of real-time skills in various formats is a major benefit. Additionally, live communication through augmentation improves this access, creating a tool that provides a more dynamic and customisable approach to acquiring knowledge.

Moreover, the search method aligns better with the cognitive processes employed in contemporary information-seeking behaviour. Modern internet users typically seek specific pieces of information by initiating targeted search queries rather than navigating through rigidly structured knowledge trees (Marchionini, 2006).

Furthermore, the search method caters to individualised learning needs and styles by allowing users to dictate the pace, sequence, and focus of their information acquisition. This contrasts with the linear progression of traditional sorting methods, which may not align with individual learning preferences (Gardner, 1983).

This knowledge paradigm is not isolated to the information management environment. Other areas can also benefit from it, such as the case of architecture. The search doesn't sort paradigms, but it actually fits in different aspects of the built environment, particularly in the era of digitisation and parametric design. This concept resonates with Mario Carpo's notion of the "Second Digital Turn" in

architecture, where he highlights the shift from standardised, repetitive design modules to the infinite variability enabled by computational design tools based on the accessibility of the design algorithms through searching processes. (Carpo, 2017).

Building Information Modelling systems also embodies the "search, don't sort" paradigm. BIM systems store vast amounts of unsorted data related to a construction project, ranging from architectural designs to materials inventory and project schedules. Advanced search algorithms allow architects and construction managers to retrieve specific data as needed rather than manually sift through sorted data categories (Eastman, Teicholz, Sacks & Liston, 2011).

The parametric design process itself is a significant trend in contemporary architectural practice. Instead of adhering to a set of pre-defined, sorted design modules, architects can use algorithms and computational design tools to search the vast space of potential design solutions, tweaking parameters to meet specific project requirements. This allows for the exploration of a more diverse and adaptable array of architectural forms and structures (Woodbury, 2010).

The knowledge acquisition and management landscape has evolved significantly from its traditional linear and hierarchical methodologies. Rooted in the concept of a "knowledge tree," traditional systems emphasised structured sequences for learning, as observed in textbooks, the Dewey Decimal System, and academic curricula. These systems provided a clear path for information organisation and learning progression. However, with technological advancements and the emergence of digital age intricacies, these linear models have faced challenges, leading to the rise of the "search, don't sort" paradigm. This shift, influenced heavily by the ubiquitous nature of the Internet and its vast informational resources, emphasises the value of flexible, dynamic searching over rigid, structured sorting.

The adoption of the "search, don't sort" paradigm has been observed across various domains, from information management systems like Google and Gmail to more specialised fields such as digital libraries and architectural practices. Platforms like JSTOR and advanced technological frameworks like NoSQL databases demonstrate the practicality and efficiency of this new approach. Furthermore, in architecture, the integration of digitisation and parametric design, as well as the implementation of Building Information Modelling systems, further validate the paradigm's applicability and transformative impact on professional fields.

This paradigm aligns more naturally with modern cognitive processes for information-seeking, providing individualised learning styles and needs. Its prominence in various domains underscores its versatility and adaptability. However, as with any innovation, the "search, don't sort" approach is not without its challenges, particularly in ensuring algorithmic accuracy and maintaining user privacy. As the digital age continues to advance and reshape traditional practices, the future of knowledge acquisition and management, influenced by both technology and evolving cognitive processes, seems to be heading towards more dynamic, adaptable, and user-centric systems.

3. Materials and methods

This thesis explores architectural innovation using a multi-faceted approach that combines theoretical frameworks with practical applications. The central concept is augmented architecture, which goes beyond traditional physical constraints by integrating digital technologies to redefine our perception and interaction with space. The approach seeks to blend digital and physical realms harmoniously, providing a richer, more adaptive architectural experience. It allows for dynamic alterations in aesthetics, function, and interaction, responding in real-time to environmental stimuli and user needs.

The thesis emphasises the use of Digital Vernacular as its central design and manufacturing philosophy. This concept serves as a connection between traditional local architecture and modern digital design and fabrication techniques. By utilising computational design tools and digital fabrication methods, the Digital Vernacular approach encourages a fusion of the past and the present, allowing for the creation of structures deeply rooted in their cultural context while showcasing the efficiency, adaptability, and innovation of modern technology. This approach is especially relevant in today's globalised world, where there is a growing demand for culturally resonant yet technologically advanced architectural solutions.

To analyse the results and case studies, the Values System methodology is employed as the main analytical tool of this thesis. This system is not just a tool for evaluating the final constructed product; it is an ongoing analytical process that runs concurrently with the design concept, production, and construction phases. It entails evaluating the architectural outcomes based on a set of predefined values, which may include sustainability, community engagement, aesthetic quality, and functional effectiveness. This assessment framework ensures that the thesis outcomes are not only innovative but also in line with broader social, environmental, and cultural objectives. Therefore, the Values System serves as both a guiding principle during the design process and a measure for evaluating the success and impact of the architectural interventions proposed in this thesis.

This thesis is based on three key methods: Augmented Architecture, Digital Vernacular, and the Values System. Augmented Architecture redefines architecture's context and interaction, while Digital Vernacular blends traditional motifs with modern technology in design and fabrication. The Values System provides a comprehensive framework for evaluating architectural outcomes. When

used together, these methods create a cohesive and explicit approach that enables the exploration of architecture that is both innovative and culturally and socially responsible.

3.1. Augmented Architecture

The integration of digital technologies into the field of architecture is transforming the traditional processes in the construction industry. One significant example is the use of augmented reality technology, which has the potential to greatly impact the future of construction. Whether it involves mechatronics or mixed realities, this technology is expected to play a crucial role in the construction industry. Mixed reality tools, in particular, have the capability to revolutionise the entire building industry, from design to manufacturing and even user experience.

3.1.1. Technicalities and general advantages.

The exploration of mixed realities in the sphere of architecture has mainly focused on augmented reality technologies. However, there are many other tools and techniques that can be seamlessly integrated to enhance the architectural design experience. This comprehensive approach provides a richer context for the design process and offers real-time interaction opportunities with the models.

The basic hardware requirements for mixed realities generally include visualisation devices such as screens or goggle sets. These tools have dual purposes: they help visualise the architectural design and enable user interaction and potential fabrication (Whyte, 2003). Essentially, these devices provide users with access to a three-dimensional projection of an architectural model, where the individual components can be visualised in isolation or within a physical context.

This utilisation of Mixed Realities marks a significant departure from traditional architectural plans. The inherent advantage of these technologies lies in the eradication of the need for abstraction or interpretation (Broll et al., 2004). The models presented can be entirely accurate and potentially full-scale, offering a perfect representation of the target structure once built.

Furthermore, Mixed Realities dramatically reduce the need for extensive documentation, which is a common feature in traditional architecture. The adoption of a three-dimensional digital model enables the encapsulation of several layers of interlinked information within a singular model (Broll et al., 2004). This

setup allows for a more comprehensive and direct understanding of the project and permits simultaneous visualisation of multiple layers, thereby promoting dynamic and effective communication.

In the context of manufacturing processes, Mixed Realities offer tangible benefits. Different stages of the construction or assembly can be exhibited within the same model. This unified display enhances the construction logic, simplifying intricate tasks through a step-by-step, three-dimensional guide (Azuma et al., 2001).

These benefits extend beyond simplifying planning and reach into the domain of sustainability. The use of Mixed Realities eliminates the need for vast amounts of paper for tests and working documentation, reducing wastage and promoting sustainable practices in architecture (Kensek, 2014).

As we venture into the digital state, fully computer-generated models serve as powerful tools, offering swift configuration and application of changes through Building Information Modelling and parametric systems (Eastman et al., 2011). The versatility of these models allows for their storage on cloud-based platforms, granting team members the ability to access and edit them in real-time. These changes can be achieved through traditional computer modelling tools or by utilising parametric or computational algorithms. Simultaneously, the models can be visualised using Mixed Reality devices by the rest of the team.

This real-time accessibility enhances team collaboration dynamics. It can significantly accelerate complex design processes by promoting interaction, contributing to more efficient problem-solving and decision-making processes (Kensek, 2014).

Along similar lines, the cloud system supports multiplayer interaction, allowing multiple team members to visualise and interact with the same model concurrently. This interaction can occur at the design desk, onsite, and with models of varying scales, from miniatures to full-scale replicas within their physical contexts (Azuma et al., 2001).

Such applications also extend to fabrication, manufacturing, or assembly processes. The sequence and progress of these operations can be monitored from remote locations in real-time or guided onsite by Augmented Reality devices or Virtual Reality systems (Broll et al., 2004). The seamless compatibility of MR technologies with various platforms enhances their usability and adaptability, making them more appealing within mainstream environments.

Turning our attention to the hardware, several key aspects come into consideration. AR technology has become ubiquitous across a variety of devices, ranging from smartphones and tablets to screens and goggles. This wide availability ensures that the technology is practically mainstream, requiring minimal adjustments to integrated hardware platforms.

Moreover, the portability of some of these devices enhances the technology's usability across diverse contexts, whether in the office, at the construction site, or in the workshop (Whyte, 2003). This flexibility represents a significant step forward in the integration of AR into everyday architectural practices, allowing for more efficient and immersive design experiences.

Despite the compelling benefits and potential of Mixed Reality in architectural design and manufacturing processes, it is pertinent to note that this technology, as a mainstream product, is still in its early stages. Indeed, the journey to fully harness the potential of this technology is ongoing, with researchers and developers persistently working towards enhancing its capabilities and usability (Coppens, 2017).

One of the focal points of this development trajectory concerns the improvement of critical hardware elements, such as sensors. More advanced sensors can augment the accuracy and interactivity of MR devices, thus enriching the user experience (Coppens, 2017).

Similarly, enhancements in the quality of visualisation are a significant area of focus. High precision in visualisation can ensure that MR models are more accurate and realistic, thereby promoting better understanding and interaction in design and manufacturing processes (Broll et al., 2004).

Another substantial challenge is extending the battery life of MR devices. More extended battery life will enhance portability and usage duration, which are key factors in professional environments where prolonged use of such devices is commonplace (Kensek, 2014). The successful navigation of these hurdles will indeed play a pivotal role in solidifying the position of MR technology as an integral tool in architecture and construction.

With its relatively short history, MR technology is increasingly gaining recognition as an innovative and valuable tool within the design and manufacturing industries. It offers a transformative new frame that seamlessly fuses digital information with reality, enhancing physical interactions within the design process. Despite being a recent addition to the suite of tools available in

professional environments, its adoption is rapidly escalating (Eastman et al., 2011).

Moreover, MR technology has already demonstrated its functional viability in various sides of construction and design. The integration of MR in these areas serves to optimize design and manufacturing processes, promoting more efficient workflows and facilitating more precise execution of complex tasks. Thus, despite its emerging stage, MR technology holds considerable promise and is steadily carving out its niche within the architecture and construction industries.

3.1.2. Augmented Architecture so far

From the origin of Augmented Reality technology, its potential as a medium for exploring novel architectural forms was evident. This potential was most apparent as AR began its transition from an exclusively military tool to broader civilian uses (Azuma, 1997). An example of this early potential was the Sensorama experiment, which aspired to create a total sensory experience for users.

The Sensorama experiment was designed to transport users to different environments, allowing them to interact and engage with these alternate realities through a machine (Heilig, 1962). By utilising a diverse array of information outputs, including stereoscopic vision, sound, and even smell, the device aimed to fully immerse users in another environment. This demonstration of AR's potential to create immersive, multi-sensory experiences underscored its potential as a transformative architectural exploration and representation tool.

In parallel with its potential for creating immersive experiences, AR technology has also demonstrated considerable promise as a tool for guiding users in performing various tasks. As outlined in the Augmentation library of this thesis, one of the earliest applications of AR technology was aimed at enhancing military personnel's performance. AR was utilised to improve various aspects of military operations, including target acquisition and navigation (Azuma, 1997).

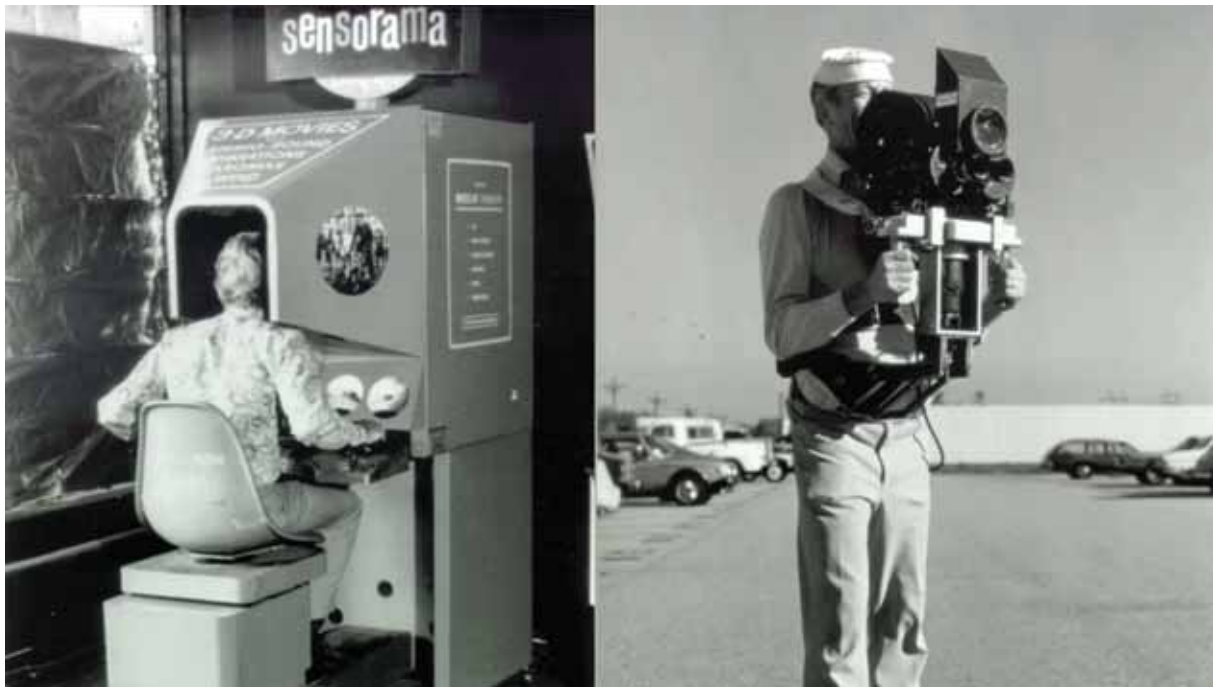


Figure 73. Sensorama and Stereoscopic Camera. Morton Heiling. 1962.



Figure 74. RAF Reflector Sight.1941

Civilian institutions also embarked on early research projects, investigating the utility of AR in enhancing and optimising human tasks, particularly in assembly processes. One seminal study conducted by Louis B. Rosenberg for NASA in the early 1990s underscored the potential of AR technology in assisting with complex tasks (Rosenberg, 1992).

Rosenberg's research demonstrated how users could assemble components remotely by using a digital projection as a guide, thus enhancing accuracy and

efficiency. This research provided a crucial foundation for the use of AR in assembly and construction, setting the stage for its eventual integration into architectural design and construction processes.



Figure 75. USAF Augmentation Hardware. L.B. Rosenberg. 1992.

The aforementioned examples underscore the potential of AR technology as a transformative tool in architecture and other sectors. From creating immersive sensory experiences to guiding complex tasks, AR has consistently demonstrated its ability to enhance and optimise human interaction with digital and physical environments. It is clear that as this technology continues to evolve, its potential applications and impact will only continue to expand.

When considering the development of Augmented Reality for manufacturing and industry-specific visualisation, it is important to look back at some early research experiences. These pioneering efforts commenced in the late 1970s under the leadership of Uno Sakae and Hideo Matsuka. Their team embarked on an experiment that used a combination of screens and cameras to record elementary assembly blocks and subsequently guide humans through the assembly process. In this case, the digital guidance was not over-imposed but showcased on a screen that the user followed to perform the tasks. Despite the augmentation in this early experiment being external to the user and lacking portability and autonomy, it nonetheless demonstrated the practicality of virtual guidance in tandem with a

physical model. This early demonstration of AR set the foundation for subsequent advancements in AR-assisted assembly and manufacturing processes.



Figure 76. Universal Constructor. John Frazer. 1990.

As the technology became more accessible to users beyond military applications, there was a growing interest in leveraging AR in architectural assemblies and manufacturing. An early example of this trend, although not strictly based on AR, was the Universal Constructor project undertaken by John Frazer in 1990. This project proposed an architectural system composed of building blocks that were augmented by a series of algorithms and sensors, facilitating interaction with the user (Frazer, 1995). While the project was not directly tied to manufacturing, it illustrated the potential of an architectural system capable of transmitting information, interacting with users, and optimising assembly processes.

This concept is highly relevant as it explores a multitude of innovative ideas. These include computational architecture, human interaction, augmented assemblies, and reactive systems within the field of architecture. Indeed, these early initiatives laid the foundation for the application of AR in modern architecture and design, underscoring the transformative potential of this technology.

Building on the basis positioned by early Augmented Reality experiments, a team led by Anthony Webster in 1996 took a significant step forward by exploring AR's potential applications in the architecture, engineering, and construction industries. The team constructed a hybrid system combining a head-up display and computers that could generate three-dimensional models for visualisation in varying layers and sequences (Webster et al., 1996).

Though the system was relatively rudimentary by today's standards, it nonetheless demonstrated the ability to display holographic projections that could be explored from a volumetric perspective. The system capitalised on the existing technology of the time, opening new possibilities for AR's application within AEC disciplines.

This groundbreaking research served as a catalyst for subsequent experiments, such as the one conducted at Columbia University, which involved testing the assembly and inspection of a structural frame for an aircraft using an improved AR device (Feiner et al., 1997). Even though this application was not directly related to architecture, the premise of utilising AR technology for assembly and inspection tasks bears considerable relevance for understanding AR's value within the construction and building industries.

The potential of AR as a tool for assembly, inspection, and visualisation within the AEC sectors underscores the transformative power of this technology. By improving communication, facilitating understanding of complex designs, and aiding in assembly and inspection processes, AR offers immense benefits for these industries. As technology continues to advance, it will undoubtedly become an increasingly integral part of the design, construction, and inspection processes within architecture and related fields.

In the field of contextual augmentation, the Archeoguide project emerges as an exceptional example illustrating the capacity of augmented reality to provide real-time, location-based information to users. By using AR in the field of cultural heritage, Archeoguide provided a pioneering demonstration of AR technology's potential to enrich and enhance the user's experience of historical sites (Vlahakis et al., 2001).

The system utilised for this groundbreaking project involved a semi-portable device comprising a backpack central processing unit, modified virtual reality goggles, and a set of cameras. Thus equipped, a user could stroll around an ancient

Greek site and visualise various temples and other constructions in their original locations and states.



Figure 77. Archeoguide. VVAA. 2001.

Archeoguide's AR projections were fully three-dimensional, incorporating textures and even incorporating rudimentary animations in certain instances. The ability to visualise and interact with architecture in its real context opened two distinct avenues for the development and application of augmented architecture.

The first key result of the Archeoguide project was its demonstration of the autonomous interconnection of real and virtual elements. This allowed users to move freely around the projections, offering a fully immersive experience of both the virtual and the real-world elements. This is a powerful idea as it opens the possibility of digital layering of our built environment, facilitating the heritage preservation of buildings and urban elements.

The second significant insight collected from the project was that if real architecture could be experienced in this manner, virtual architecture could similarly be situated within the real world using this type of hardware. This realisation has profound implications for how we conceive of, design, and experience architectural spaces and the ways in which AR technology can contribute to these processes. The Archeoguide project was instrumental in exposing the significant potential of AR technology in enhancing our interaction with and understanding of architectural spaces, paving the way for further research and innovation in this field.

The integration of augmented reality techniques into non-assembly manufacturing methodologies did not see steady development until around the mid-2010s. The initial explorations of this potential often relied on rudimentary systems based on computer vision and tracking markers.

An early experimental approach in this sense is the project developed in 2012 by Modelical. This project innovatively approached the construction of a Catalan vault by applying computer-guided manual brick layering (Modelical, 2012). This pioneering initiative demonstrated how AR can be harnesses to transform traditional construction methods.

The project deployed a relatively simple distance calculation from a reference point, using ARUCO markers to place bricks. Through this technique, the bricklayer was able to accurately position elements according to a predetermined sequence, which in turn followed a digitally designed geometry.



Figure 78. Augmented Catalan Vault. Modelical. 2012.

While the scope of this experiment may have been limited by the technological constraints of the time, it bears significant historical importance in the evolution of AR in the field of construction and architecture. The Modelical project showcased the possibility of utilising AR for traditional brick layering through computer-assisted guidance, thus introducing the idea of digitally assisted assembly into the realm of traditional craftsmanship (Modelical, 2012).

In the broader perspective of AR application in manufacturing, these early experiences showcased the potential of external digital tracking and computer vision. Despite their initial simplicity, these techniques have laid the foundation for a much more sophisticated and wide-ranging use of AR in the manufacturing sector. This embryonic exploration of AR's possibilities has opened up a wide array of research opportunities and continues to shape the current and future direction of AR in architecture and construction.

In line with the advancement of augmented reality in manufacturing, the Obuchi Lab at the University of Tokyo has been at the forefront of exploring the potential fusion of computational design and human labour via digitally augmented guidance. A succession of interesting projects were launched in 2014, testing various guidance systems such as QR codes, digital projections, and computer vision (Obuchi Lab, 2014). Notably, these projects did not incorporate any AR hardware, yet they conceptually delineated how computational design could seamlessly blend into craftsmanship fabrication through digital mediums.

Among these significant projects, the Toca Pavilion deserves special attention. This experiment sought to forge an innovative workflow based on computational design principles. The creative process involved the synthesis of a set of choreographies, which were then converted into geometric forms and further processed to yield a distinctive architectural design.

The construction of the pavilion was directed and executed by humans, with QR codes serving as a tool to monitor the building process and provide feedback on any errors detected during the construction phase. The resultant error data was recomputed and incorporated into the final design iteration.

This experimental approach provided a prototype for the concept of recursive digital design, a system that could adapt to manufacturing errors through the integration of computer vision. Simultaneously, it revealed the potential to digitise manual, body-dependent tasks and transform them into computational data for generating architectural designs.



Figure 79. Toca Pavillion. ObuchiLab. 2014.

The innovative work carried out at the Obuchi Lab demonstrated a potential pathway for integrating AR and digital technologies into traditional craftsmanship. This integration has the potential to revolutionise the construction industry and the broader fields of design and manufacturing.

The second relevant project of equal significance from the Obuchi Lab was the Computational Clay Pavilion, which further explored the concept of human-based manufacturing strategies augmented by digital technologies. At the heart of this design was a series of mass-customised components, each of which was manually constructed using projections as guidance. The instructions detailed the necessary deformation for each panel to correspond with the computationally designed vault.



Figure 80. Digital Clay. ObuchiLab. 2014.

A distinguishing feature of this project was the choice of materials - each panel was formed from a mixture of natural clay, which was subsequently vacuum-hardened. This aspect demonstrated how traditional materials could be seamlessly incorporated with computational design strategies and augmented reality technologies (Obuchi Lab, 2014).



Figure 81 (left) Toca Pavilion. Figure 90 (right) Digital Clay.

These two pioneering projects by Obuchi Lab were instrumental in investigating the role of the human factor within the framework of computational design. They

explored how computer vision could be harmonised with human skills and how computational design strategies could effectively accommodate human error.

These early explorations of augmented reality technology in architecture established a vital foundation of principles critical to maximising the full potential of AR. From basic visualisation and fabrication guidance through computer vision, contextual visualisation, and the incorporation of reactive design logic to the realisation of responsive architecture - these foundational projects exemplify the commencement of a trend in architecture that could play a crucial role in the industry's evolution within the digital society.

These outcomes also have wider implications beyond architecture, suggesting new directions for the entire design and manufacturing industry. The innovative combination of traditional craftsmanship, computational design, and augmented reality opens up exciting new possibilities for a range of fields, potentially revolutionising how we think about the design and construction process in the digital age.

3.1.3. State of the Art: What is happening now?

Hardware

The beginning of the XXI century saw a notable expansion of the accessibility of augmented reality devices across different areas. Previously, the availability of such devices was limited, predominantly focused on Head-up Displays for cars from the early 1980s and experimental pieces of hardware.

As for autonomous devices, the options were primarily experimental and not accessible by the general public until a notable leap in technology occurred with the launch of Google Glass in 2013 (Google, 2013).

Although limited in capabilities and not particularly suited for manufacturing applications, Google Glass was instrumental in demonstrating the capability of AR technology in portable devices. This wearable technology employed a One-Eye system to superimpose basic AR information, although this was not contextually or environmentally connected.



Figure 82. Google Glass. Google. 2013.

This specific functionality and its relative novelty prevented the device from gaining widespread adoption. Furthermore, the maturity of the technology at the time was perhaps not fully realised, resulting in the device not gaining traction commercially.

Despite these shortcomings, the existence of Google Glass played a critical role in the AR industry. It demonstrated the potential for AR devices in the consumer market and sparked interest among other technology companies. Following Google's venture, major corporations like Microsoft and HTC were inspired to explore the possibilities of AR technology, launching their own development projects in the field (Microsoft, 2015; HTC, 2016).

This pivotal shift marked the beginning of a new era in the accessibility of AR technology. Although Google Glass failed as a commercial investment, it represented the first step in the AR technological sphere, presenting itself as the first accessible piece of technology for the mainstream user.

The implementation of Augmented Reality technologies in smartphones in 2016 initiated a transformative trend that has significantly impacted how we integrate AR into everyday life (Coppens, 2017). The capability of mainstream devices like smartphones to support AR visualisation greatly simplified its accessibility for the general public, propelling its adoption and use.

Although these handheld devices may not possess the functionality of a Heads-Up Display, they have facilitated the initial experimental efforts to incorporate AR into the realm of architectural manufacturing. Today, due to their ubiquitous presence, smartphones have become the primary tool for the first-hand exploration

of AR technologies. The construction industry, for instance, now frequently employs these devices for augmented quality control inspections on-site (Coppens, 2017).

Additionally, smartphones equipped with AR functionalities are being utilised for Architecture, Engineering, and Construction purposes during site visits. This trend underscores a broader shift toward the mainstream adoption of simple AR visualisations through handheld devices in the building industry, particularly for non-manufacturing processes.



Figure 83. Hololens 2 Commercial. Microsoft. 2017.

The proliferation of autonomous devices for manufacturing processes, particularly with the introduction of various consumer Heads-Up Display devices since 2016, has been a game-changer for the integration of augmented reality technology within the field of architecture (Azuma, 2016). Cutting-edge devices like Microsoft's Hololens 1 & 2 and the Magic Leap have provided a more interactive and independent method for experiencing AR visualisations.

The amplified accessibility of these devices has led to an influx of new participants in the field of AR research, largely due to the user-friendly nature of these devices in terms of programming and usability. These HUD devices support more complex AR experiences, leveraging an array of cameras and other sensors to enhance the user's experience substantially.

Compared with handheld devices such as smartphones and tablets, HUDs can interpret the surrounding environment and generate precise models for creating detailed contextual information. The inclusion of various cameras provides a more comprehensive perception of the environment's three-dimensionality, leading to a more realistic adaptation of AR visualisations. Furthermore, the broad-spectrum cameras ensure steadier visualisations that are less dependent on light conditions than handheld devices (Coppens, 2017).

An additional significant advantage of HUDs over smartphones and tablets is the provision of stereoscopic vision. While handheld devices project augmented models onto a flat screen, HUD devices utilise stereoscopic vision that more accurately simulates the human perception of depth, resulting in a more realistic and immersive experience for the user (Milgram, Kishino, 1994).

Given these distinct advantages, HUDs are becoming increasingly accessible to the general public, contributing significantly to their broader integration into the manufacturing industry. They facilitate a more direct, hands-free interaction, thus allowing for a more dynamic user experience. Moreover, certain HUD devices feature voice command options, further simplifying their usage during fabrication processes (Coppens, 2017).

The advancement and growing accessibility of AR technology, particularly in the form of autonomous HUD devices, is rapidly transforming the architecture and manufacturing industries, facilitating more interactive and immersive experiences that enhance productivity and improve accuracy.

The synergy between handheld devices and Heads-Up Displays is giving rise to a vast array of possibilities for professionals within the architectural realm to incorporate Augmented Reality into their practices. Though the technology is undoubtedly still evolving and maturing, the current state of AR hardware is already sparking significant transformations in the way the building industry operates.

Progress in this area is evident in the initiatives of companies such as XYZ, which is currently implementing commercial uses of AR technology as a tool for project surveying. Their unique approach incorporates an AR visualiser into a safety helmet, providing technicians with a comprehensive tool for site surveying and participation in the building process. This device, designed with an emphasis on visualisation, is further complemented by a multipurpose hand controller.

XYZ's AR solution proposes utilities, including quality control, error reporting, and progress definition. Early feedback indicates its effectiveness in optimising construction processes. This practical application of AR technology underscores the potential for widespread implementation in mainstream projects. While still in an emerging stage, the integration of AR technologies is not a distant reality. Rather, its potential to become a mainstream tool is increasingly apparent, primarily due to its capability to enhance existing building processes.



Figure 84. XYW AR Helmet. XWZ. 2022.

From preliminary design visualization to quality control inspections, the diverse applications of AR technology in the field of architecture and construction are gradually unfolding (Jahn, G. 2022). With handheld devices, architects can provide clients with real-time, on-site demonstrations of proposed designs, allowing them to view a three-dimensional model superimposed onto the actual construction site.

On the other hand, with their stereoscopic vision and hands-free operation, HUDs are seen as a promising tool for more complex applications in the construction industry. They can aid in fabrication processes by guiding workers in assembling components, enhancing precision, and reducing errors (Behzadan, 2015).

However, it is crucial to note that AR technology is still in the developmental stage and has substantial scope for improvement. For instance, challenges related to computational power, battery life, and user interface design are some of the areas requiring further innovation. Yet, despite these limitations, the existing technology has proven sufficient in instigating a blossoming relationship between AR and the building industry, signalling a future in which AR becomes an integral part of architectural practices.

The simultaneous progress in handheld devices and HUDs' development is opening a wide-ranging catalogue of opportunities for architects to integrate AR technology into their professional practice. Although technology is on a journey ahead in terms of further advancements, the integration of AR within the building industry is already well underway and shows great promise for the future.

Software

The evolution of augmented reality software in recent years has grown concurrently with advancements in hardware. With the introduction of mainstream devices such as smartphones and tablets capable of functioning as AR devices, there has been a push to develop AR software specifically for the architectural and building industry. The usability of these devices as platforms for AR applications has made the technology more accessible, leading to wider acceptance across multiple sectors (Schmalstieg & Hollerer, 2016).

One area that benefited from AR software's evolution was the video gaming industry. By developing experiences that leveraged the urban environment as a game field, games like the immensely popular Pokemon Go demonstrated the potential to connect the real world with digital interactions using geolocation. This further underscored the concept that the built environment could function as a dynamic platform for AR applications.

The proliferation of AR software extensions for mainstream game engines such as Unity and Unreal has facilitated the development of AR applications designed specifically for the built environment. For example, the AR Toolkit for Unity and the MRKit have significantly simplified the creation of AR experiences (Kaufmann & Schmalstieg, 2003).

A significant example of AR software that capitalised on this new accessibility is the ARKi application. Developed by Sahar Fikouhi in 2012, ARKi represented one

of the pioneering efforts in AR architectural model visualisation for smartphones. The application enables users to upload 3D models to the cloud and visualise them in an AR environment, regardless of location. Additionally, ARKi incorporates functions that allow user interaction with 3D models, making it a dynamic tool for both professionals and casual users (Fikouhi, 2014).

Over time, ARKi has evolved through multiple iterations, gradually expanding its capabilities. In 2017, it incorporated professional functionalities and compatibility with HoloLens and Magic Leap devices, reinforcing its role as a versatile tool in the AR ecosystem. Additionally, ARKi's semi-open-source nature facilitates collaboration and the development of bespoke functionalities by its user community.



Figure 85. Arki mobile app. Sahar Fikouhi. 2015.

Another significant piece of software in this area is Fologram, which provides strong support for architectural applications, further exemplifying the expanding accessibility of AR technologies. This innovative software was developed in 2017 by Gwyllim Jahn, Cameron Newnham, and Nick van der Berg, and it offers a unique interface for architects and designers to integrate AR into their processes (Jahn, Newnham, & van der Berg, 2017).

Fologram works by connecting to Rhinoceros, a popular 3D modelling software widely used in architectural and industrial design fields. Conceived as an add-on to Rhinoceros, Fologram enables real-time interaction between the 3D model

displayed in Rhinoceros and an AR device, thus bridging the gap between digital modelling and augmented visualisation. Its compatibility extends to a wide range of AR devices, including smartphones, tablets, and AR goggles, adding flexibility for the users.

A significant feature of Fologram is its ability to connect to the Grasshopper add-on in Rhinoceros. Grasshopper is known for its parametric and computational design logic, which means that Fologram can bring these advanced design techniques into AR environments in real-time (Jahn, Newnham, & van der Berg, 2017). This integration paves the way for dynamic design capabilities and interaction, opening up new possibilities in AR-driven design and manufacturing processes.



Figure 86. Fologram mobile app. Fologram. 2019.

This ability to connect parametric design logic with AR projections is fundamentally important in manufacturing. It enables sequential model visualisation through a custom user interface, enhancing the understanding and execution of complex manufacturing processes. In essence, Fologram streamlines the transition between digital design and digital manufacturing by introducing an AR layer that offers an intuitive understanding of the design and manufacturing processes (Jahn, Newnham, & van der Berg, 2017). Fologram represents a notable

step forward in the integration of AR in the field of architecture and manufacturing. It illustrates how AR can enhance the visualisation, interaction, and execution of digital design and manufacturing processes, thus making it a valuable tool in these industries.

In the realm of traditional architectural design, there has been a noticeable increase in the integration of augmented reality. Architectural software programs commonly used in the architectural, engineering, and construction industries, such as Autodesk 360, SketchUp, and ArchiCAD, are now incorporating AR features into their platforms (Behzadan et al., 2015). These software tools, traditionally utilised for 3D modelling and building information modelling, are expanding to include extensions that can produce AR models. This new capability enables improved visualisation and quality control in the construction process, bringing the benefits of AR into a familiar user interface.

Autodesk 360, a leading software package in the AEC sector, now incorporates AR functionalities. The tool enables users to overlay their virtual designs onto the physical world, providing a new perspective on how their projects integrate with the surrounding environment. (Jahn, 2022)

Similarly, SketchUp, a user-friendly 3D modelling software, has extensions like SketchUp Viewer, allowing users to experience their AR models on mobile devices. This functionality enables an immersive way of viewing and sharing designs, providing a novel perspective and approach to visualisation.

Lastly, ArchiCAD, a BIM software GRAPHISOFT developed, includes features allowing AR visualisation. By using its BIMx mobile application, users can superimpose the virtual model over the construction site, enhancing their understanding of the project's integration with the physical site (Eastman et al., 2011).

In sum, the development of AR software has been crucial in realising the full potential of AR technologies. From popular games that leverage the built environment to sophisticated applications designed for architectural visualisation, the evolution of AR software demonstrates a promising trajectory for integrating AR in many industries.

This steady, albeit slow, integration of AR technology across different platforms and for various goals marks a significant transition in the AEC industry. As these technologies gain traction in more generalist offices, we're witnessing a shift from

AR being an experimental tool in research environments to becoming a commercial and industrial tool integrated into daily work processes.

Architecture.

The evolution from more primitive methods of augmentation, such as screen trackers and projections, to a more direct approach to augmented manufacturing using Head-Up Display devices has significantly propelled the technique's advancement. The expanding access to both hardware and software, coupled with the fusion of mainstream design software and augmented reality software, has fostered an environment in which prototyping and testing have become attainable for the majority of research entities in the field (Jahn, 2022).

Since 2016, a multitude of experiments and prototypes with considerable implications have been conducted, further propelling the field. Although numerous examples exist beyond the scope of this text, a selection of works directly related to subsequent case studies will be discussed.

Three key projects or research entities have been chosen due to their relevance and connection to the subject matter at hand. First, the research developed by Gwyllim Jahn and Cameron Newnham at the Royal Melbourne Institute of Technology (RMIT) serves as a significant example. Their work in developing software solutions for integrating digital design and manufacturing with AR has resulted in a more intuitive connection between these elements, making it a prime example of innovative applications of AR in architecture (Jahn et al., 2019).

Secondly, the Steam Punk Pavilion, a collaborative architectural project, is noteworthy. This project showcases how digital fabrication processes, parametric design, and augmented reality can merge to form novel design and construction methods (Jahn, 2022).

Lastly, the research developed by Someen Hahm at the Southern California Institute of Architecture (SCI-Arc), along with the 2023 Venice Biennale Pavilion designed in collaboration between Skidmore, Owings & Merrill (SOM) and Princeton University, represent important instances of AR applications in architecture. Hahm's research exhibits the potential of AR in enabling real-time interaction with design elements, while the 2023 Venice Biennale Pavilion demonstrates the use of AR in facilitating immersive design visualisation and review processes (Jahn, 2022).

Augmented reality's utilisation in manufacturing can be perceived through diverse lenses, each emphasising varying aspects and potential enhancements over traditional methodologies. One such perspective conceives AR as a facilitator for exploring design possibilities and forming shapes that could otherwise remain elusive due to their dependency on digital understanding and human intervention (Dunser et al., 2012).



Figure 87. Steam Odyssey. Someen Hahm. 2021.

Notable research illustrating this viewpoint has been conducted by Someen Hahm. Her projects, such as the Steel Odyssey and Steam Odyssey, adopt an approach that is not strictly critical towards manufacturing. Instead, the focus is on an in-depth exploration of geometrical forms. The Wood Project, a progression from the Steam Punk Pavilion, presents a sequence of complex fluid geometries. This project delves into the capabilities of digital modelling tools with the objective of providing a direct translation from digital design to physical product (Hahm, 2021)

Although the technique and the selection of wood as the material play a role in the final shape, they are not the central focus. The project remains somewhat material-

agnostic while maintaining its affinity towards a particular manufacturing technique. The complex form and the intricate assembly of the components necessitate the use of AR for the construction process.



Figure 88. Steel Odyssey. Someen Hahm. 2021.

Similarly, the Steel Project echoes the same approach. It is characterised by an emphasis on geometrical exploration, with the material being secondary. Whether it is constructed from metal tubes, plastic tubes, or any other mouldable pipe material is of less importance. The critical component, once again, is AR's indispensable role in manufacturing individual components and assembling them into the final prototype (Hahm, 2021). This approach underscores an exploration of the boundaries of computational geometry when it is transposed into tangible entities. This exploration, in turn, reveals the profound potential of AR as a conduit for transforming intricate digital designs into physical realities (Azuma et al., 2001).

The Steampunk Pavilion represents a unique area of research that deviates from pure design exploration. This project, which won the 2019 Tallinn Biennale, involved creating a full-scale structure based on augmented manufacturing (Jahn, 2022).



From a structural perspective, the pavilion operates within a balance between the

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reality and QR markers to bolster precision (Jahn, 2022). Fologram served as the primary software that integrated the augmented reality guidance throughout the project.

An interesting element of the project was its short timeframe for construction, which necessitated the authors of the project to build it alongside a team of volunteer students. This involvement of non-professionals, who lacked prior experience or specific skills in wood or metal crafting, was instrumental in manufacturing this complex structure in a relatively limited span.

This occurrence underscores how augmented reality can enhance workers' skills, even imparting skills to untrained staff (Jahn, G. 2022). Additionally, using AR negated the need for training or previous experience to conduct manufacturing processes, effectively expanding the labour pool by not relying solely on trained professionals. This allowed local communities - in this case, architecture students to participate and learn from the experience.

In essence, the Steampunk project embodies many of the benefits of implementing augmented reality in architecture. By facilitating the integration of digital design into craftsmanship, overcoming the shortage of skilled labour, and making the process more accessible to non-professionals, the project exemplifies how AR can pioneer a new paradigm for more human and accessible.

An alternative perspective on the application of augmented manufacturing in architecture places emphasis on research centred around material exploration. The work spearheaded by Gwyllim Jahn and Cameron Newnham exemplifies this approach. These individuals stand as prominent figures within the realm of augmented manufacturing for architecture, having contributed a substantial line of prototypes and the creation of the most influential software for the AR environment, Fologram (Jahn et al., 2019).

The series of projects developed by this team since 2016 demonstrates significant extensiveness and depth. Three particular examples have been selected due to their direct correlation and relevance to the topic at hand.

In the context of architectural scale and materials, their metal-based projects, specifically the Woven Steel project, serve as a compelling demonstration of the intersection between digital design and traditional, entirely manual fabrication techniques (Jahn et al., 2018).



Figure 90. SteamPunk Pavilion. VVAA. 2019.



Figure 91. Woven Steel Pavilion. VVAA. 2018.

The Woven Steel project proposed a metallic tube structure crafted from bent bars. A straightforward analogue tube bending tool affixed to a workbench facilitated the formation of these bars. AR guidance became instrumental in ensuring the

accuracy of the tube bending process and specifying the exact bending sequence. This was particularly important, considering the bars featured multiple kinks.

Moreover, the AR system proved beneficial for quality control, enabling the use of projections to juxtapose the final product with the digital design, thus ensuring their alignment. Subsequently, AR served as the primary guide for assembly. This proved particularly beneficial given the intricate, non-intuitive logic of the geometry.



Figure 92. Woven Steel Pavilion manufacturing. VVAA. 2018.

The joinery system adopted simple fasteners, which would have made the assembly impractical without AR. Traditional paper methods would have presented significant difficulties in defining position and rotation, making the process laborious and nearly impossible. Consequently, the Woven Steel project highlighted the advantages of employing augmented reality in the field of architecture, particularly in terms of facilitating traditional forms of making, pioneering innovative assembly methods, and enhancing intuitiveness.

A second example of the innovative application of augmented reality in architecture stems from the research lab at RMIT, specifically the "Barkitecture" project conceived in 2022. This venture offers a unique perspective on the use of

natural, non-uniform materials, as demonstrated by its incorporation of gum tree bark. Underlying this project is a standard approach to surface-based digital design, which is enhanced by focusing on an intricate minimal surface-like geometry crafted from reclaimed tree bark (Jahn et al., 2022).

The implementation of augmented reality serves as a guide during the assembly process and the adhering of parts. Yet the significance of this project extends beyond this functionality. It probes the potential of merging digital design, human intuition, and material tolerance within the construction process. For example, the AR guidance provides an overarching visualisation of the shape and suggests directionality for the bark components. However, it ultimately defers to the user's creative intuition regarding the specific placement of each component.

As a result, the final product exhibits characteristics of a hybrid sculpture. It clearly reflects the digitally designed surface yet also embodies a sense of organic and intuitive quality. It offers an interesting counterpoint to common perceptions about digital architecture, which often emphasise precision and low-tolerance components that allow little room for human intervention. By contrast, the "Barkitecture" project implies that AR-guided manufacturing can foster a more intuitive design process that aligns with traditional human approaches to construction (Jahn, 2022).

In essence, this project contributes to a broader discourse on the intersections between technological innovation, intuitive craftsmanship, and ecological consideration within the sphere of architectural design. It invites further exploration of how AR can bridge the digital and physical realms, promoting a harmonious integration of human intuition, traditional craft techniques, and high-tech computational methods.



Figure 93. Barkitecture. VVAA. 2023.

A third instance that underscores the potential of augmented reality in architectural manufacturing derives from traditional building techniques merged with contemporary technologies. This instance pertains to the 'All Brick Wall' project, undertaken in 2018, and its subsequent evolution implemented in the Royal Hobart Hospital in 2019. Both projects originate from the same conceptual perspective, proposing a curved, parametric brick wall that explores the symbiosis of conventional brick use with digital design (Jahn et al., 2020).



Figure 94. Augmented Brick wall. Fologram. 2019.

The unique proposition of these projects rests in the notion that with augmented reality guidance, traditional bricklayers can accomplish complex assembly tasks required in digitally conceived designs. In both instances, the construction workforce comprised trained bricklayers with substantial experience in the building industry. The distinguishing factor was the incorporation of augmented guidance, which enabled the bricklayers to execute tasks that would normally be time-consuming and complex and were akin to routine straight-line brick-laying tasks.

This use case also presents an interesting argument about the role of AR in augmenting the abilities of unskilled workers and amplifying the capacities of skilled workers, aligning their skill sets to the requirements of digital design. Moreover, it suggests that the incorporation of augmented reality in the construction industry does not pose a significant obstacle with respect to workforce adaptation.



Figure 95. All Brick Project2. Fologram. 2019.

This project, therefore, promotes a provocative debate about the optimal source of labour for adapting building techniques to various digital geometries. In this case, the project proposes that augmented human labour can match the efficacy of

autonomous robotically operated alternatives, leading to a comparison with similar projects such as those undertaken by ETHZ or ICDE (Jahn, 2022).

It is worth noting that the introduction of HUD devices for the bricklayers did not disrupt their conventional routines; rather, they were smoothly integrated. As such, these projects provide insightful examples of how augmented reality technology could impact standard industrial practices and demonstrate the compatibility of traditional methods with modern technology.

The 'All Brick Wall' project and its subsequent evolution offer practical implications and prompt broader considerations about the future of architectural manufacturing. They highlight the transformative potential of augmented reality, with the capacity to redefine labour roles, optimize efficiency and forge a new narrative for the interaction of traditional practices with digital design.

The range of projects developed under RMIT includes simple explorations such as brick layering, as well as radical new approaches to new materials. While most works fall within the realm of experimental and temporary architecture, the wide range of geometries, materials, and manufacturing techniques on display demonstrate the versatility of augmented reality. The focus on material and craftsmanship in all processes solidifies the idea that AR fabrication can be useful across a wide range of scales, from object/craftsmanship to construction/builders scale. It proves to be a valuable, accessible, and scalable alternative compared to other computer-aided manufacturing techniques. One of the significant advantages highlighted is the ability to quickly transition from scaled models to the real thing. AR enables rapid and intuitive prototyping that involves humans as part of the process, making it a practical and affordable system for exploring digital technologies.



Figure 96. Angelus Novus Vault. SOM. 2023.

The final illustration of a project is highly relevant to the thesis, as it demonstrates a position that emphasises the potential integration of augmented reality technology into the mainstream architectural industry. Unlike previous examples, this project results from a collaboration between a research entity and a well-established architectural firm. The Angelus Novus Vault project serves as an intriguing model, showcasing how AR can enhance traditional building techniques by combining experimental geometrical approaches with standard materials.

Inspired by Brunelleschi's construction techniques for the Florence Cathedral dome, this project focuses on creating a self-balanced masonry vault. It reimagines and revitalises age-old building practices with a contemporary twist, centring on digital design as the core theme for geometrical exploration.

The application of AR guidance in this project was instrumental in assisting professional bricklayers in mastering the specific techniques required to execute the envisioned design. It serves as a compelling example of how traditional workers can seamlessly adopt AR technology to enhance their performance and align their craft with the demands of the digital era. The project's construction phase was executed by skilled artisans from a bricklaying arts association dedicated to preservation in Spain. Notably, the entire project, from design to construction, was digitally conceived and executed within a remarkable timeframe of just three

months. This showcases the potential of AR to streamline the traditional making process, reducing resource consumption and minimising the reliance on conventional guidance methods.

Ultimately, the Angelus Novus Vault project exemplifies how a centuries-old bricklaying technique can be revitalised and improved through the integration of modern technology, leading to a more efficient, digitally enhanced outcome. It serves as evidence of the transformative power of AR when applied to traditional construction practices, highlighting the potential for the industry to embrace digital advancements and propel architectural manufacturing into the future.



Figure 97. Angelus Novus Vault. SOM. 2023.

3.1.4. Augmented education.

The integration of Augmented Reality as a pedagogical tool in architectural education has shown remarkable potential for enriching learning experiences and enhancing design skills. In many studio-based courses, AR offers a dynamic platform where students can visualise, interact with, and manipulate digital 3D models in ways that closely mirror real-world conditions. This immersive, hands-on approach is particularly beneficial in helping students grasp complex design principles, enabling them to explore structural systems, material assemblies, and spatial relationships in real-time.

Beyond its growing use in architectural education, Augmented Reality has demonstrated significant pedagogical value in a wide range of fields. In K–12 science classrooms, AR enhances topics like anatomy by allowing students to explore animal dissections or human body systems safely and interactively (Bacca et al., 2014). In mathematics, dynamic 3D shapes and overlays help clarify geometric concepts such as symmetry and angles, enabling learners to manipulate polygons directly.

In medical and nursing education, AR-based simulations offer realistic practice scenarios—such as taking vital signs or administering injections—without endangering actual patients, and they allow for repeated practice under controlled conditions (Barsom et al., 2016). Language learning is similarly enriched by AR content that provides instant translations and cultural context, accelerating vocabulary acquisition (Ibáñez & Delgado-Kloos, 2018). Museums and cultural institutions utilise AR to offer visitors immersive, interactive experiences, from 3D reconstructions of historical sites to multimedia guides (Damala et al., 2007).

A particularly striking example is in astronomy and earth sciences, where AR helps students explore celestial bodies in real time. Learners can walk around virtual planets, adjust orbital planes, or visualise tectonic plate movements, fostering deeper understanding and a sense of wonder (Cheng & Tsai, 2013). This interactive, multisensory approach encourages active learning and supports the development of robust mental models across diverse subject areas.

One of the most prominent advantages of AR-enabled teaching lies in its capacity to foster collaboration. In traditional design studios, group work often involves sharing static media—such as physical models or digital renderings on 2D

screens—that can limit the depth of engagement. By contrast, AR systems allow multiple users to occupy the same physical space while simultaneously viewing and modifying the same virtual model. For instance, a small group of students can stand around a table, each using a handheld device or headset, and collaboratively refine the details of a building façade. This shared environment promotes teamwork, encourages the exchange of ideas, and accelerates the iterative nature of design (*Fanani et Al, 2021*).

Beyond collaboration, AR technology has proven valuable in bridging theoretical concepts with practical applications. In a typical design course, instructors may introduce structural fundamentals through textbook diagrams or slide presentations, but AR facilitates a more experiential process. Students can project virtual beams, columns, and trusses into their physical studio space, testing how different design alterations—such as changing material thickness or geometry—impact structural integrity. This hands-on exploration can enhance problem-solving abilities and give students a more visceral understanding of load transfer, tension, compression, and other engineering considerations central to successful architectural outcomes (Wang & Dunston, 2013).

Moreover, AR can catalyse learning about environmental factors. In architecture programs that emphasise sustainability or energy efficiency, learners can overlay digital simulations of lighting patterns or solar trajectories onto scale models, evaluating how daylight penetrates interior spaces across different seasons or times of day. Such immediate, visually compelling feedback not only deepens conceptual understanding but also strengthens students' capacity to incorporate environmental considerations into their designs from the earliest stages of ideation (*Sareika & Schmalstieg, 2007*). Similarly, students can “place” virtual models in outdoor campus environments and study how they interact with existing buildings, topography, and vegetation, thereby reinforcing lessons on context-sensitive design.

Additionally, AR can serve as an equalising tool for diverse learning styles, offering multisensory engagement to students who might otherwise struggle with abstract or text-based representations. By layering digital content directly onto physical models or real-world scenes, AR addresses visual, tactile, and even kinaesthetic learning preferences. Instructors have reported that students who are less inclined to engage through conventional methods often become more active participants when they can explore designs in an immersive format (Dorta, Kalay, & Lesage,

2011). This heightened engagement often leads to improved retention of course material and higher-quality final projects.

Despite these evident advantages, challenges related to the adoption of AR in architectural pedagogy should not be overlooked. Developing robust AR content typically requires specialised software skills and hardware resources, which may be a barrier for some institutions. Additional training for faculty members and technical staff is often necessary to ensure that the technology is used effectively rather than merely for novelty. Moreover, while AR supports a highly visual, immersive approach, educators must carefully balance these benefits with maintaining fundamental design workflows—such as hand-sketching and traditional physical model-making—that continue to play a critical role in cultivating a well-rounded architectural skill set. Nevertheless, as hardware becomes more affordable and user-friendly and as new software solutions emerge, the roadblocks to broader implementation are likely to diminish.

In conclusion, using AR as a teaching methodology in architecture studios has proven to be an innovative way to enhance student understanding, collaboration, and creativity. From interactive explorations of structural concepts to full-scale visualisations of proposed buildings in real environments, AR provides an engaging, context-rich learning experience. It not only bolsters conceptual clarity and practical skills but also prepares graduates to enter an evolving profession increasingly shaped by advanced visualisation tools.

3.1.5. Where we are and where we could be.

The construction industry and architectural practice are at a critical moment where adopting new technologies and fully integrating digital design tools are imperative for progress. Among the many elements that will drive this transformation, mixed realities and augmented reality technology hold significant promise. The examples discussed in this text highlight the growing interest in and the potential benefits of AR, offering an optimistic outlook for the future. From the transmission and preservation of skills to the seamless integration of digital tools, mixed realities have the capacity to revolutionise key aspects of the manufacturing and building industries.

However, the implementation of new technologies is never a linear process. In the case of augmented reality, the evolution and enhancement of hardware pose significant challenges that must be overcome for successful implementation. Augmentation involves various technologies and approaches that extend beyond head-up displays, incorporating various frameworks and setups. The research conducted by the Obuchi Lab exemplifies this diversity, demonstrating how augmentation can be approached from different angles to facilitate diverse forms of human-machine interactions. The choreography of the making process and the active participation of humans in the manufacturing workflow are crucial factors to consider. It is important to avoid limiting augmented manufacturing to a singular method, as the exploration of alternatives and alternative approaches enriches the values and potential of augmented architecture.

When examining the study cases, one notable project that aligns with the exploration of traditional making skills is the Steam Punk Pavilion. This project represents a new architectural language that preserves certain elements of traditional architecture while introducing a range of new values. It offers an intriguing approach to the seamless integration and joint enhancement of digital architecture and traditional craftsmanship. This departure from the mainstream trajectory of digital architecture underscores the significance of preserving the art of handmaking and the role of human intuition in a world dominated by automation and computer-aided manufacturing technologies.

Taking the RMIT research lineage into consideration, it becomes apparent that digital design embraces materiality and infuses it with human intuition and professional expertise, as evidenced by projects like Barkitecture and Full Brick Wall. Digital design transcends the topic of precision and prefabricated construction, embracing the inherent beauty of natural materials. It celebrates the richness of imperfection, embraces the attraction of the unpredictable, and showcases the ingenuity of human intuition. In essence, digital design with mixed reality technologies has the potential to restore a sense of value that digital architecture seemed to diminish—the inherent value of the natural world.

Heritage preservation and the integration of traditional making systems, as exemplified by the SOM project, offer significant value and opportunities within Augmented Architecture. The digitalisation, archiving, and transmission of nearly forgotten building techniques present a compelling path for safeguarding historical architectural heritage and propelling it into the digital era. This dual benefit is particularly noteworthy, as it not only advances building techniques while

preserving the knowledge of traditional processes but also facilitates the dissemination of this knowledge to future generations of builders.

By leveraging augmented reality technology, the challenges associated with knowledge loss due to the disappearance of skilled artisans can ideally be overcome. Moreover, this approach ensures the continued survival of traditional techniques by mitigating the effects of localism. The transmission of craftsmanship and making will no longer be limited to local contexts but will instead embrace a new global perspective accessible to craftworkers and builders worldwide.

The field of augmented architecture is still in its early stages, but its potential is becoming more apparent. This cutting-edge technology demonstrates that alternative forms of digital architecture can express more humanistic values than current mainstream proposals. In the past, humanistic values were crucial in the making and design of objects. The skills of the creator and their craftsmanship were fundamental in establishing the relevance and quality of an object. This concept is preserved and enhanced through the use of augmented reality, which reinforces the integral process from design to the final product. This approach brings designers and makers back into the process, drawing from the craftsmanship tradition of the past with a current and modern perspective. Essentially, state-of-the-art augmented reality technology proposes an alternative that embraces the past, present, and future.

3.2. Digital Vernacular

Any significant change to an established system invariably incurs frictions that can only be reconciled over time through adaptation. This holds especially true for the implementation of new technologies, particularly those intended to replace existing ones. A certain level of chaos and crisis is to be expected during these transitions, highlighting the often tumultuous nature of change. One such transition currently underway is the shift from a predominantly analogue world to a hybrid digital one. This transformation is in a phase of settlement, where novel changes are continuously emerging and integrating into the existing paradigm.

In light of this evolution, it becomes crucial to encourage and develop concepts that do not outright negate the previous state. Instead, they should aim to embrace and adapt it to the new ecology of technologies that a hybrid digital society inevitably introduces (Zittrain, 2006). This sensitive approach is important in ensuring the smooth transition and integration of old and new technologies, thereby minimising potential conflict or resistance.

3.2.1. The Fading Craft

The impact of this digital shift can be observed across various sectors, with traditional craftsmanship and manufacturing techniques being significantly affected. The ubiquity of digital technology, especially in the architecture and fabrication industries, has introduced disruptive changes. Tools such as digital design, automation, and 3D printing are reshaping the way goods and buildings are produced and manufactured (Sass & Oxman, 2006).

Consequently, the roles within these industries are rapidly evolving to require more technologically skilled individuals, subtly pushing traditional workers out of the equation. This situation introduces a significant risk to the preservation and integration of manufacturing heritage. The fear is that vernacular knowledge could gradually be lost, replaced by a globalised mainstream industrial production approach.

The potential erosion of local culture represents a possible disconnection between individuals and their local identities. The loss of vernacular ways of making extends beyond the realms of artistic and craftsmanship perspectives. It also signifies a sociological loss, eroding the richness of multicultural diversity (Harvey, 1993).

To avoid this cultural and social impoverishment, solutions that can preserve traditional craftsmanship in the face of advancing digital technology are necessary. Exploring potential strategies to integrate traditional craftsmanship with digital technologies may provide a viable path forward, encouraging a synergetic coexistence and promoting cultural preservation and technological advancement.

The challenge in the ongoing digital transformation lies in identifying a solution that would facilitate the preservation of traditional craftsmanship, the integration of modern technologies, and the preservation of local professionals within the industry. The tension between the rapidly evolving digital world and the slow-changing world of traditional craftsmanship presents unique challenges, one of which is integrating computational design with time-dependent techniques (Kolarevic, 2003).

Contemporary designers, who primarily operate within the digital domain, will be central to ensure the evolution of craftsmanship. To do so effectively, a seamless workflow that connects digital design methodology with handmade craftsmanship is essential. Achieving such a link can help harmonise traditional craftsmanship principles with digital design opportunities, leading to new approaches that pay homage to the past while innovatively moving forward.

The second significant challenge involves transforming and digitalising traditional skills, an important step towards fully integrating digital design technologies. This process requires converting tacit knowledge, often tied to a specific location and its people, into explicit knowledge that can be utilised in digital platforms (Nonaka & Takeuchi, 1995). It's imperative that the digital design takes into account the manufacturing process, ensuring the final product is both feasible and viable.

To effectively achieve this, a comprehensive evaluation of traditional techniques is necessary to identify potential paths for digitisation. This involves a thorough analysis of existing practices, techniques, tools, and materials used in traditional craftsmanship. The objective is not to replace these techniques but to find ways in which they can be enhanced and recontextualised within a digital framework.

This dual challenge—the integration of digital design methodologies into traditional craftsmanship and the digitalisation of traditional skills—necessitates the creation of a new hybrid approach. This approach would need to balance the specificities of the local vernacular and the global demands of contemporary digital design while maintaining the inherent value and richness of both (Ingold, 2013).

The third challenge is the need to facilitate and fixate the local workforce. In the context of digital transformation, it is imperative to support and sustain the local workforce. This challenge has a dual impact, as it directly influences knowledge transmission and the survival of local artisan communities. A potential solution lies in the development of an integrated approach that combines digital design methodologies with traditional craft techniques. Such an approach would optimise the manufacturing process while simultaneously preserving and perpetuating valuable skills and knowledge across generations.

Achieving a fair and equitable solution to these challenges is of paramount importance to ensure the preservation of traditional craftsmanship and local heritage. It is worth noting that the decay of skilled manual labour affects local communities and has repercussions in various building industry sectors. Within architecture and construction, experience-based skills and craftsmanship hold immense significance. Preserving traditional heritage and cultural craftsmanship is linked to retaining skilled workers in mainstream construction.

Both domains face similar challenges stemming from the digital transition; consequently, comparable solutions can be implemented to address them. The risk of losing the human labour component and the accumulated knowledge embedded within these crafts and professions pose a threat to the diversity and richness of these industries. Should the human factor be replaced solely by automation, the continued standardisation of products would lead to the erosion of values and individuality in buildings and products, further homogenising the global design culture.

At its core, the intrinsic value of human labour and its unique contribution to construction and manufacturing processes necessitates a multifaceted approach to its preservation. This preservation must be approached from various perspectives, recognising the social, cultural, and economic dimensions at play (Sennet, R. 2008). Through such comprehensive and collaborative efforts, we can safeguard the essential role of human labour and maintain the distinctiveness and diversity inherent in the architectural and manufacturing realms.

3.2.2. Augmenting the Solution.

The environment of digital design and architecture incorporates a wide range of technologies and manufacturing techniques, each with unique characteristics. These technologies often align with industrial processes, CNC-based methods, prefabrication, automation, and mass customisation (Oxman, 2010). Moreover, due to the inherent complexity of the components and assemblies proposed by digital design, translating these designs into physical plans for manufacturing or assembly can prove challenging. Consequently, the connection between digital design and traditional craftsmanship remains somewhat limited.

Existing standard solutions often fall short of fully achieving the integration of these two distinct environments. To address this limitation, a more hybrid approach is required, one in which the digital and the physical intertwine harmoniously, enabling both worlds to collaborate seamlessly. This hybrid approach seeks to leverage the strengths of digital design and traditional craftsmanship, developing a symbiotic relationship that capitalises on the precision and efficiency of digital processes while preserving the human touch and bespoke nature of traditional craftsmanship (Glynn, 2017).

By embracing this hybrid approach, designers and craftsmen can explore new possibilities bridging the digital and physical realms. Through the integration of digital tools and technologies into traditional craftsmanship practices, artisans can enhance their craft, unlocking novel forms of creativity and expanding their capabilities (Beorkrem, 2014). Simultaneously, digital designers can better understand the materiality and fabrication processes involved in bringing their digital designs to life (Schodek et al., 2005). The hybrid approach facilitates a fruitful collaboration between digital design and traditional craftsmanship, empowering designers, craftsmen, and manufacturers to overcome the limitations of each domain individually. It allows for a more nuanced exploration of form, structure, and materiality, fostering innovation and enabling the realisation of complex and highly customised designs. By intertwining the digital and the physical, this approach paves the way for a more integrated and harmonious future in architecture and manufacturing.

In light of the challenges discussed, Futurist Michio Kaku puts forth an approach that envisions humans augmenting their capabilities to enhance performance and integration with the digital world (Kaku, 2014). He anticipates that such

enhancement will stem from advancements in hardware, empowering individuals with improved mobility skills and cognitive abilities. Similarly, technology researcher Brett King argues that human enhancement will largely be facilitated by augmentation technologies, such as Mixed Reality devices that seamlessly integrate with other technological tools (King, 2016). These devices are poised to become commonplace in various professional domains, including design, mechanics, medicine, and navigation. King goes on to propose that humanity is entering what he terms the "Augmented Era," signifying a future where collaboration between humans and machines becomes the norm, enabling individuals to leverage the potential of digital technology fully.

By embracing augmentation technologies, individuals can transcend their inherent limitations, accessing information and expertise in real time and enhancing their problem-solving capabilities. This symbiotic relationship between humans and technology offers tremendous potential for numerous fields, from healthcare to design and beyond.

The Augmented Era represents a paradigm shift in which humans actively collaborate with machines, harnessing the power of digital technologies to augment their abilities and amplify their potential. This collaboration promises to revolutionise various industries and unlock new opportunities for innovation and creativity. As society moves towards this era, it is crucial to carefully navigate the ethical, social, and cultural implications that arise from human-machine integration (Miah, 2017). A thoughtful and inclusive approach is essential to ensure that augmentation technologies are developed and deployed in a manner that prioritises human well-being and fosters a harmonious coexistence between humans and machines.

The potential of manufacturing enhancement tools is vast, and among them, Mixed Realities technology emerges as a promising solution to mitigate the challenges brought about by society's ongoing digital transformation. MR technology revolves around a device, be it head-mounted or external, that projects information covering a wide range of topics. This information can include assembly processes, manufacturing guidance, quality control for painting or finishing processes, and more (Milgram & Kishino, 1994).

What sets MR apart from traditional two-dimensional plans is its ability to display information in a three-dimensional format, fixed to a predefined origin. This allows workers to experience real-time guidance as if the final object already exists within

its intended context. The volumetric nature of the augmented information enhances intuitiveness and contextualisation, leading to a quicker and easier understanding of the manufacturing process (Billinghurst & Kato, 2002).

Moreover, MR devices can possess environment-sensing capabilities, enabling them to gather real-time information from the surroundings and relay it back to the computer system. This adaptiveness allows the hardware to display information tailored to the manufacturing process, ensuring compatibility and alignment with the specific environmental context (Billinghurst & Kato, 2002). This advantage holds particular significance in industries like architecture, where precise contextual information is crucial for accurate construction and fabrication.

Furthermore, when combined with artificial intelligence, MR devices can record the expertise of experienced professionals, creating a valuable repository of manufacturing skills. This knowledge can then be transmitted to the next generation of workers through MR technology, irrespective of their geographical location (Jahn, G. 2022). This seamless transfer of expertise across time and space has the potential to revolutionise the training and skill development processes within the manufacturing industry.

Consequently, utilising MR technology in manufacturing processes offers several distinct advantages. The immersive nature of MR, with its three-dimensional and context-aware displays, enhances worker comprehension and performance. Its adaptiveness to the environment ensures accurate and informed decision-making, especially in complex industries like architecture. Additionally, the integration of AI allows for the efficient transfer of expertise, facilitating skill development and knowledge transmission across generations.

The specific challenges previously mentioned can be effectively addressed by harnessing the unique capabilities of Mixed Reality devices. When it comes to the integration of digital design, MR offers a seamless connection between the digital model and holographic projection, establishing a direct link between the design and the manufacturing process (Jahn, G. 2022). This enables a more fluid and efficient workflow, eliminating the disconnect that often exists between the virtual and physical realms. Furthermore, the versatility of MR devices allows for the incorporation of various apps and functionalities, enhancing the user's understanding and utilisation of the digital model.

Another remarkable feature of MR technology is its ability to facilitate direct interaction between the user and the design. MR devices can serve as design tools

or integral components of the design process itself, and MR technology proves invaluable (Jahn, G, 2022). By providing real-time guidance, MR can assist in the execution of manufacturing tasks associated with traditional arts, such as steam bending (Kim et al., 2018). The inclusion of MR guidance streamlines the technique, allowing for the fabrication of more complex digital designs that incorporate elements of traditional craftsmanship. Moreover, MR devices facilitate the seamless integration of components manufactured using different techniques, enabling the fusion of traditional and automated processes like 3D printing. This convergence of technologies opens up new possibilities, ranging from the preservation of traditional styles and processes to the creation of entirely novel design proposals and manufacturing methods (Jahn, G, 2022).

The characteristics of Mixed Reality devices offer a comprehensive solution to the challenges at hand. By seamlessly integrating digital design and manufacturing processes, MR technology enhances workflow efficiency and eliminates the gap between virtual and physical realms. Additionally, MR's capacity for real-time guidance empowers the preservation and evolution of traditional arts, facilitating their integration with digital designs and automated techniques. This convergence presents an opportunity for the exploration of new design possibilities and the realisation of novel manufacturing processes.

The conservation of labour and preservation of knowledge play crucial roles in addressing the challenges faced by the artisanry and building industries. In this context, Mixed Reality technology can play a decisive role. As mentioned previously, the ability of MR devices to record and transmit skills offers a means to incorporate non-skilled labour into the manufacturing industry. Through real-life tutorials presented via holographic projections, workers with limited experience can effectively perform more advanced tasks and acquire new skills (Jahn, G. 2022). Moreover, the recording of skilled craftsmen practising their art allows for the preservation and dissemination of these invaluable skills, not only locally but also globally. With its intuitive training capabilities and portability, MR technology presents itself as an accessible and mainstream solution for skills development and knowledge sharing (Jahn, 2022).

The challenges arising from the decline of apprenticeship models and the scarcity of skilled labour in the artisanry and building industries are complex and multifaceted, involving various socio-political factors. There is no single, all-encompassing solution to this problem. However, the utilisation of MR technologies holds significant potential in mitigating some of the issues and

facilitating the industry's evolution toward the Augmented Era (Sennet, 2009). By bridging the gap between traditional craftsmanship and digital innovation, MR technology empowers individuals with diverse skill levels to contribute to manufacturing while preserving and transmitting invaluable knowledge and techniques.

MR technology, particularly AR, presents a promising solution to the challenges faced by the artisan and building industries. Its capacity to record and transmit skills, coupled with its intuitive training capabilities, enables the inclusion of non-skilled labour and the preservation of traditional craftsmanship. By embracing MR technology, these industries can navigate the path towards the Augmented Era, opening the practice to a more inclusive and sustainable future.

3.3. The Values System

The technological revolution in the 20th century and the shift toward a digital society are causing significant changes in various industries and their traditional practices. Architecture, design, and manufacturing are some of the sectors facing a period of transition and requiring rethinking in many aspects. To understand how these industries can integrate into the digital world, it is crucial to establish a new framework that aligns with the current era. Traditional models of styles and craftsmanship are being challenged, necessitating alternative approaches to contextualise them. The rhizomatic model of the digital society, therefore, requires a comparable system to comprehend design and architecture in this new context. Solutions need to be multidimensional and multi-directional. It's important that the evolution of these industries involves adapting to and embracing technology without compromising their heritage and identity.

3.3.1. The Simulated Society.

Traditions and cultural identities have shaped cultural heritage throughout history. This rich mixture of human experience condenses the diverse practices and customs adopted by various tribes and civilisations. As the individuals within these groups endeavoured to preserve their unique cultural heritage, they promoted a powerful sense of belonging and community. This sentiment played a critical role in encouraging unity and cooperation among individuals and shaped the evolution of architectural practices, dictating stylistic and aesthetic trends across various cultures and periods.

However, the beginning of the twentieth century brought radical social changes, transforming the landscape from a localised heterogeneous phenomenon into a homogeneous global phenomenon. This transition has gradually eroded the distinctiveness of old traditions and arts, a process intensified by the rise of digital technologies, which continue to blur the boundaries between reality and simulation (Baudrillard, 1981). The prediction of a Simulated Society appears to be transforming into a stark reality. With the increasing influence of media and its ubiquitous reach, visual culture is merging into a uniform pastiche of

postmodern themes and topics. Consequently, localised and traditional sensibilities are gradually fading, giving way to a globalised, mainstream concept of cultural identity that often comes at the cost of losing valuable traditions and cultural values. Reality is moving towards a modern where the truth is ruled by the mainstream media and not by the facts, primarying the aesthetics over the content.

This is not to say that collective evolution is inherently negative. On the contrary, cultures and civilisations must adapt and evolve to survive, mirroring the biological principle of survival and favouring change (Darwin, 1859). The issue arises when societies lose sight of their historical traditions and end up retracing their steps in a ceaseless cycle of repetition. Disregarding our traditional heritage and the artistic production of our past only catalyses this circumstance.

Historical precedents, such as the collapse of the Roman Empire in Europe or the Aztec Empire in America, demonstrate the repercussions of cultural deletion. When a dominant culture seeks to replace and negate its predecessor, this invariably leads to stasis in technological and cultural progress (Tainter, 1988). Therefore, to ensure meaningful societal evolution, it is imperative to not only acknowledge the past but also integrate it for the attainment of healthy future development.

This integration becomes even more crucial in the context of architecture. Architectural progress is fundamentally grounded on the accumulation of empirical experiences that underpin the knowledge required for durable architecture (Alexander, 1979). The building industry should, therefore, embrace technological advancements without relegating the millennia of craftsmanship that propelled architecture to its current state as a principal manufacturing art. We can only navigate the path to holistic progress by balancing respect for our past with an open embrace of the future.

As academics, we assume the responsibility of collecting, organising, and explaining information to enhance comprehension. Historically, we have navigated this process by dividing extensive knowledge into manageable subsets akin to puzzle pieces, each finding its place within a larger temporal frame (White, 1973). The field of architectural history is an excellent example of this, delineated by distinct periods that have shaped its trajectory, often examined from a Western perspective. Conventional categorisation delineates architectural evolution into identifiable epochs such as Ancient Greek, Byzantine, Romanesque, Gothic,

Neoclassic, and Modern, among others. This taxonomy relies fundamentally on aesthetic characteristics that distinguish one style from another, enabling methodical organisation. This approach maintains relevance beyond the European environment as it lends itself to the study of other cultures (Curtis, W. 1982).

However, without negating its efficiency, the contemporary architectural landscape appears to diverge from this organisational paradigm, driven by globalisation and technological homogenisation within the design industry. Twenty-first-century architecture presents an intriguing paradox, reflecting simultaneous homogeneity and heterogeneity from an aesthetic perspective. This divergence is primarily attributable to a paradigm shift that prioritises utility over stylistic uniformity. Consequently, architectural design in the current era can be broadly classified into two categories based on function: Commercial and Landmark.

Commercial architecture, which constitutes the majority, is devoid of a specific style and focuses predominantly on pragmatism, with variations appearing mainly in decorative elements. In contrast, Landmark architecture, though a minority, is designed to make a statement. These structures are aesthetically distinct but are unified under the common objective of creating notable, memorable buildings. Nevertheless, with these differing aesthetics, most contemporary buildings exhibit similarities in their proportions and spatial design (Colquhoun, 2002).

Such observations indicate that traditional means of categorising architectural progression may no longer suffice. While the terms 'Commercial' and 'Landmark' may offer a rudimentary framework to understand the contemporary architectural landscape, they fail to capture the essential features or underlying theoretical considerations that would anchor them within a well-defined theoretical context.

Moreover, contemporary buildings, regardless of whether they fall under the Commercial or Landmark category, exhibit many aesthetic and design trends. Often, these are derived from the stylistic signatures of renowned architectural firms. The current landscape lacks a singular narrative or style, transforming instead into a Baudrillardian spectacle of imitation, where urban environments swarm with both original designs and those 'inspired' by recognised offices (Baudrillard, 1981). Establishing a coherent narrative amongst this diversity becomes a difficult challenge. While the historical method of cataloguing architectural evolution based on aesthetic characteristics and periods served us well, it appears less effective in the context of the 21st-century architectural

landscape. As we continue to convey the evolving architecture of this era, a more fluid and multi-dimensional approach to classification may be needed to capture the complexities of contemporary design.

In an era of shifting paradigms in architectural styles, the paramount need for an evolution in the classification methods for architectural designs becomes increasingly apparent. Traditional classification systems, once essential, have become outdated in the face of a globalised, rapidly evolving field of architectural design. Our focus must thus shift from a primarily aesthetic criterion to a more sensible, holistic understanding of buildings that considers various facets beyond the traditional scope.

3.3.2. How to read Digital Architecture

Traditionally, classification in architectural discourse has been founded on the delineation of 'styles', a term predominantly associated with the aesthetic sensibilities of a particular era or movement (Ching, Jarzombek, & Prakash, 2017). However, in the context of the present's diverse and multi-faceted architectural landscape, aesthetic factors alone do not suffice as the defining features of a style. Herein lies the imperative to explore other less apparent or conventional characteristics as key criteria for classification.

One promising path for such an evolved system of classification is an in-depth understanding of the structures themselves. Several underlying aspects, such as the narrative or design philosophy, research undertaken in the design process, the technologies employed, and the building's contextualisation within its environment, can serve as values for a more contemporary classification system (Kolarevic & Malkawi, 2005). These factors extend beyond the aesthetic realm and delve into the essence and *raison d'être* of the buildings.

It is important to explore the concept of 'Value' in this context. Distinct from 'style', 'Value' is a term that transcends aesthetics, focusing more on the functional and conceptual aspects of architecture (Tavernor, 2007). This idea could serve as a new and more encompassing substitute for the traditional notion of style, tying closely with the fundamental definition of architecture rather than its visual characteristics alone. The transformation of architectural paradigms calls for an

equivalent evolution in classification methodologies. By shifting our focus from aesthetics to a multifaceted evaluation approach, we stand to gain a deeper, more meaningful understanding of architecture in its contemporary context. This transition towards considering 'Value' over 'style' could mean a new era of architectural discourse, empowering us to embrace the future and present of architecture in all its complexity.

3.3.3. Value, don't sort as a Paradigm.

In the current architectural environment of the 21st century, there is a distinct shift towards a more ornamental conceptualisation and usage of architectural aesthetics. This phenomenon can be observed as an international trend, and it is characterised by a departure from the minimalist ideals of the past - the so-called "Loosian" principles are dwindling, and we find ourselves amidst a new wave of architectural thought where "Less is Boring" and "More is Better" (Jencks, C. 2002). This shift in perception and practice is a key determinant of contemporary architectural design, heralding an age of ornamental abundance and complexity.

Carpo's "Search, don't sort" position offers an alternative perspective on understanding architectural design in this evolving context (Carpo, 2017). While primarily intended to address Digital Architecture, Carpo's approach can be extended to incorporate all aspects of the building industry. Traditional classification systems, which hinge on a limited set of architectural elements, are gradually proving to be inadequate, primarily due to an increasing disconnection between aesthetic and spatial considerations in contemporary designs.

In many instances, the buildings of today assume a post-postmodern stance, where facades and volumetric designs are ornamental, while the interior space is pragmatically driven and governed by utilisation and optimisation parameters. In such a scenario, it is more fruitful to adopt a search-based approach that focuses on specific factors relevant to the research inquiry. For instance, if the criterion of interest is energy efficiency, the search-based approach would filter out architectural designs based on their energy consumption or conservation features. Despite their diverse aesthetic appearances, all resultant structures share a common thread – their energy efficiency Value.

This search-based approach opens up many possibilities, allowing for an expansive exploration of architectural styles and concepts that have shaped architectural history. This is a timeless approach, freed from rigid classifications, and it fosters an appreciation of the inherent production values of architecture—be they aesthetic, spatial, or material. Ultimately, the concept of 'values' is an effective tool for classifying architecture, as it can distinguish and highlight quality and relevance in architectural designs, regardless of their aesthetic leanings.

In this light, it is clear that the architectural landscapes of the XXI century call for a rethink of traditional classification systems. The ornamental conception and usage of aesthetics in architecture and the increasing disconnection between aesthetic and spatial considerations necessitate a fresh, more dynamic approach. By using the concept of 'values' and adopting a search-based approach, we stand to gain a more nuanced understanding of architecture and its multifaceted manifestations in contemporary society.

Establishing a chronological understanding of architectural progression is an integral component in our analysis of architecture's evolution. A comprehensive understanding of architecture would remain elusive without considering the temporal context and socio-political circumstances surrounding each creation. Traditionally employed in architecture, the linear-style system is proof of this importance. Yet, like all facets of life, it is subjected to the inevitability of change and adaptation (Buchanan, 1992).

Architecture demonstrates a cumulative nature as a discipline, constantly integrating and transforming past knowledge for its evolution. In light of this, there has been a growing sentiment towards reforming the linear system to incorporate a rhizomatic approach, which recognises the intricate interconnections within architectural history (Deleuze & Guattari, 1987). This shift would facilitate a more precise comprehension of contemporary and future architecture, which is becoming increasingly complex and multifaceted.

Adopting a values-based system of classification promotes a more holistic understanding of architecture. Values, unlike styles, are atemporal, reflecting consistently across various architectural epochs. This non-linear method could potentially revitalise the evolution of aesthetics, as architectural designs would no longer be bound by temporal constraints. This could usher in an era of re-exploration and reinvention in architecture, devoid of time-induced limitations.

Thus, architecture can be envisioned as timeless, primarily promoting quality living environments and transcending stylistic and temporal factors.

While the broad spectrum of values could be considered, certain characteristics could provide a common thread that binds all manufacturing and building arts. This discussion conjectures the potential symbiosis that can be developed at the intersection of human endeavour, technology, and architecture. The role of local communities and their cultural heritage in shaping Augmented Architecture and Augmented Manufacturing is particularly interesting. Recognising the human factor and preserving the cultural integrity of local communities enriches these contemporary architectural practices.

The consideration of such an approach provides a more human framework for evaluating architectural development. The shift from linear to rhizomatic approaches, the adoption of values-based classification, and the emphasis on human and cultural factors all contribute to a more comprehensive and meaningful understanding of the evolution and future of architecture. These shifts do not negate the importance of traditional methodologies but enhance our understanding by adding more facets and perspectives to the architectural discourse.

3.3.4. How to classify the Augmented Architecture.

This Values System can be used to establish a more understanding framework for the classification of new forms and approaches in architecture, where the need to differentiate by aesthetic features loses relevance in favour of more humanistic and meaningful values.

This does not pretend to mean that aesthetics and design are irrelevant, but it should be the result of the amalgamation of other ideas and concepts that sublimate into design. In fact, translating values into aesthetics is one of the most relevant tasks that architects, as creative professionals, should perform during a building design sequence. As a matter of fact, the failure to connect intrinsic values to design and to the final production can have a consequence in that the values that conform to the building can be lost in translation and, therefore, not perceived.

That, by definition, renders the project mute as if values cannot be perceived, and the human experience can become unconnected.

This alternative approach allows Augmented Architecture to be analysed based on other prevalent values that entwine its conception with the ideas of craftsmanship, heritage, digitalisation, or knowledge dissemination and preservation, among others. In that sense, the definition of the values and the meaning of the overall scheme within digital architecture explains a new methodology that defines the goals that augmented architecture should have.

Upon examining the aspects developed in this thesis, four principal values could be used to establish the main borders of this approach. These values are:

1. **Craftsmanship:** The role of augmentation has a fundamental capacity to preserve and enhance traditional making towards the digital era.
2. **Digitalization:** As an immersive technology heavily connected with the digital environment, AR is the ideal bridge between tradition and technology for manufacturing and design purposes.
3. **Materiality:** Augmented reality can facilitate a more tactile approach to digital design, strengthening the capacity to not only propose new technologies but also update traditional uses.
4. **Human Factor:** Augmented reality facilitates human performance and allows for human behaviours in this environment. It creates value by preserving these "inaccuracies" that eventually create beauty.

These four values establish the base for understanding and analysing Augmented Architecture. Although not unique, they better exemplify the virtues that this new path for architecture has to offer. They represent the qualities that can reinforce architecture as a practice and prevent the homogenised mass production scenario of the purely industrial manufacturing approach. In that sense, it is paramount for this methodology to clearly define and contextualise them in the framework of architecture and how they can be used to define the study cases that will follow.

3.3.5. The Craftmanship Value

Traditional craftsmanship is a vital aspect of cultural heritage and has been human civilisation's bedrock foundation for millennia. The value of traditional craftsmanship goes far beyond the mere creation of objects, encapsulating condensing principles, values, and skills that have been refined through generations. The values inherent in traditional craftsmanship are deeply rooted in human history and social structures, often embodying many principles encompassing cultural heritage, personal growth, and community identity. A detailed examination of traditional craftsmanship unfolds a collection of values such as patience, precision, sustainability, and reverence for materials, each of which is universally relevant in the contemporary world.

Traditional craftsmanship carries an inherent respect for material and technique, embodying a profound understanding and appreciation of natural resources (Adamson, G. 2007). This value is particularly epitomised in Japanese wood joinery, a centuries-old art that eschews nails or screws. Instead, intricately designed joints bind wooden elements together, requiring deep knowledge of the material, patience, and extraordinary precision (Nakashima, 1981). Craftsmen view the material with a reverent, almost spiritual regard, cherishing its unique qualities and optimising its use, thereby creating not just an item of utility but a manifestation of nature's beauty.



Figure 98. Traditional Japanese Joinery.

Sustainability is another value deeply rooted in traditional craftsmanship. Many traditional crafts evolved in harmony with nature, utilising local resources responsibly and creating objects designed to last. Native American pottery serves as a second example of this value. For instance, the Hopi and Pueblo communities have been creating pottery for centuries, sourcing clay from local deposits and using traditional coiling techniques (Brody, 1971). These pottery pieces, beautifully painted with mineral and plant-based dyes, are utilitarian items and expressions of cultural stories and spiritual beliefs. Through the responsible use of local resources and the creation of long-lasting products, these communities demonstrate an early form of sustainable practice.



Figure 99. Hopi Pottery.

Traditional craftsmanship embodies the value of respect for materials. Recognising the inherent worth of raw materials and the labour invested in their transformation reflects a profound understanding of interdependence. Indian handloom weaving illustrates this principle. This ancient craft, which creates

intricate textiles using manually operated looms, considers every thread essential. Weavers respect the raw materials – often silk, cotton, or wool – and the complex process of transformation from fibre to fabric. This admiration extends to the weaver's connection with the loom, as the rhythm of the shuttle moving back and forth becomes an integral part of the weaver's identity.

Moreover, traditional craftsmanship is steeped in the value of intergenerational knowledge transfer, as techniques and secrets of the craft are often passed down through families or guilds (Ingold, 2013). Traditional Persian rug weaving, for instance, has been kept alive through such continuous transmission of knowledge, embodying rich cultural narratives and representing a form of non-verbal communication (Beaudry, 2006). Each rug, with its intricate patterns and vibrant colours, is not merely a decorative item but a tangible link to the past, a testament to a family's lineage, and a rich archive of societal norms and values.



Figure 100. Traditional carpet making.

Traditional craftsmanship also promotes the values of community identity and social cohesion. Craftsmen often serve as crucial social agents, forging ties within

and beyond their communities (Dormer, 1997). For example, the Mande blacksmiths of West Africa are custodians of their community's cultural heritage, creating functional objects and ceremonial items and contributing to significant social ceremonies (McNaughton, 1988). Their work reinforces community bonds and offers a platform for shared narratives and cultural rituals.

The practice of traditional craftsmanship is also marked by a strong ethic of self-improvement and mastery. The craftsman's journey often involves a lifelong pursuit of excellence, involving both personal development and technical proficiency (Sennett, 2008). The process of crafting is seen as an ongoing dialogue between the artisan and the material, fostering patience, resilience, creativity, and a deep sense of satisfaction in one's work.



Figure 101. Mande Iron Mask.

On an economic level, traditional craftsmanship, with its emphasis on hand-made quality and durability, contrasts sharply with today's throwaway culture and mass production systems (Sennett, 2008). Traditional crafts preserve the value of slow production, high-quality materials, and lasting functionality, qualities that are becoming increasingly attractive in our fast-paced, consumption-driven society.

The principles of traditional craftsmanship go beyond creating objects. They include respect for materials and techniques, passing knowledge across generations, building community identity, and fostering personal growth. These values are increasingly important as we tackle sustainability, climate change, and

social responsibility. Traditional craftsmanship can serve as a model for rethinking our relationship with materials, objects, and the world. Recognising these values is a way to show appreciation for the craftsmen, their exceptional skills, and the timeless principles that guide their work.

The value of craftsmanship in architecture is a notion deeply intertwined with the discipline's evolution, representing the meticulous application of skill, knowledge, and innovation to generate built environments of lasting quality. This value manifests in the ability of a structure to reflect a unique story of material mastery, cultural identity, and design excellence, wherein craftsmanship and architecture unite to transform raw materials into meaningful and enduring buildings.

Craftsmanship in architecture primarily expresses detailed skill and mastery, creating an intrinsic value beyond a structure's mere functionality. The integration of craftsmanship in architecture fosters a deep connection between the material, the creator, and the user, elevating the built environment from a basic shelter to an expression of cultural, social, and personal narratives (Adamson, G. 2007).

The Sagrada Familia, designed by architect Antoni Gaudi, represents an outstanding example of craftsmanship in architecture. Commenced in 1882 and yet to be completed, this basilica encapsulates Gaudi's mastery over diverse materials and his unprecedented architectural vision. From its intricately carved facades to the complexly designed interior columns that mimic trees, the craftsmanship demonstrated in the Sagrada Familia is reflective of a profound understanding of both material characteristics and innovative design, providing a tangible testament to Gaudi's artistic genius (Zerbst, 1993).

Craftsmanship in architecture also fosters the conservation of traditional skills and techniques, enhancing the cultural value of built structures. By integrating craftsmanship, architecture provides a vehicle for preserving and perpetuating a community's intangible cultural heritage (Crysler, Cairns, & Heynen, 2012). In this regard, the construction of the Kiyomizu-dera temple in Kyoto, Japan, exemplifies such preservation of traditional carpentry techniques. Reconstructed numerous times since its original establishment in 778 AD, the temple showcases the 'miyadaiku' technique, a traditional Japanese carpentry method requiring no nails or screws, emphasising instead the skills of the craftsmen in creating precise and durable joints.



Figure 102. Sagrada Familia façade detail. Antoni Gaudi.

Craftsmanship in architecture also fosters the conservation of traditional skills and techniques, enhancing the cultural value of built structures. By integrating craftsmanship, architecture provides a vehicle for preserving and perpetuating a community's intangible cultural heritage (Crysler, Cairns, & Heynen, 2012). In this regard, the construction of the Kiyomizu-dera temple in Kyoto, Japan, exemplifies such preservation of traditional carpentry techniques. Reconstructed numerous times since its original establishment in 778 AD, the temple showcases the 'miyadaiku' technique, a traditional Japanese carpentry method requiring no nails or screws, emphasising instead the skills of the craftsmen in creating precise and durable joints.

The Trulli houses in Alberobello, Italy, are a part of the vernacular architecture and have been recognised as a UNESCO World Heritage Site. These structures exemplify traditional dry-stone building techniques that have been passed down through generations (UNESCO, 1996). The distinct conical roofs, built without the use of mortar, demonstrate the craftsmen's expert knowledge of local materials and climatic conditions. The Trulli houses showcase how craftsmanship, when combined with a deep understanding of the local context, can lead to an architecture that is sustainable, resilient, and reflective of a community's cultural heritage.



Figure 103. Trulli Houses. Italy.

Craftsmanship plays a crucial role in driving innovation in architecture. While it connects us to the past, it also unlocks opportunities for the future by enabling architects to explore new materials and techniques and develop innovative design solutions (Pallasmaa, 2005). Architects like Shigeru Ban exemplify this through their use of unconventional materials like paper tubes. Ban's pioneering use of recyclable materials, combined with a high level of craftsmanship, has resulted in the creation of environmentally friendly and cost-effective buildings, such as the Paper Church in Kobe, Japan (Ban, S. 2009).

The value of craftsmanship in architecture lies in its ability to give built environments a deeper cultural significance, preserve traditional techniques, and enable innovative design solutions. Architectural craftsmanship can result in structures that are not only functional and aesthetically pleasing but also deeply rooted in cultural traditions and sensitive to their environmental context. The combination of craftsmanship and architecture can create built environments that truly enhance the human experience, connect us with our cultural heritage, and inspire future generations of builders and creators.



Figure 104. Paper Church. Shigeru Ban. 1995.

3.3.6. The Value of Digitalization

In the ever-changing field of design, the use of digitalisation and computational methods has become crucial. This combination represents a significant departure from traditional design approaches, as it incorporates algorithms, simulations, and digital manufacturing techniques. This shift, driven mainly by technological advancements, has created new opportunities for creativity, efficiency, and problem-solving. From the fashion industry to product design, graphics, and interactive media, digitalisation and computational methods are shaping the future of design.

Digitalisation and computational design spark innovation by empowering designers to address complex problems and venture into unexplored design territories. By using algorithmic logic and parametric design, designers can rapidly generate and evaluate a multitude of design permutations, culminating in optimal outcomes (del Campo et al., 2019). Autodesk's generative design software is an excellent example. It is widely used in industrial design and automotive engineering. This software allows designers to create numerous design options based on specific goals and limitations. It optimises design results in ways that would be impossible to achieve manually.

In the domain of design, digitalisation serves as a catalyst for enhanced creative expression and exploration. Computation and algorithms are now part of the essential toolbox of many designers, allowing them to generate a vast range of design alternatives and possibilities (del Campo et al., 2019). In the fashion industry, for example, Iris van Herpen, a Dutch fashion designer, uses computational design and digital fabrication techniques to create intricate, organic forms that redefine conventional aesthetics. Her haute-couture collections, often inspired by natural phenomena and scientific concepts, harness the power of digital tools to bring complex and imaginative visions to life (Quinn, 2012).

Moreover, computational design empowers designers to optimise their creations for performance and user interaction. In the realm of product design, computational techniques are used to test, refine, and improve products before they're physically manufactured, ensuring their safety, durability, and efficiency (Kolarevic, 2005). For instance, Dyson, a renowned brand in home appliances, employs computational fluid dynamics and finite element analysis to simulate and optimise the performance of its products. These methods played a crucial role in

designing their bladeless fans, combining efficiency and safety with a sleek, modern aesthetic (Otto and Wood, 2001).



Figure 105. Computational Dress. Iris van Herpe. 2012.

Computational design also plays a vital role in optimising product performance and sustainability. Through digital prototyping and performance simulations, designers can predict and enhance a product's lifecycle, environmental footprint, and efficiency (Kolarevic and Malkawi, 2005). A remarkable example is the design

of the Boeing 777 aeroplane. Using computational design tools, Boeing created a virtual prototype that underwent numerous simulations for performance optimisation, thereby drastically reducing the need for physical prototyping and improving the plane's overall performance and efficiency.

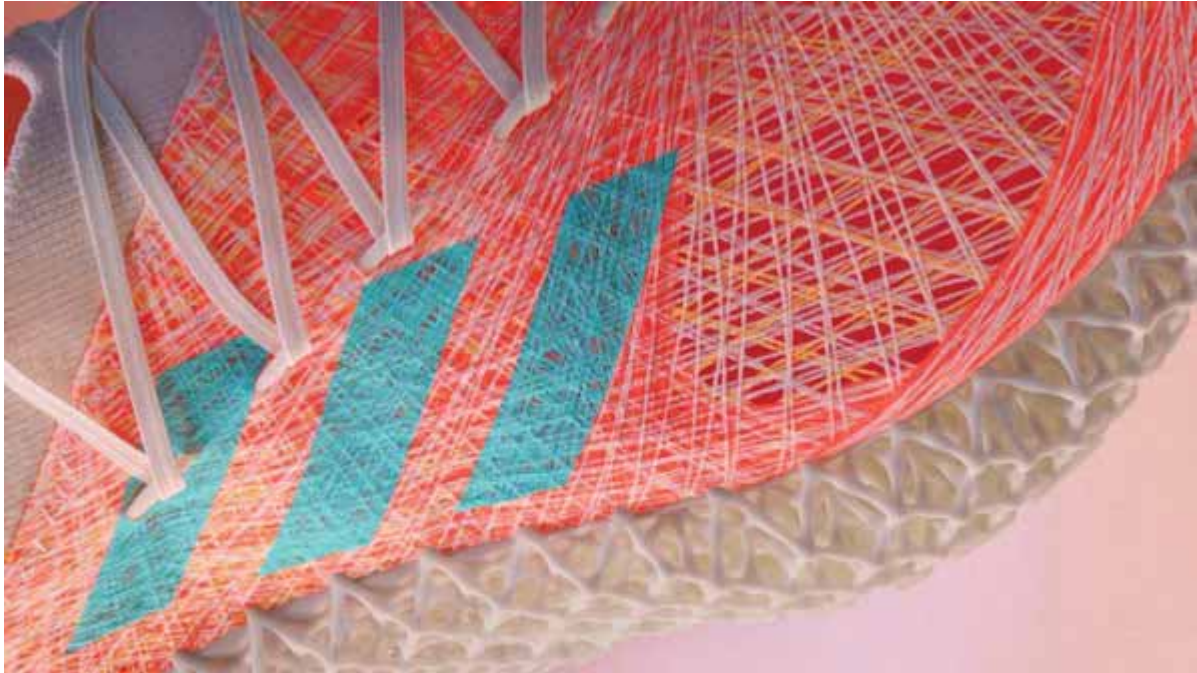


Figure 106. 3D printed shoe. ADIDAS.

Digitalisation significantly enhances collaboration and coordination within design processes. Digital tools facilitate synchronised work within multidisciplinary teams, real-time updates, and a common understanding of the design, thereby reducing errors and redundancies. An example is the use of Product Lifecycle Management software in the design of complex products like automobiles and electronics. These systems manage and integrate all stages of a product's lifecycle from conception to disposal, enabling seamless collaboration and data management across different teams (Stark, 2015).

Digital fabrication, the translation of computational design into physical form, has revolutionised production methodologies and material usage. Techniques such as 3D printing, CNC milling, and robotic assembly can produce complex forms and assemblies, allowing intricate designs to become reality (Carmo, 2017). Adidas' Futurecraft Strung shoe is a great example. The placement and tension of each thread were calculated using computational design, and the shoe was assembled

using a robotic manufacturing process. This resulted in a shoe that combines exceptional performance with material efficiency.

Digitalisation and computational methods are not merely reshaping design practices but are also democratising the field by making advanced tools and techniques more accessible. They allow designers to push the boundaries of creativity, enhance product performance, foster collaboration, and redefine manufacturing methodologies.

In the environment of architecture, digitalisation and computational methods have become transformative factors. In a distinct departure from conventional architectural practice, the integration of digital technologies and computational design strategies has introduced sophisticated tools and methodologies, including algorithms, simulations, and digital fabrication techniques. This shift has led to a profound enhancement in efficiency, creativity, and complexity within architectural processes, thereby redefining the foundational principles of the field.



Figure 107. Heydar Aliyev Centre. is Zaha Hadid Architects. 2012

Digitalisation and computational design stimulate innovation by enabling architects to handle complex problems and explore novel design territories. Architects can swiftly generate and evaluate numerous design permutations by employing algorithmic logic and parametric design, thereby facilitating optimal design solutions (del Campo et al. 2017). An example of innovative architectural design is the Heydar Aliyev Centre in Azerbaijan, designed by Zaha Hadid Architects. This building showcases the potential of computational design by seamlessly integrating walls, ceilings, and floors into a continuous, fluid surface.

This architectural achievement was facilitated by the use of intricate parametric design software.

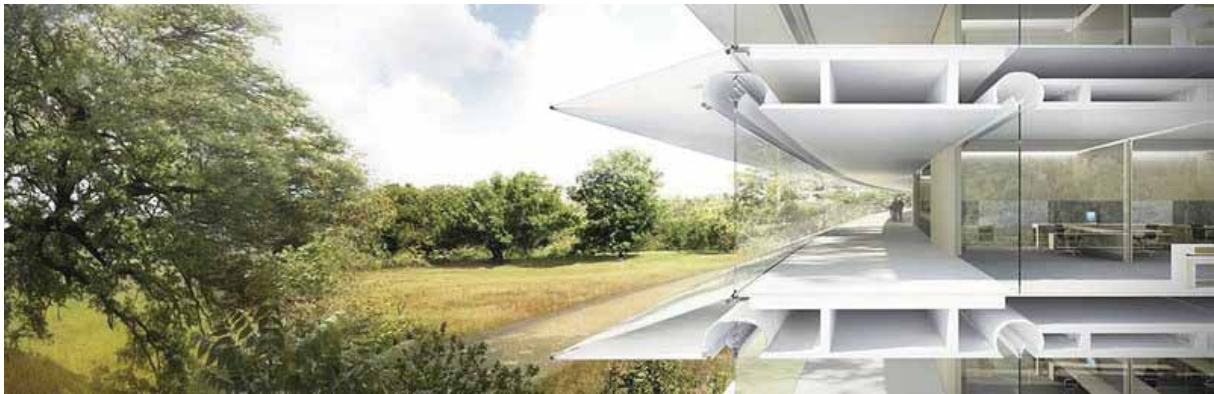


Figure 108. Apple Park ventilation detail. Foster & Partners. 2018.

Likewise, computational design plays a critical role in optimising building performance and sustainability. Through Building Information Modelling, data-driven design, and performance simulations, architects can predict and improve a building's environmental impact, structural efficiency, and energy performance (Kolarevic and Malkawi, 2005). Foster + Partners' Apple Park in California exemplifies this aspect. The design was extensively optimised using computational simulations, resulting in a building that doesn't require heating or air conditioning for most of the year, making it one of the world's largest naturally ventilated buildings.

Digitalisation also significantly enhances collaboration and coordination within architectural processes. Digital tools enable synchronised work within multidisciplinary teams, real-time updates, and a shared understanding of the design, thereby reducing errors and redundancies (Otto, P. 2000). A relevant example of this approach is the innovative use of BIM by Arup in the design and construction of the Beijing National Stadium, also known as the Bird's Nest. BIM enabled unprecedented collaboration and coordination among different teams involved, ensuring the successful realisation of this complex structure (Underwood and Isikdag, 2009).



Figure 109. Bird's Nest Stadium. Herzog & DeMeuron. 2008.

Incorporating computational design into the fabrication process has revolutionised construction methodologies and material usage. Digital fabrication techniques such as 3D printing, CNC milling, and robotic assembly can handle intricate forms and assemblies, bringing complex designs to life (Carpo, 2017). One such example is the DFAB House in Switzerland, the world's first fully inhabited building to have been digitally planned and largely built with the help of robots and 3D printers, demonstrating how computational design can drive efficient and innovative architectural constructions (Gramazio, Kohler, & Willmann, 2014).



Figure 110. 3D printed concrete slab DFAB House. DBT. 2018.

The integration of digital and computational tools has revolutionised the concept of responsive architecture. Digitalisation directly results in buildings' ability to respond and adapt to changing environmental conditions and user needs. An innovative example is the Al Bahar Towers in Abu Dhabi, designed by Aedas. The towers feature a dynamic facade that adjusts in response to the movement of the sun, reducing solar gain and energy consumption (Kolarevic, 2005).



Figure 111. Parametric façade Al-Bahar Tower.AEDAS. 2012.

The transformative power of digitalisation and computational design in the domain of architecture is multifaceted and profound. It fuels innovation, optimises building performance and sustainability, enhances collaboration and coordination, and reimagines construction methodologies. Digitalisation represents a vision of the future where architects, empowered by digital tools, are set to redefine and transform our built environment, bridging the gap between the realm of imagination and the physical world. Digitalisation and computational architecture are not just trends but rather fundamental tools that are here to stay. The exciting

possibilities brought about by the fusion of digitalisation and computational architecture are truly limitless, and we are just scratching the surface of its potential. The realm of architecture continues to evolve in response to these advancements, making it an exciting time to be a part of this ever-changing field.

3.3.7. The Value of Materiality

The concept of materiality embodies a fundamental role in the field of craftsmanship and design. In essence, materiality results in a deliberate and mindful approach towards the choice, adaptation, and application of materials in the crafting of objects. This interaction shapes the final product's perception, functionality, and aesthetic appeal.

Materiality is essential for inspiring innovation in craftsmanship and design. There is a strong relationship between the craftsman or designer and the material, where the physical and aesthetic characteristics of the material guide and inspire new forms, functions, and creative explorations (Dormer, 1997). This innovation goes beyond just aesthetics, and it also influences problem-solving related to function and structure. It fosters a creative dialogue between the craftsman and the material, directing the exploration and discovery process that leads to unique creations (Dormer, 1997). In the realm of design, the inherent characteristics of a material, such as its texture, durability, flexibility, colour, and even its limitations, shape the designer's approach and determine the final product's attributes.

The innovative use of materiality can be seen in the designs of Charles and Ray Eames. They were the first to use moulded plywood in furniture design, taking advantage of its ability to be formed into organic shapes. This led to the creation of iconic furniture pieces like the Eames Lounge Chair. Their work demonstrates how a thorough understanding and creative application of materials can transform design (Kirkham, 1998).



Figure 112. Lounge Chair. Eames. 1956.

Furthermore, materiality plays a critical role in preserving cultural heritage and tradition within craftsmanship. The selection of materials is often intricately linked to a cultural and geographical context, aiding in the preservation of traditional knowledge and techniques and associating the craft with a specific locale and community.

An example of this phenomenon is the craft of Irish crystal making. The raw material, in this case, silica sand, is sourced locally, and the traditional techniques of glass blowing and hand-cutting used in its transformation are deeply ingrained in the cultural heritage of places like Waterford, Ireland. The final product's distinctive clarity and refraction quality make it a revered symbol of Irish craftsmanship. In that sense, the particular composition of the sand used for the manufacturing of the glass is unique and completely connected to the surrounding context. Additionally, its particular shaped edge design gives the final product its unique reflections and sparkly effects. Finally, its quality reputation for centuries has ensured that even the formula could be closely replicated somewhere else; the real value of this product relies on its procedure as a reputable trademark.



Figure 113. Waterford Glass. Ireland

In modern design, the consideration of materials has become more important in terms of sustainability. With growing environmental concerns, there is a greater emphasis on using materials that are renewable, recyclable, and have a low environmental impact. By understanding and using these materials efficiently, the environmental impact of design projects can be significantly reduced.

A prime example of sustainable material use in design is the work of Dutch designer Piet Hein Eek. He is known for creating furniture from scrap wood, using discarded wood pieces to showcase their unique grains and patterns and create distinctive furniture items. This not only minimises waste but also adds a unique aesthetic quality to his designs (Betsky, 2002).

The material used in design also greatly influences the sensory experience of the object, enhancing its emotional value. The tactile, visual, and even olfactory qualities of materials can evoke certain emotions and memories, enriching the user's interaction with the object.



Figure 114. Scrap Wood Table. Piet Hein Eek.

Materiality was a key element in the design philosophy of Hans J. Wegner, a highly influential Danish furniture designer of the 20th century. Wegner, known for his functional, elegant, and timeless designs, believed that the materials used in furniture were integral to the final product's aesthetic and longevity rather than just a means to an end. He meticulously selected durable and naturally beautiful woods like oak, teak, and ash, recognising their ability to age gracefully. Wegner often highlighted the natural qualities of wood, allowing its texture and grain to influence the form of his pieces.

Wegner's designs, such as the well-known "Deck Chair" and "The Round Chair," showcase his deep understanding of materiality. He respected wood, creating joints and curves that reflected the natural properties of the material rather than forcing it into unnatural forms. This sensitivity to material contributed to the organic feel and human-centred functionality of his furniture.

Furthermore, Wegner's focus on craftsmanship and the tactile experience of his designs meant that materials had to not only look good but also feel right to the user. In this way, materiality was central to Wegner's philosophy of creating pieces that were both beautiful and built to last, embodying the principles of Danish modern design (Oda, 2002). Materiality can also serve as a tool for social commentary and critique in both craftsmanship and design, providing a tangible medium for expressing societal reflections. The work of the British ceramist Grayson Perry provides a compelling example. Perry employs traditional ceramic materials and techniques to create intricately decorated pots. However, the imagery and text depicted on these pots often confront contemporary social and political issues, using the historical materiality of ceramics to juxtapose and critique modern society (Perry, 2019).

The importance of materiality in craftsmanship and design is diverse. It serves as the corner stone for innovation, cultural preservation, sustainability, and sensorial experience. The thoughtful selection and use of materials shape not only the physical attributes of a work but also its broader cultural, environmental, and social implications.



Figure 115. PP524 Deck Chair. Hans Wegner. 1958.

This is evident in the Pueblo architecture of the Southwestern United States. The use of adobe, a material made from earth and organic matter, links the architecture to the landscape, reflecting the Indigenous communities' relationship with the land. The sustainability and thermal properties of adobe make these buildings culturally significant and environmentally friendly (Brody, 1971).

Materiality plays a critical role in the domain of architecture, shaping not just the physicality of built structures but also their character, relevance, and relationship with their surroundings. Materiality is a foundation in the architectural discipline, where it serves a fundamental role beyond the physical manifestation of design intent. Materiality, in this regard, denotes the considered selection, processing, and implementation of materials that significantly impact a building's functional, aesthetic, and experiential attributes.

Foremost, materiality serves as a catalyst for innovation in architecture. The inherent properties of materials, such as their form, texture, durability, and even their limitations, act as a source of inspiration, guiding architects towards unique design solutions (Frampton, 1995). The selection and application of materials can



Figure 116. Ceramic Vase. Grayson Perry. 2019.

Push the boundaries of architectural design, resulting in structures that challenge conventional notions and enrich the built environment.

Peter Zumthor's Therme Vals in Switzerland exemplifies the innovative use of materiality. Zumthor utilised locally quarried quartzite stone, masterfully manipulating its texture, colour, and thermal properties to create an atmospheric thermal bath complex. The structure appears as a natural extension of its alpine environment, and the strategic use of stone engenders a unique sensory experience for the users, marked by tranquillity and introspection (Zumthor, 2006).



Figure 117. Vals thermae. Peter Zumthor. 1996.

Materiality in architecture also carries cultural and historical significance. The use of locally sourced materials and traditional building techniques can establish a tangible link between a building and its geographical and cultural context. This aspect of materiality helps preserve architectural traditions and gives a sense of identity and continuity to places.

The consideration of materiality in architecture is crucial, especially in terms of sustainability. With growing environmental concerns, architects are increasingly choosing renewable and recyclable materials with low environmental impact. This change in material selection significantly helps to reduce the environmental effects of architectural projects.

An excellent example of this approach is the work of the Dutch architectural firm Superuse Studios. They advocate for the practice of 'reuse in design' and have shown an innovative way of using waste materials in architectural projects. Their project, Villa Welpeloo, is mainly constructed from recycled steel and timber obtained from a disused textile mill, demonstrating the potential for sustainable material choices in architecture (Brand, 2007).



Figure 118. Welpeloo Villa. Superuse Studios. 2009.

Lastly, materiality significantly contributes to architecture's tactile and sensory experience, heightening its emotional resonance. The sensory qualities of a material, such as its texture, temperature, sound, and smell, can elicit emotions, associations, and memories, thereby enriching the user's interaction with the built environment.

Portuguese architect Eduardo Souto de Moura's architecture demonstrates the importance of materiality. His Braga Municipal Stadium in Portugal utilises concrete in a remarkable way, manipulating its form, texture, and acoustic qualities to enhance the spectator's experience. This design shows how the strategic use of materials can evoke a rich sensory response and amplify the architecture's emotional depth (Frampton, 2002).

Along the same line, the election of the material affects the temporality of the building and how it evolves in its life. The Salk Institute in California, designed by Louis Kahn, exemplifies this idea. Kahn used concrete and teak, materials that age gracefully, to construct the building. Over time, these materials have developed a patina, making the building more engaging and visually appealing. The textural contrast between the rough concrete and smooth teak also contributes to the building's sensory experience (McCarter, 2005).



Figure 119. Braga Stadium. Eduardo Soto da Moura. 2003.

The importance of materiality in architecture is diverse. It is a key determinant of architectural innovation, cultural relevance, sustainability, and emotional resonance. We see how thoughtful and strategic use of materiality can shape architecture, lending it relevance and value in its physical, cultural, environmental, and emotional contexts.



Figure 120. Salk Institute Louis E. Kahn. 1965.

3.3.8. The Value of the Human Factor

The essence of design lies in its deeply human nature. It not only caters to human needs, but also to emotions, behaviours, and sensitivity. Human intuition is crucial in the traditional design process, as it taps into designers' tacit knowledge and experience, enabling them to create products that deeply resonate with people. As cognitive scientist Donald Norman pointed out, design is essentially a form of communication requiring a deep understanding of the end user. This underscores the significance of the human element in the intricacies of design.

One of the most prominent examples of the human factor and intuition in traditional design is seen in the craft of Murano glassmaking in Italy. The creation of Murano glass is a dance of human intuition, skill, and experience, where the glassblower's actions are guided by a deep understanding of the material and the process. This innate understanding and intuition inform everything from the manipulation of molten glass to the final touches that bring the piece to life. The result is a unique piece of art that speaks of its creator's intuition and the human-centric nature of its design (Barovier, Mentasti, & Tonini 2004).



Figure 121. Murano Glass. Italy.

A similar dynamic can be seen in traditional textile design, particularly in the handweaving practices of Southeast Asia. Here, the weaver's intuitive understanding of the loom's materials, colours, patterns, and rhythm plays a crucial role in the creation process. This intuition, trained through years of

practice, guides the weaver in making on-the-spot decisions that affect the final product's look and feel, resulting in textiles that are truly unique (Gittinger & Lefferts, 1992).



Figure 122. Traditional Weaving. South Asia.

Another domain where human intuition shines is in the crafting of traditional ceramics. For example, the pottery made in Stoke-on-Trent in the UK exemplifies how a deep, intuitive understanding of the material, the process, and the final product can lead to designs that are not only functional but also beautiful. These traditional potters manipulate clay in ways that reflect their understanding of its properties, resulting in pottery that is aesthetically pleasing and inherently human (Shaw, S. 1970).

Lastly, the traditional design and crafting of musical instruments, such as the Stradivarius violin, underscore the importance of the human factor and intuition. Luthiers, or instrument makers, transform raw materials into instruments capable of producing sublime music through an intuitive understanding of sound

quality and material intricacies. Their craftsmanship caters to deep human emotional responses, thus connecting the user and the instrument at a profound level (Fritz et al., 2012).



Figure 123. Stoke-on-Trent pottery. England.

Human intuition and the human factor serve as the lifeline of the design process, particularly in traditional crafts. They bring an understanding of human needs and behaviours to the table, coupled with an instinctive feel that breathes life into designs, making them not merely functional or aesthetic but resonant with the human spirit. Human intuition bridges the gap between the maker and the user in many ways, enriching the final product with an ineffable quality that makes it not just a tool or an artefact but an extension of human emotion and experience.

The genius of a design lies not only in its tangible features but also in its ability to foster a bond with the user. This is where human intuition, with its keen sensitivity to human needs and emotions, comes into play. It elevates a design from being a mere object to being an entity that users can relate to, find comfort in, and ultimately incorporate into their lives. The final product, shaped and enriched by

human intuition, is invariably more attuned to human needs, more sensitive to human limitations, and more fulfilling of human aspirations. In this manner, the design becomes a reflection of the user's identity and values, thereby adding a deeper meaning to its existence.

This is particularly true in traditional crafts, where the creator's intimate connection with the craft and the intuitive understanding of the process and material lends a unique warmth and personality to the product. Whether it's a piece of pottery, a handwoven fabric, a musical instrument, or a glass artefact, the product carries in it a part of the creator's spirit, passion, their intuition. This brings a kind of authenticity and richness to the product that is hard to replicate through mass-production methods. The resultant product, therefore, stands as a testament to human skill, intuition, and creativity, making it a cherished possession for the user.

Including the human factor and intuition in the design process cultivates a sense of harmony between the user and the product. This harmonious relationship, where the user finds a reflection of themselves in the product and the product finds its meaning in serving the user, is the hallmark of great design. This empathetic and intuitive approach to design has the potential to make the world more understanding, accommodating, and, ultimately, more human.

The human factor is paramount in design, particularly in digital design. In an increasingly digital world, where technology forms the backbone of many of our everyday activities, the human factor remains the essence that anchors design to reality, ensuring it resonates with its intended users. Notably, human intuition, which forms a substantial part of the human factor, plays a significant role in the digital design and making process. This subtle yet crucial aspect transcends explicit knowledge, becoming an invaluable tool in the designer's toolkit, enabling the creation of designs that are not only functional but deeply meaningful and resonant.

One of the classic instances of the power of human intuition in digital design can be seen in the design of Apple's first iPhone. Steve Jobs, known for his intuitive understanding of design and user experience, steered his team toward a minimal, intuitive, and user-friendly design. Guided by their intuition and deep understanding of user behaviour, the team designed a product that went on to revolutionise the smartphone industry (Isaacson, 2011).

In video game design, the human factor and intuition are integral to creating immersive and engaging experiences. Game designers rely on their intuition and understanding of human behaviour to create compelling narratives, intuitive gameplay mechanics, and engaging user interfaces. For instance, in the creation of the popular game *The Last of Us*, the designers at Naughty Dog used their intuition and understanding of human emotion to design a narrative and game mechanics that deeply resonated with players, creating an unforgettable experience (Druckmann, 2013).

Web design is another area where the human factor plays a vital role. Designers must intuitively understand users' needs and behaviours to create interfaces that are easy to navigate and pleasant to use. For instance, Google's design team opted for a simple and clean design when designing its search engine interface. Their intuitive understanding of the user's need for simplicity and efficiency led to a design that users worldwide appreciate and use daily (Google Design, 2020).

In the field of app design, human intuition often guides designers to create intuitive user interfaces and user experiences. For example, in designing the Spotify app, the designers leveraged their understanding of user behaviour and their intuition about what users would find aesthetically pleasing and easy to navigate. The result is a functional, intuitive, and engaging app, providing users with a seamless music streaming experience (Rochet, 2003).

Lastly, human intuition plays a significant role in designing digital tools and platforms for creative tasks. For example, consider the design of a digital painting application. The designer's intuition guides the development of brush tools, colour palettes, and other features, aiming to create a tool that feels natural to the user, almost mimicking the experience of painting on a physical canvas. The success of such an application depends significantly on how well the designers understand and cater to the intuitive practices of the end-users (Buxton, 2007).

The importance of the human factor and human intuition in digital design cannot be overstated. The human-centric approach allows designers to tap into the unarticulated needs and behaviours of the users, guiding the design process in subtle yet profound ways. When the design process is guided by human intuition, the final product transcends mere functionality, morphing into a resonant, meaningful experience for the end user. This human intuition enables the creation of designs that not only cater to the functional needs of the users but also speak to their emotions, thereby fostering a deeper connection with the product.

The power of human qualities in the digital design process lies in its ability to understand and respond to the nuances of human behaviour. It often leads to solutions that a purely analytical approach might overlook. Human qualities add a layer of richness to the design and a sense of depth that makes the product relatable, intuitive, and enjoyable to use.

In the ever-evolving landscape of digital design, it is critical to retain this focus on the human factor and human intuition. As designers, we must continually strive to understand our users better and let our intuitive understanding guide our design choices. Through this nuanced understanding of the human factor, we can continue to create digital products that are not just functional but deeply resonant, bringing joy to the users and making a lasting impact.

From an architectural perspective, human intuition is not only a traditional value but a fundamental foundation for the design processes. As we advance in technological capabilities, the understanding and integration of human needs, behaviours, and intuition continue to hold paramount importance in the architectural design process. The human factor ensures that design transcends aesthetic or functional considerations, becoming an experience that connects with its intended users on a deeply human level. In tandem with this, human intuition, an integral part of the human factor, plays a significant role in the architectural design and making process. This tacit knowledge, refined through years of experience and practice, facilitates the creation of architectural designs that resonate strongly with users. As the renowned architect Le Corbusier once said, "Architecture is an art when one consciously or unconsciously creates aesthetic emotion in the atmosphere, and when this environment produces well-being."

A notable example of the human factor and intuition in architecture is observed in the work of Louis Kahn. Kahn's philosophy emphasised the importance of serving the community's needs and understanding the place's spirit'. His intuitive understanding of materials, light, and space is evident in buildings like the Salk Institute. The design, while straightforward and functional, emanates a unique emotional resonance achieved through the intuitive positioning of spaces and the ethereal management of natural light. The building, in line with the materiality value, established an architectural space that not only attempts to quality space but also enhances sensorial perception. The perspectives, volumes, and craftsmanship involved construct a hybrid between monumental and human scale. (Brownlee & De Long, 1991).

The works of Alvar Aalto provide an insightful understanding of human intuition in architectural design. His designs, like the Paimio Sanatorium, embody his deep empathy towards the users. Aalto's intuitive understanding of human comfort, healing, and connection with nature shaped the design, creating an environment that catered to the patient's physical and psychological needs. This humanistic approach, together with a very sensible use of materials and textures, defines how human experience can drive quality and innovative design.



Figure 124. Salk Institute Louis E. Kahn. 1965.

Another relevant example of human values-infused, designed in 1935, is the Falling Water House, designed by Frank Lloyd Wright in Pennsylvania. Wright's intuitive understanding of the human need to connect with nature informed his design, leading him to create a building that blends seamlessly with its surroundings. His design offers the dwellers a profound sense of integration with the environment, showcasing how intuition can lead to the creation of spaces that

deeply resonate with human sensibilities. Also, the improvisation that came from adapting the architecture to its natural environment and the river exemplifies the value of human intuition in the decision-making process (Hoffmann, 2002).

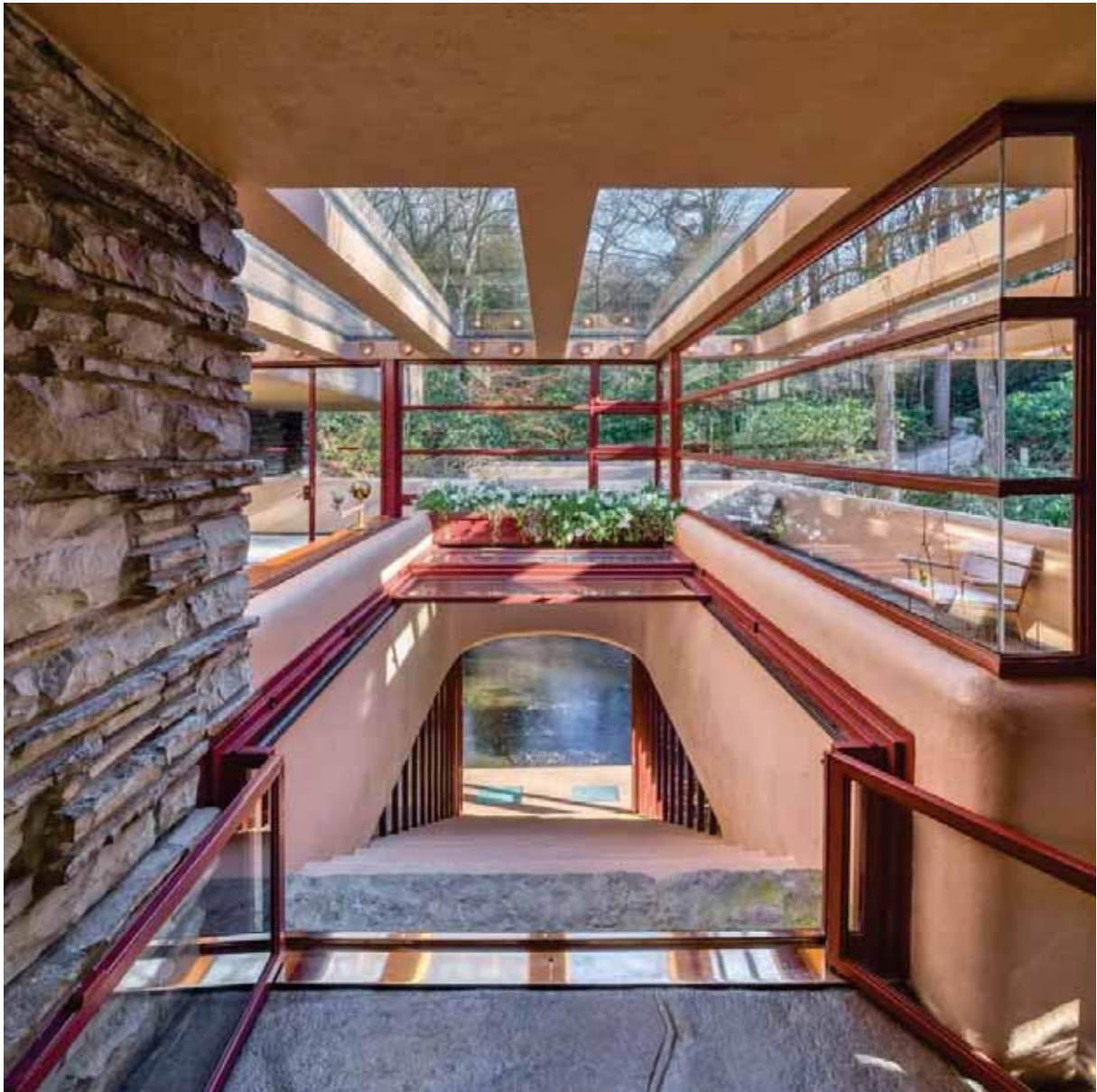


Figure 125. Fallingwater House. Frank Lloyd Wright. 1965.

The role of the human factor and intuition in architectural design is critical in shaping buildings beyond functional and aesthetic considerations. By tapping into the intuitive understanding of human needs, behaviours, and interactions, architects can design spaces that resonate deeply with their intended users.

Human intuition influenced critical design decisions, resulting in architecture that not only served its functional purpose but also connected with users on a profound level. This connection stems from the architect's understanding of the human factor, guided by intuition, resulting in a final design that enhances user experience, interaction, and well-being.

The impact of human intuition in architectural design underscores its ability to perceive and cater to subtle nuances of human behaviour and interaction that might otherwise be overlooked. It adds a layer of depth to the architectural design, creating spaces that are not merely structures but experiences that resonate with users.

As we continue to advance in architectural design, the importance of the human factor and human intuition remains constant. By placing the user at the centre of the design process and allowing human intuition to guide design decisions, architects can create spaces that are not just functional and aesthetically pleasing but are also deeply meaningful, contributing positively to the human experience.

3.3.9. What the Values Result In.

The integration of values such as craftsmanship, materiality, and the human factor plays a pivotal role in shaping the future of architecture in an era increasingly defined by technological advancement. The rapid development of digital technologies is transforming every aspect of our lives, from the way we communicate to how we design and interact with the built environment. As these technologies continue to evolve, it is essential to recognise that the values we hold can help us navigate this change in a way that respects the integrity of human experience while embracing innovation.

Craftsmanship, with its emphasis on skill, tradition, and attention to detail, is a key value in preserving the human element in architecture. As technology pushes the boundaries of what is possible in design and construction, it is important not to lose sight of the artisanal quality that has long been a hallmark of architecture. By maintaining a focus on craftsmanship, we ensure that the human touch remains evident in the built environment, providing spaces that are not only functional but also imbued with meaning, beauty, and cultural significance. The integration of digital tools with traditional methods can result in innovative designs that honour both past and present, creating a harmonious blend that enriches the architectural experience.

Materiality is another essential value that grounds architecture in the physical world. While digital technologies allow for increasingly complex and abstract designs, materiality ensures that these designs remain connected to the tactile and sensory experience of space. The selection and use of materials in architecture is not just a technical decision; it is a reflection of cultural, environmental, and historical context. By valuing materiality, architects can make informed choices that balance technological possibilities with sustainability, durability, and aesthetics. This holistic approach encourages the responsible use of resources, ensuring that architecture remains sustainable and relevant in a world facing pressing environmental challenges.

The human factor is perhaps the most critical value in defining how architecture responds to technological change. Architecture is ultimately about creating spaces for people, and as society evolves, the needs and expectations of individuals and communities evolve with it. A human-centred approach to design takes into account not only the physical and functional aspects of a building but also the emotional, social, and psychological needs of its users. Technology can enhance this process by providing tools for better analysis, visualisation, and customisation, but it should not replace the human insight that is necessary for creating truly meaningful spaces. By prioritising the human factor, architects can ensure that their designs remain relevant and responsive to the changing dynamics of society.

In a rapidly evolving world, the values of craftsmanship, materiality, and the human factor serve as essential guides in shaping the future of architecture. By embracing these values alongside cutting-edge technologies, we can create buildings and spaces that respect our heritage, honour our environment, and meet the needs of a changing society. Rather than seeing technology as a replacement for traditional methods and values, we can use it as a tool to enhance and amplify the qualities that make architecture meaningful. In doing so, we ensure that the future of architecture is one that celebrates both innovation and the enduring importance of the human experience.

4. Results

When researchers define a thesis, the tools and methodologies they choose are crucial as they can greatly impact the entire investigation. While it may seem like just another method, the case study offers academics a detailed and contextual perspective that is unique. Case studies are rooted in real-world scenarios and lived experiences, enabling researchers to capture the multi-layered intricacies of their subjects.

Broad research methodologies allow us to comprehend a wide spectrum of knowledge from a high-level perspective, capturing its overarching contours and widespread patterns. However, this panoramic view often overlooks the subtle nuances and hidden details that give the landscape its true character. This is where the case study becomes essential. It acts as a magnifying glass, bringing these overlooked intricacies into focus. When defining a thesis, these details become the cornerstones of groundbreaking academic arguments.

A case study ensures that the research is firmly rooted in the concrete realities of the world and not floating in the realm of abstract theorisation. This foundation is indispensable for a compelling thesis, which must resonate with the academic community and hold relevance beyond the confines of academia. By delving deeply into a single case or a few of them, researchers gain insights that are rich with the complexities of real-life scenarios. These complexities enrich the thesis, making it more robust and multifaceted.

The effectiveness of a case study depends on how well it is used. If a case is chosen poorly or not analysed thoroughly, it can mislead researchers. However, with careful selection and rigorous analysis, a case study can provide valuable guidance to researchers as they define their thesis.

Among the many tools available to researchers, the case study is particularly valuable. It serves as a reminder that behind every data point, there is a story waiting to be told, and behind every trend, there is a tale to uncover. In the pursuit of defining a thesis, these stories and tales are the threads that come together to form the rich tapestry of academic inquiry.

In this thesis, a series of case studies will showcase the value and relevance of the architectural world of Augmented Manufacturing. In terms of methodology, the system that this display will follow is structured. First, every case will be generally

contextualised and described to define its core concepts and explorations. Every project will be analysed from the conceptual logic, design approach, algorithmic logic, geometry proposal, and material election. Also, the architectural goal will be discussed and how the experiment matches the target building scale. From this general categorisation, the second stage of the study case analyses will be the classification within this thesis's Values System. The objective data extracted from the previous section will be synthesised to define how they achieve or fit into the values selected. Although not conclusive, the result of this filter should indicate how these projects demonstrate the potential for Augmented Manufacturing in progressing the architectural design and how they promote positive values toward the future of the profession.

In terms of values, the study cases contain multiple of them, and they will be mentioned when relevant. Four values that resonate with the concepts that this thesis proposes are selected to constrain and develop a more consistent and clear analysis of the project.

The Value of Craftmanship. This value is selected because it can define and establish how the projects approach traditional making techniques and, as a result, how sensible these projects are with heritage conservation. In that sense, elements like how handcrafting is involved or how the uniqueness in manufacturing affects the final result will be determinant factors to define this value. Likewise, the use of standard tools or vernacular techniques will be determinant in judging the real connection of the project to the Craftmanship Value.

The Digitalization Value. The relevance of this value lies in ensuring its survival; every new architectural proposal should be receptive and, ideally, a promoter of new technologies. Due to the fast digitalisation of the world, the implementation of these sorts of technologies is fundamental and necessary for the profession's survival. From the Thesis perspective, this means the implementation of Computational design, whether it is based on digital design, generative design, or assembly algorithms. It will be used as the base to define this Value. Other parallel concepts include the use of AI or Digital Platforms. These two factors are also key to defining the role of automation and its integration with the people. In that sense, Digitalization, at the end of the day, is defined by how the computational power is used to produce and improve the design and how digital tools can help access more people to the profession.

The Value of Materiality. Material and sustainability are also essential elements to define how positive a project is. In this case, multiple ideas are to be considered as this Value can be understood from different perspectives. From the heritage perspective, the selection of materials can be fundamental to understanding the capacity to integrate tradition with digital design. Understanding what materials are used and how they are used defines an interesting value that defines the preservation of traditions and vernacular knowledge. The sustainability perspective is also relevant in the sense that the ecological perspective is paramount to evolving the profession towards an environmentally conscious and caring position. These two perspectives can establish how The Materiality Value can create worth within the Augmented Architecture.

The Human Factor Value. In the same way, the preservation of traditional tools and making techniques is a relevant value for considering the potential of augmented architecture. The role of the human experience and human intuition in architecture is also relevant. This value is defined by ideas like how imperfection can be beautiful and how, at the same time, it makes things unique and, therefore, worthwhile. Also, its human qualities and how the human experience can feel natural and connected with tradition are paramount to defining the "humanity" of a project. In this sense, this value then focuses on categorising how the Augmented Architecture can move forward without losing its human feeling, preserving vernacular and traditional sensations and readings.

Once the analytics criteria are defined, it is also important to comment on and explain the case study selection and how they are not casual but intentional to better illustrate the potential of the Augmented Architecture. The series of Study cases will be composed of six different projects that closely tackle different aspects related to the ideas and positioning of this thesis.

The first criterion is the use of traditional materials. The use of mainstream construction materials like clay, wood, steel, or concrete played a significant role in selecting the study cases. Although one of the six instances does not use these types of materials, the rest aim to explore its use from an Augmented perspective without losing the traditional approach. The contesting project, in fact, is selected precisely as an example that, together with tradition, new materials like plastic can also be adopted through the augmentation of traditional feelings.

Another factor determinant in choosing the Projects is the scale. The projects explore different scales from object to house scale. This selection is not casual and

aims to exemplify how this technology is flexible and scalable. Also, together with the scale, the building approach is also relevant as this architecture can be used in different modes, from industrial production to in situ self-built scenarios.

The third factor for selecting the case study is innovation. Every project, even those rooted in tradition and craftsmanship, explores new ideas and approaches, such as the use of AI, algorithms, digital platforms, computer vision, or user participation. The intentional exploration of innovative elements creates a contrast with current CAM technologies, establishing an alternative path for implementing digital design without automated manufacturing.

The six study cases then constitute a varied set that can, at different levels, demonstrate the potential of Augmented Manufacturing and its intrinsic Values. They represent a collection of concepts that can define the role of augmentation technologies in architecture and, as a result, what the augmented architecture can represent for the built environment.

4.1. The MindCraft Project.

Augmented technology has the potential to revolutionise the current collection of artisan tools. One of the main areas where this technology can be applied is in traditional manufacturing processes and materials. The MindCraft project is a great example of this approach, using augmentation to achieve a modern design approach while still utilising traditional manufacturing techniques and materiality.

Wood is one of the oldest materials used in architecture, and the methods used in its manufacturing have remained relatively unchanged over the last few centuries. Subtractive procedures like carving have traditionally been used to deal with the complexity that wood offers. However, this approach is inefficient as it wastes a lot of material and requires a high level of skill from the manufacturer. The Tverrfjellhytta Pavilion project by Shohetta exemplifies this approach. It proposes a "computational architecture" made of wood that is manufactured through an "automated" process. This process increases waste and requires a qualified production team.

To challenge this traditional concept of architecture, MindCraft explores how augmented reality can be used. Focused on woodwork as a craft technique, MindCraft proposed an innovative view of traditional wood steam bending and how to implement digital design. For this purpose, a digital strategy was generated, from computational design to actual crafting, binding together concepts such as material behaviour, joinery generation, and emerging manufacturing.

4.1.1. Design Approach

The computational approach for MindCraft was also based on the interactivity between the designer and computational logic through augmentation. The new proposal improves the role of the designer, allowing them to participate in the entire system. This introduces an innovative approach to architecture by fully integrating design, manufacturing, and assembly through augmentation. It challenges traditional architectural practices by removing highly skilled craftsmen

from the manufacturing process and enabling unskilled labour to take over the production.

Initially, this project focused on the free interpretation of human gestures for the design process. So, in terms of general design computation, the user would directly interact with the tracking system from the holographic goggles to generate the base guidance for the computational design. The gesture recognition, in this case, generates some attractors that actively guide the generating “voids”, creating the main lines of the design. For this design stage, a vector field interacts with the attractors and makes the voids flow through it. The primary line generation has a behavioural logic added, in this case, a vortex generation, to implement specific patterns into the design.

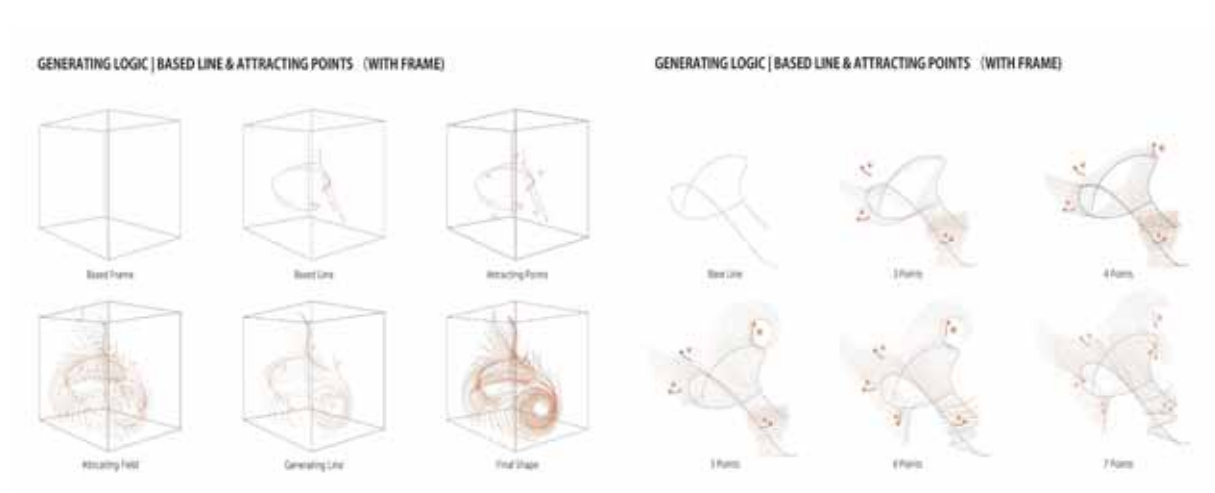


Figure 126. Generative Process, Step 1. MindCraft.

Once the main lines and vortexes are generated, the interactive system allows editing of the lines after the generation using the AR device and control points edition. This concept is very relevant since it adds a factor of human intelligence into the machine logic of computation.



Figure 127. Generative Process, Step 2. MindCraft.

The second layer for the computational design is based only on generative code, and it implements the material behaviour into the project. Following the main lines, the software generates a series of branches to compose the main structure. For the generation of the branches, the actual geometry of the wood is used together with the bending parameters extracted from the empirical experimentation, and scientific data is applied. After this logic, the main family of elements is generated.

The joinery system in this project was designed as an integral part of the overall design, following the same rules as the main structure to ensure complete integration. From a technical standpoint, the joinery layer serves two main purposes: to connect the main branches and to reinforce the overall structure. The design of the joinery layer was subject to certain constraints, with the primary constraint being the requirement for a tangent connection system due to the idea of a fully wood-made frame. In terms of design, every joinery element was bent to achieve the tangent connection. Another constraint considered was the wood's bending capabilities. Various strategies were developed to allow proper bending based on the distance the joinery element needed to cover, taking into account the wood's bending radiiuses. The result of this design approach was a set of unique connection elements that reinforced the overall design and were fully integrated into the design logic.

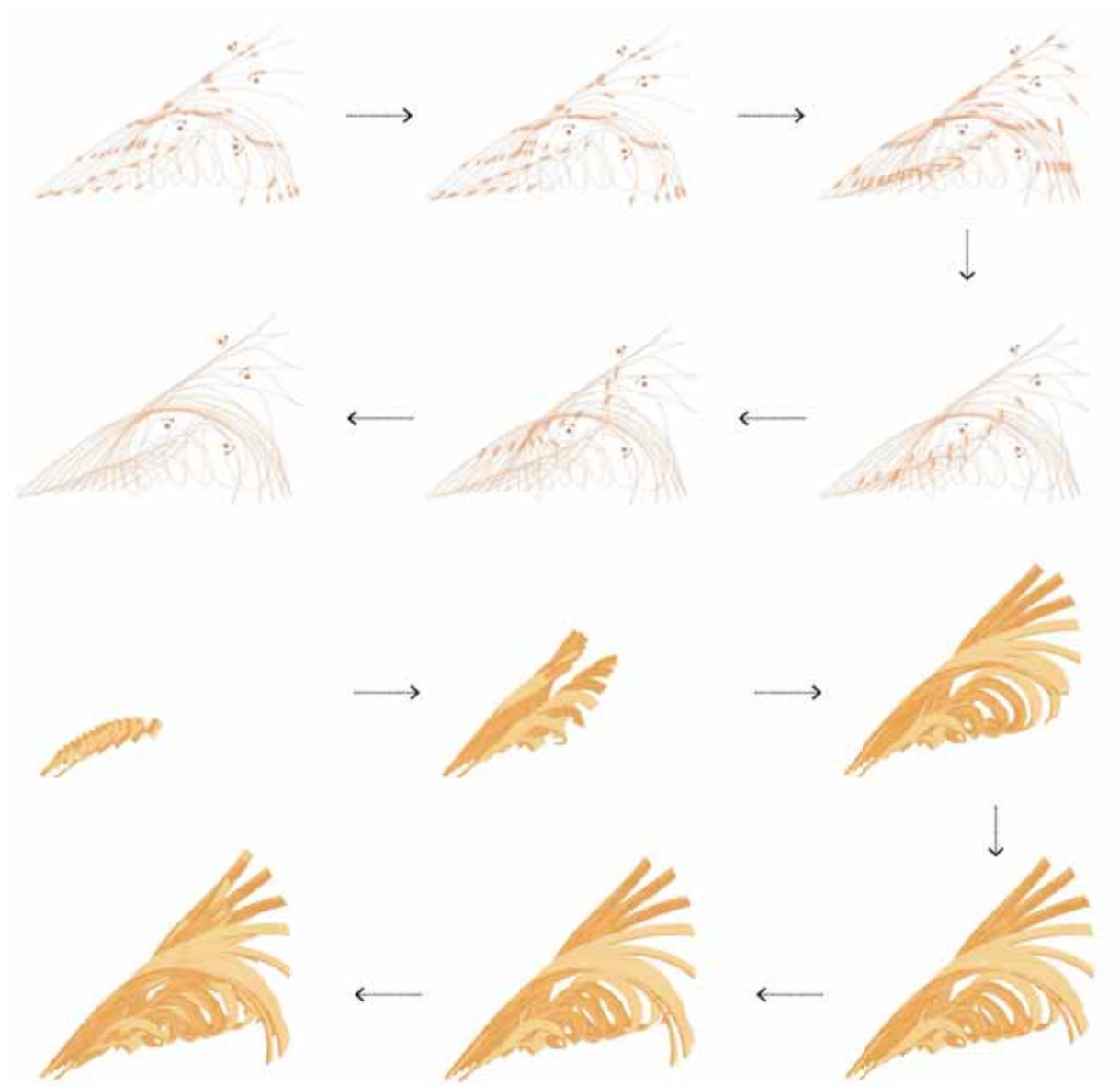


Figure 128. Generative Process, Step 3. MindCraft.

The whole generative algorithms were also connected into a free, open-source app available online and free to use. This app, designed as a Grasshopper plugin, enhances access to unskilled people in the design and manufacturing phases of the project. The integrative design process was created to produce an outcome that would comply with the wood's structural behaviours and a simple part-based design accessible for manual assembly.



Figure 129. Generative Process, Completed. MindCraft.

The result of the digital workflow represents a top-down system that takes the generative digitalisation of human gestures and delivers a base geometrical guideline that is populated in a reiterative sequence. This densification of the base geometry results in an architectural object that, through simulation, embeds the essential properties of the whole material used. It, therefore, represents an interesting digitalisation approach of material and technique that is now enhanced and capable of producing highly intricate results without losing its natural spirit. It combines human interaction with structural performance to result in a behavioural design that accounts not only for the material properties but also for the fabrication processes to follow.

4.1.2. Augmented Approach

The Mindcraft project takes an integrated approach to augmented manufacturing, from the manufacturing of slats to assembly, including the use of tools. It aims to modernise a traditional steam bending process for the digital environment. The workflow is simple and guides the craftsman through the entire process with augmented step-by-step guidance.

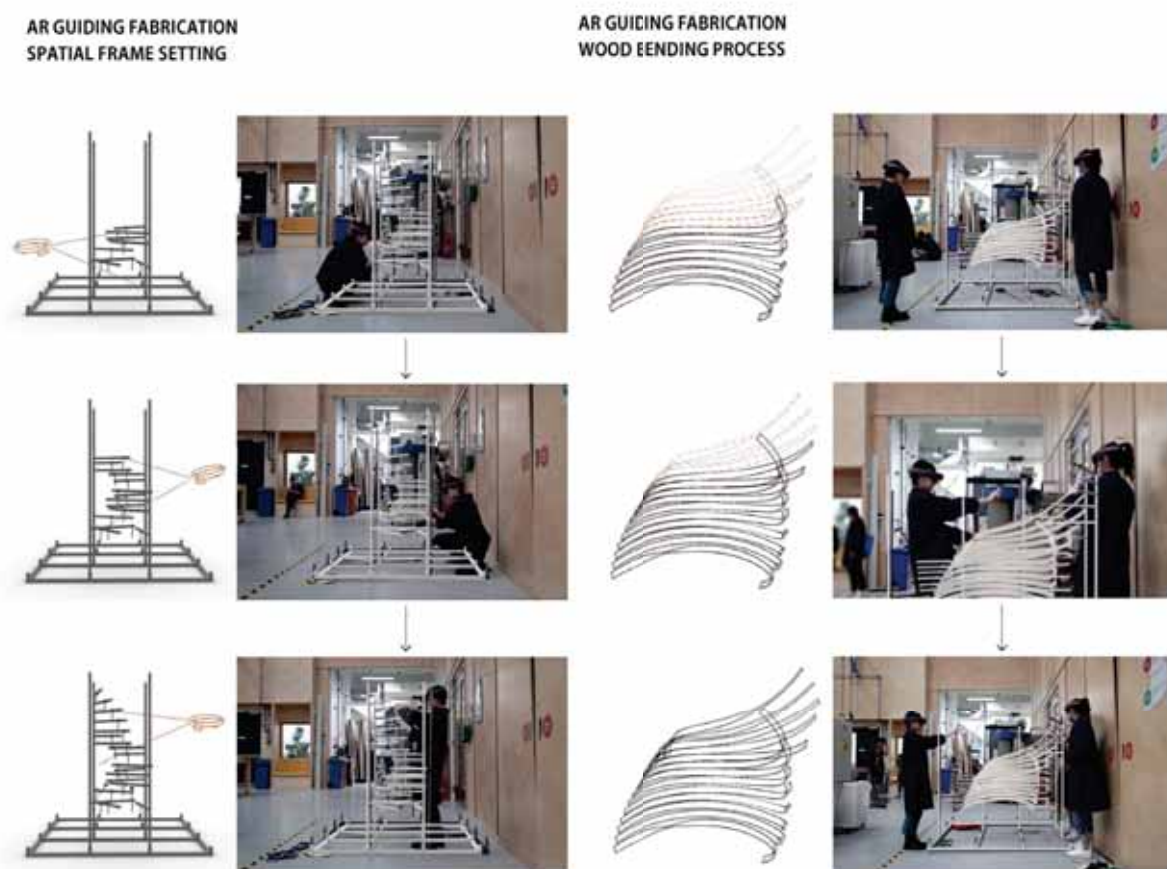


Figure 130. AR Manufacturing Sequence. MindCraft.

The basic workflow involves creating the main slats and then using them as formwork for subsequent layers. Since steam bending requires time to dry and harden the wood once formed, creating a flexible and interactive frame was a significant part of the manufacturing process design. The frame was constructed using a grid to locate a series of posts according to the model's needs. Also, within

the posts, orientable clamps can be positioned to fix the steamed wood so it can be hardened. The entire frame was then digitised and implemented into the augmented manufacturing process.

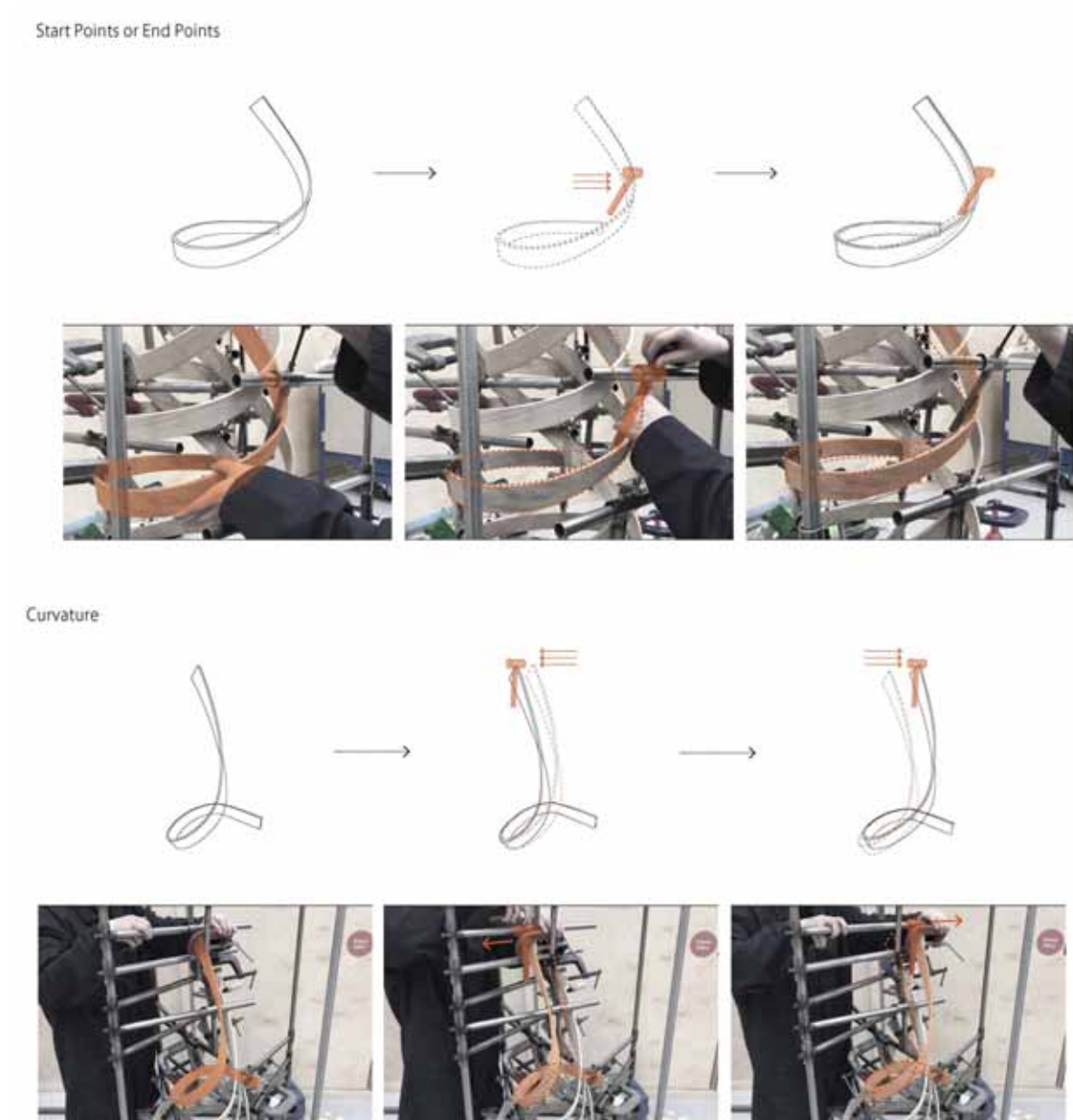


Figure 131. AR Manufacturing Sequence, AR Frame. MindCraft.

Positioning, bending, and twisting actions were visualised in the AR device and guided by a specific sequence. This guidance also included the adjustment of the position of the frame elements as well as the addition, if required, of new bars and

clamps. The AR projections over the digitalised frame were used to make the steamed parts. To increase efficiency, the frame was designed to form individual parts or larger chunks of several steamed parts. The augmented guidance made it possible to form and assemble even complex parts that were impossible to construct with hardened pieces. This augmented logic enabled students with no previous experience in wood steaming or wood making to produce a complex and intricate prototype with the help of the Augmented Reality Device.

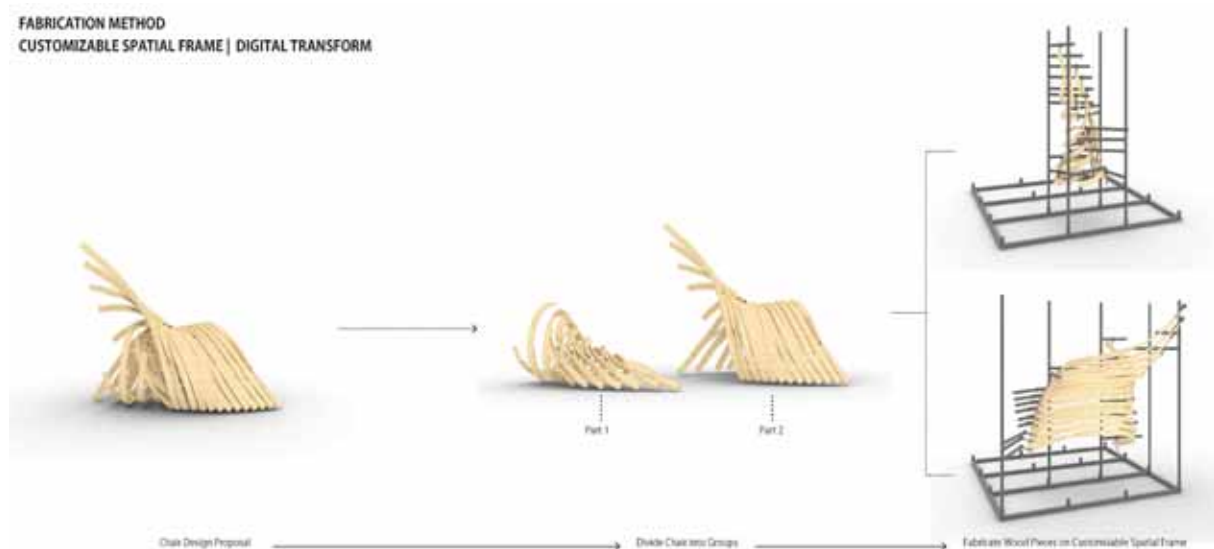


Figure 132. AR Manufacturing Sequence, component division. MindCraft.

Although assembly was not the primary focus of the MindCraft project, the complexity of the prefabricated components required AR guidance to help assemble the final model. Due to size limitations, efficiency, and material constraints, the final model had to be divided into several smaller sections that could be fabricated individually within the frame's capabilities. The result was a series of complex assemblies for this section that required an exact connection of border elements and the addition of connective elements to ensure the stability of the model. Augmented Guided assembly was also used to construct the prototype to ensure the final assembly was correctly processed.

The combination of making and assembly, even for big models within the same app, shows the potential and flexibility of these techniques to promote instant skills to workers through augmentation technology. In this project, the same

individuals conducted the entire development of the project, from digital design to final on-site assembly, adapting their role in the project with the assistance of technology.

An interesting factor that is relevant to mention is that the final prototypes were manufactured by non-trained and inexperienced workers. Following the instructions given through the app, the crafters managed to steam, bend, drill, and assemble the components with a high level of accuracy. Also, the intricate design demonstrated that pieces that normally would require a high level of skills in their production are now achievable with the use of Augmented Reality. This also remarks on the importance of AR in connecting digital design and the final product.



Figure 133. AR Manufacturing Sequence, App Interface. MindCraft.

4.1.3. The Values Classification

The MindCraft project is a fundamental example of augmented manufacturing and encompasses many of the themes present in this thesis. It combines digital design, craftsmanship, and material heritage to produce a distinct result that reflects the current era. From beginning with a completely digital and automated design

process to providing fully augmented guidance during production, the project explores the potential of this technology and how it can quickly become a standard tool in architecture and craftsmanship. The prototype created during the research, along with its influence evident in the Steam Punk Pavilion, confirms that augmented manufacturing has both current and future applications in the construction industry.

From the Digitalization Value, the project presents an interesting, completely automated approach that develops the whole geometry from the idea of Voids and that, through a series of iterations, delivers a final 3D. This workflow demonstrates an intrinsic digitalisation value as the design result completely depends on the simulation and algorithmic generation. Likewise, the fact the material behaviour was included within the algorithm logic that drives the design adds to this value as it translates physical behaviours into digital knowledge to produce informed design. This factor also facilitates the addition of structural reinforcement to guarantee the stability of the final product. This is a very important characteristic as it uses the full potential of digital and computational design at its fullest. Not only is the project able to achieve a high-resolution, high-definition geometrical result, but it also defines a behavioural and structural result that complies with the science related to wood and its architectural performance. Furthermore, facilitating this system through an accessible digital app enhances the idea of digitalisation as it allows for easier and wider access to digital design and manufacturing processes.

From the Materiality Value, using a traditional craftsmanship material resonates with the idea of conservation. The use of wood is intentional as it is not only a commonly used construction material but also is inherently connected to craftsmanship. In that sense, the project attempts to propose a radical geometry approach but keeps it familiar by showcasing the wood qualities and restraining the whole system to the wood used, even the fastening and connections. The result is a highly intricate piece that preserves and enhances the material textures and feelings. Likewise, the use of steam bending reinforces this idea as the material is shaped following the natural behaviour of the fibres as well as its bending capabilities. In that sense, the value of MindCraft materiality resides in the concept of using a natural material in a traditional way without additions, which is wood as the main protagonist. Also, the decision to only use wood for the whole piece adds an extra layer to the material value as it proves the intricacy and

complexity of digital design are completely compatible with old-making techniques and traditions.

From the Human Factor Value, the most relevant idea is the handcraftsmanship approach that this project proposes. Although the system is pretty straightforward and does comprehensive guidance, the manual labour involved accentuates the role of the maker. Also, the unpredictable wood behaviour during the hardening process emphasises the need for the human eye and intuition, as some parts can render off shape, and impromptu adaptation might be required. In that sense, the role of humans is unavoidable and completely connected to the manufacturing process. The human value then does not delve into the skills or craftsmanship but into the human participation and adaptability to ensure that the assembly is produced in a correct manner. In essence, even though the project is fundamentally digital, its material and manufacturing approach promotes human participation.

From the Augmentation Value, the integral approach that MindCraft explores demonstrates an interesting result. On the one hand, the formation of the slats is not only guided by the projection of the required shape but also by the configuration of the hardening frame. In that sense, digitalisation is not connected only to the material but also to the mechanics of the frame. This workflow allows for a more precise manufacturing process as well as for more affordable access as it reduces the level of skills required. The assembly process is also connected to the use of the mechanical frame. In this case, the hierarchical approach facilitates a behaviour-based system where the main components are formed first to serve as the frame for the following components. As a result, the piece is assembled as big sections that can be transformed and completed in situ. The strategy facilitates a simple and functional sequence that, in the same line as the rest of the augmentation, reduces the required skills. Consequently, the main value of the augmentation is based on the idea of labour accessibility and skill requirements reduction to allow for a wider and less specialised workforce.

The research and prototyping developed by Mindcraft explored how the augmentation can result in a very helpful tool to reduce the problems derived from the skilled labour shortage, the loss of craftsmanship and the sustainability of the construction. It proposes a fully digitally integrated app that drives the whole project from computational design to augmented manufacturing. It facilitates access to any kind of user by simplifying the stages and guiding every step of the project. MindCraft, in fact, represents one of the principal values Augmented manufacturing can provide to architecture as it merges tradition in materials and

making with the most advanced computational design approaches. It also settles an interesting frame that can be easily applied in the industry for the present. On its scale and functionality, the prototype proves that this and similar concepts are already affordable in terms of technology and are also accessible even for completely inexperienced labour. This project demonstrates at different levels the potential of this new Augmented Architecture.



Figure 134. FINAL PROTOTYPE. MindCraft.

4.2. The Difussion Project

The tradition of metalworking in architecture is of great importance, making it a fundamental part of the industry. With the revolution of mass production, the approach shifted from craftsmanship based on forging to an industrialised method based on cold forming and casting. As a result, the role of the human worker changed from a hands-on position to a supervisory one. Building on this idea, the Diffusion project aims to explore how traditional methods like forging can be reintroduced, integrating them with digital design. To achieve this, it suggests using Augmented Manufacturing as the main tool.

Several contemporary projects aim to replicate the intricacy of traditional ironwork while incorporating modern techniques. One such project is the MS3D Bridge, which uses high-tech robotic welding to create a complex metal structure. However, this approach requires highly skilled technicians and is not easily accessible. Additionally, contemporary metal structures typically require expensive machines and digital skills without addressing the unique properties and behaviour of metal and metal-forming. As a result, bespoke metalworking in contemporary architecture is still limited due to its high cost and the scarcity of experienced metal workers, particularly in developed countries.



Figure 135. Augmented App. Diffusion.

Diffusion is a research project that introduces a new method for metal manufacturing and crafting. It involves using augmented reality instead of traditional drawings in the manufacturing process. By wearing holographic goggles like the Microsoft HoloLens, manufacturers can access real-time tutorials on how to produce items without the need for models, drawings, or prototypes.

4.2.1. Digital Approach:

One of the main elements of the design approach is the idea of a metal bar. As the project is based on forging metal components, the design logic was designed to comply with this idea. Another aspect that was essential for the design was the twisted joinery that the project experiments with. This type of join was also included as a part of the strategy to connect bars without the need for welding in situ fully. Additionally, the project aimed to create an integral app that could drive the whole workflow from design to manufacturing and assembly.

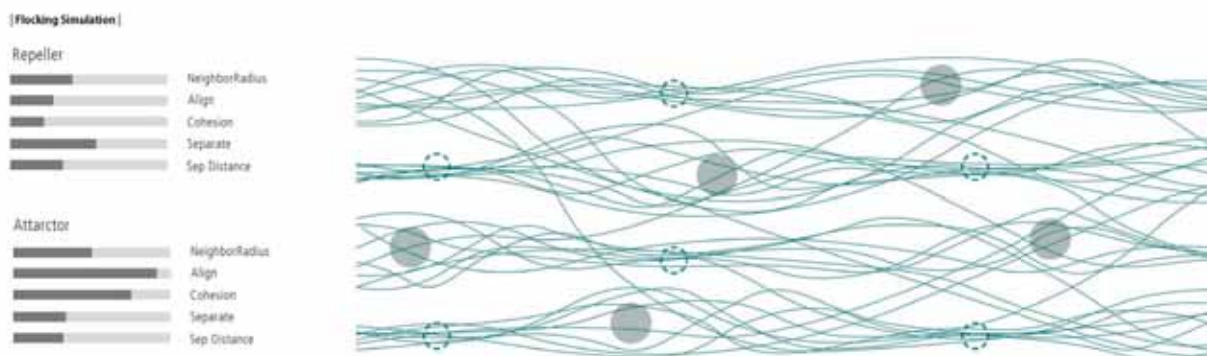


Figure 136. Generative Algorithm. Diffusion.

The main design algorithm is based on particle logic that uses “Boids” to control the generative growth within the base space frame. To construct the main lines that articulate the design, the mentioned “Boids” run in a semi-random way through a three-dimensional space following the influence of a series of attractors that can contain a positive (attraction) or negative (repelling) force on them. That way, the void can flow through the space and is guided and affected by the attractor particles from an origin seed and to a target goal. Also, by using the Boids, the

algorithm is able to model the bars that will be transformed into metal components. To ensure fixability, the behaviour of the voids is also programmed to comply with the physical characteristics of the material used. This essentially guarantees that all geometries proposed by the void will be suitable for manufacturing.

Two strategies are proposed from the design perspective to control the attractors: the environmental one and the interactive one. The environmental strategy is related to the real goals that the structure needs to comply with. This includes the origin and goal targets, every obstacle in the way or inside the reference frame that needs to be avoided, and every additional element that needs to be addressed. In this case, the attractors and “repellers” will be fixed and used as the first reference system for growth. An Augmented interface is proposed to control and edit this process. The algorithm also optimises the shape within the design. Approach to effectively populate the space to fill with the optimal amount of metal.

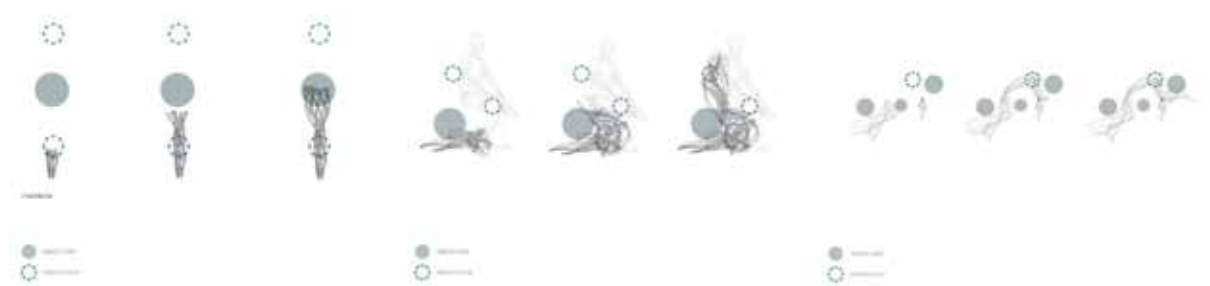


Figure 137. Generative Algorithm. Attractors. Diffusion.

The interactive strategy contains all the extra attractors and “repellers” that can be edited or changed during the design process, but they are not affected by the existing environment. In this case, those particles have been integrated into the augmented reality interface. This allows the designer to directly interact with them by hand-manipulating them in the virtual model. With this design method, the integration between computational and interactive design is direct and works in a reciprocal loop. The augmentation research in Diffusion proposed integrating digital design into the whole system. The aim was to achieve a direct connection between the designer and the maker. This would blur the barriers of both roles. To achieve this, the project used generative computational logic to create the design.

After the base frame is created via an interactive augmented process, the technical part of the design is implemented. This involves a second-layer algorithm that generates a series of complementary elements or "branches" that interconnect the main elements, thereby adding structural performance capabilities to the system. Additionally, the second-layer generative algorithm is also responsible for surface generation. It fills the gaps in areas that require user interaction, such as floors or walls, or in the actual prototype, such as balustrades for a bridge.

The third layer of the algorithm is the joinery logic. A series of adaptive joints are added to every intersection between elements to connect them. This system is particularly suitable because it uses a "twisting method" based on the augmented forging technique. This method is very flexible and requires low skill to create. The twisting logic also allows any number of elements to be connected into the same joint while allowing for various directions and thicknesses of bars. As a result, every join can be unique, responding to a series of specific requirements, which can produce a full three-dimensional result.

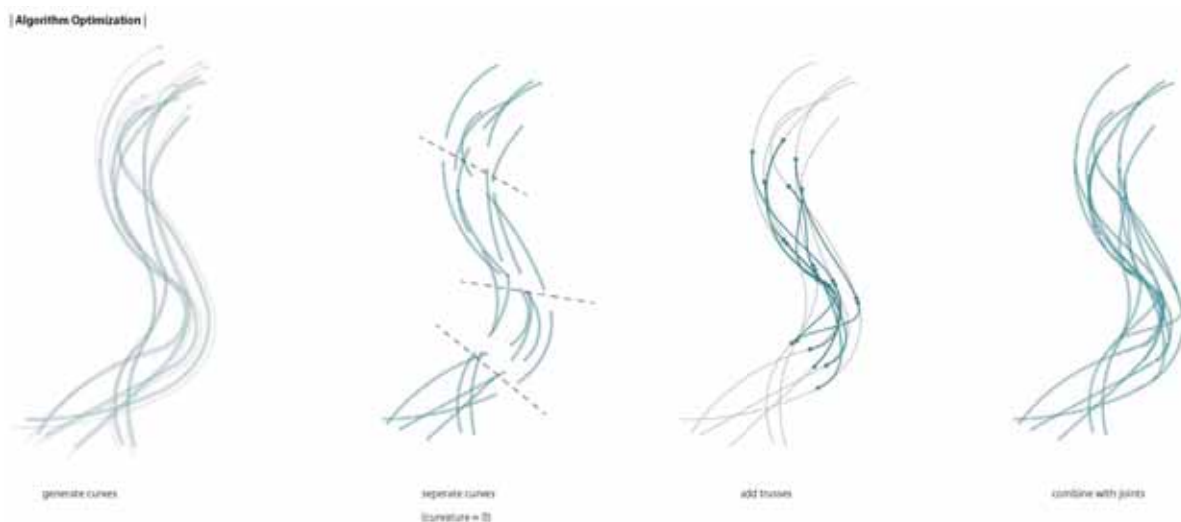


Figure 138. Generative Algorithm. Branches. Diffusion.

To finalise the process, the algorithm analyses the structural behaviour and checks that the proposed geometry will be resistant as per the parameters defined. Once the geometrical procedure is completed, the algorithm also evaluates how to segment the geometry into smaller sections that can be prefabricated prior to the final assembly. This step is relevant because the system is purely based on

mechanical connections and does not use welding. The different sections need to be self-standing and stable enough to be transported.

4.2.2. Augmented Approach

The augmented forge method, proposed in diffusion, adds a new layer of complexity to traditional forging tools and techniques by combining digital production from generative algorithms with human interaction in manufacturing. It uses a series of traditional and standardised metal-making tools that are digitalised and embedded into the augmented manufacturing process. Also, for the assembly part, the disposition of the temporary scaffolding and the sequence to add or remove it is integrated into the manufacturing workflow to allow for a simple and safe process. In that sense, the whole system embraces an accessibility philosophy where the requirement of skills is maintained intentionally low.

The first step is joinery manufacturing. Each joint is analysed and categorised based on the number of elements and directions. After framing all the bars in standard jigs, they are heated to forging temperature, and the maker proceeds to the twisting process guided by a holographic device and projection of the exact amount of twists and lengths required. Once twisted, the join is located in another jig to proceed with bending for precise direction. This process is managed through augmented projection. After cooling, the joint stabilises, which is crucial as it affects the friction the twisting creates.

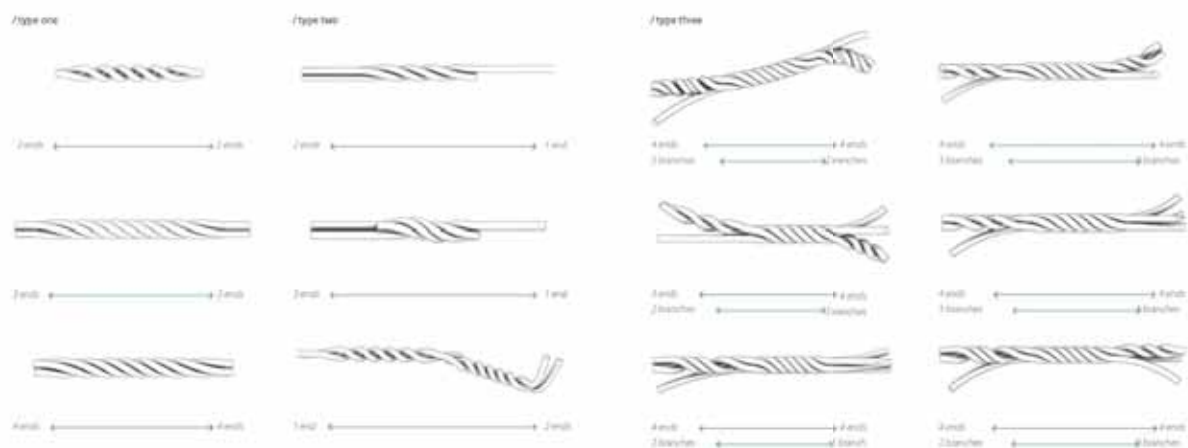


Figure 139. Augmented Manufacturing. Joinery types. Diffusion.

The second phase is bar bending, where augmentation is implemented in two aspects: actual bending and machine use. The bending process, based on cold pipe bending, is computerised and guided by the holographic device. The bending machine is included in the Augmented reality guidance and computed to generate specific curvatures. After categorising every bar by length, the bending process is divided into two stages. The first stage involves a general angle, integrating step-by-step guidance that allows the maker to bend every bar precisely for the correct curvature by projecting the actual shape of each bar for every step and calibrating the bending machine. The second stage is the fine adjustment for three-dimensional bending. This is achieved by locating the bar into a jig so the maker can bend it into the right 3D position by following the augmented projection.



Figure 140. Augmented Manufacturing. Cold Bending. Diffusion.

The proposed prototype in this study is a bridge that requires using pre-assembled meta-elements due to size and weight constraints. The assembly was completed in two stages, with the first stage involving the assembly of the meta-parts with the help of augmented reality projection, which projected the meta-part into a computerised scaffolding. This helped with the correct positioning of the pieces.

The parts, bars and joinery were assembled in a specific order defined by the projection, and the elements were chemically welded during the process. Once completed, the part was removed from the scaffolding and stored until the second stage. The scaffolding was then adjusted according to the next meta-part.



Figure 141. Augmented Manufacturing. Joinery bending. Diffusion.

In the final assembly phase, the parts were first tested in place in relation to the digital projection. The scaffolding was then re-assembled into the correct configuration, and the final piece was assembled using augmented projection. This same projection was used to adjust any small discrepancies that arose during the crafting and the first assembly phase. Once assembled, the bridge was compared against the digital model to check for any possible errors.

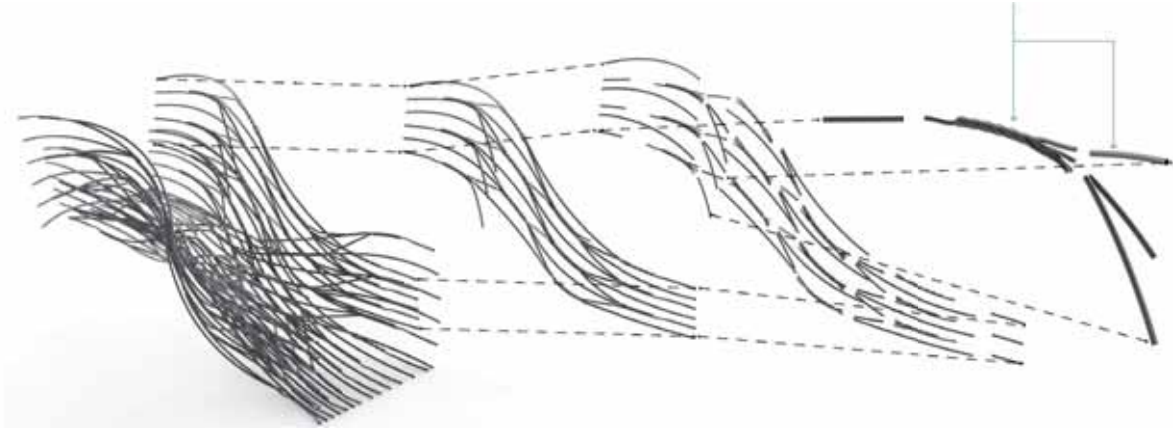


Figure 142. Augmented Manufacturing. Building sections. Diffusion.

The diffusion project presents a straightforward approach where the digitalisation of traditional metal crafting art is produced through the use of computational design and Augmented manufacturing. In that sense, it does comply with the base philosophy that this thesis proposed as to how augmented manufacturing can be used and what positive effects it can have for the future. It embraces the idea of low or non-skilled workers as a labour source and the use of traditional materials from a more flexible and creative perspective. Also, the fact that welding is not part of the equation is an intentional decision to remark on the unskilled labour approach. The prototype built during the research proved to be successful, and it behaved as expected. Whether the manufacturing process or its structural performance, the results were accurate to the expectancy of delivering an attractive, functional bridge.



Figure 143. Final Design. Diffusion.

4.2.3. The Values Classification

The project Difussion is a great example of how traditional and modern elements can be combined to create something new that still respects the past. From an aesthetic standpoint, the project embodies one of the most popular trends in digital design and offers a practical and affordable way to achieve it in physical form. Additionally, it supports low-skilled workers, which is important in light of the Skilled Labour Shortage situation, especially in industries like metalwork. By using traditional tools with augmented reality instead of customising them, the project demonstrates how this technology can be immediately applied in the industry.

From the Digitalization Value, the main interesting value resides in the fact that this project proposed a fully digital design flow that included performance optimisations. Its layering process helps to produce a piece that is not only completely digital in its conception and fully automated in its production but also contains the reiterative process required to produce a stable object. The use of Voids as the main geometry generator also emphasises the digital design ethos. This system is able to create a purely generative design that responds and adapts to parameters without the need for any human input. The complexity and density of the elements position this technique as a solution that outperforms any human equivalent process. Consequently, the design logic is distinctively computational. Another relevant aspect connected to the design algorithm is the digitalisation of the “Twisted Joints”. By creating a material behaviour-based deformation algorithm, the app can generate precise, unique joints to connect the metal bars in multiple directions. This part of the system ensures that the final joints not only fit but also comply as well with the overall performance of the final piece. The Digitalization Value, in that sense, is clearly defined by these concepts that allow for a new computationally focused language that uses all the digital tools like optimisation or performance calculations to produce a fully automated design.

From the Materiality Value, using metal through the traditional manufacturing processes of cold bending and forging adds a craftsmanship flavour to the project. Although, in this case, the design creates a clear digital feeling, the use, particularly of forging. Rememorates the tradition of metal-making. Also, the intricacy generated through the process resonates with other traditions in design, like the art nouveau. In that sense, the use of metal is fundamental as it is the only

material that could perform such an intricacy and joint system and at the same time have the right structural performance. The geometry exploration and the material use are, therefore, intrinsically connected and necessary for the project's success. Another positive factor that adds to the materiality value is the optimisation derived from the digital process that allocates material smartly to save such an expensive and CO₂-producing material.

From the Human Factor Value, two ideas are to be considered. On the one hand, the fact that the design logic can be configured by humans within the digital framework preserves part of the traditional roles in design. Although, in this case, it is not completely necessary as the algorithm can work stand-alone, the possibility of including the human as part of the process humanises the whole design workflow and allows for some human intuition to participate in the final result. On the other hand, manufacturing is where humans take a significant role. The craftsmanship techniques based on forging and cold bending, as well as the assembly, are completely based on human interaction. These processes require not only AR guidance but also human intuition to address the inaccuracies and unpredictable behaviours of the metal during the manufacturing process. In that sense, Diffusion supports the aid of humans as part of the manufacturing process, preserving the role of the craftsman as well as traditional metal-making techniques.

From the Augmentation Value, one of the concepts is outstanding in comparison with the other study cases. Digitalisation and augmentation assistance for using traditional analogue metal-making tools represents an interesting approach that fully adapts digital design and traditional craftsmanship into a streamlined process. Other study cases in this thesis present their own set of bespoke tools or frames to allow for manufacturing, while the Diffusion case uses the self-tools that can be found in any metal workshop, facilitating access to this technique. Also, by augmenting these tools, the access barrier to the skills is significantly reduced as the knowledge necessary to operate them is digitalised and integrated into holographic assistance. As a result, whether forging or cold forming, the user can produce parts with a high level of accuracy with minimal training, as was demonstrated during the prototype building during this research. Additionally, the use of AR for assembly also reinforces the idea of accessibility, as the complexity of the project would require an unbearable set of traditional documentation to be assembled, which would impede inexperienced people from participating. Its replacement by AR step-by-step guidance facilitates the assembly by using a real

scale in place 3D model projection that displays an intuitive building sequence. In essence, the manufacturing and assembly in this case would be, at the very least, impractical, reinforcing the Augmentation Value.



Figure 144.Final Prototype. Diffusion.

4.3. CeARamics Project

The CeARamics Project introduces a unique and intriguing approach to using Augmented Reality for democratic skill development. It suggests creating a digital platform that can facilitate a grassroots design experience. Furthermore, the project explores the integration of concepts like the "gig economy" and distributed manufacturing into the mainstream architectural industry based on this platform.

The introduction of technology into the manufacturing process during the Industrial Revolution changed the way things were made. While automation in manufacturing has reduced production time, it has limitations in tasks that require human-like movements. Human presence is needed to oversee the shift between tasks or complete the rest of the process. Augmented craftsmanship combines digital tools and physical craftsmanship, providing a more holistic approach to fabrication. AR technologies allow for dialogue between automated processes and craftsmanship. Designers and architects are implementing AR technologies in their projects to create interactive holographic instructions that translate design models into intelligent manufacturing processes. In a recent example, a woven steel pavilion showcased how AR technologies can accelerate manufacturing while allowing for mass production and customisation using human labour guided by HoloLens.

The research focused mainly on developing ceramic building facades, as shown in the study. Although ceramic facades exist, they are limited in terms of form and volume. Therefore, the team proposed a system that can produce volumes and elevations defined by their complexity and plasticity using the ceramic manufacturing method proposed in this paper.

This research aims to discover a method that is accurate and efficient in manufacturing and assembling complex clay structures. The research team developed a method for creating and assembling clay models using holographic guidance. This method can be used by individuals of varying skill levels, from novice to expert.

4.3.1. Design Approach

Weaving was an essential step in the fabrication process and was too complex for a robotic arm. The human factor was needed for the success of the physical models, as the maker needed to have a good understanding of their form and materiality. Mass-production of the components with highly customisable features was important. Augmented Reality was selected to enhance the user's natural crafting abilities and facilitate mass production and customisation using human labour guided by HoloLens.

Prior to digital modelling simulations, the team conducted material testing. After studying different clay moisture levels and structural options, they established a material workflow that allows for quick modelling without causing cracks or firing issues. They also created a template system that enables AR-assisted assembly. The AR system was developed using HoloLens2 and mobile devices, making it easily accessible.

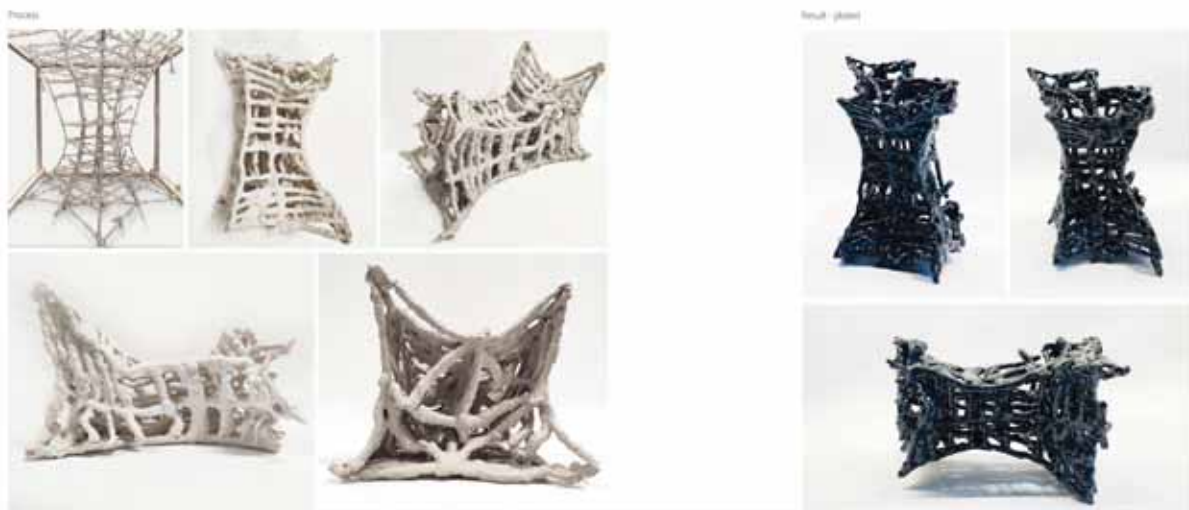


Figure 145. Early Analogue Tests. Ceramics.

To maintain the clay element's organic features and unpredictability, sprayed clay was applied to the weaved frame of the components instead of moulds or 3D printers. The idea was to be true to the matter and generate a method that best represents its identity by respecting and testing its limits.

To enable large-scale model stitching, the team used polyhedrons as the geometrical representation that can be replicated in an infinite number of stitches. The generative logic is provided by the Grasshopper© plugin WASP©. Components can be stitched together using custom rules. Growth simulations, such as growth along curves, surface constraints, and aggregations through point clouds, were used. The defined rules can be altered during the procedure. Digital clay models can replace these geometries, allowing designers to obtain real-time simulation results via AR.

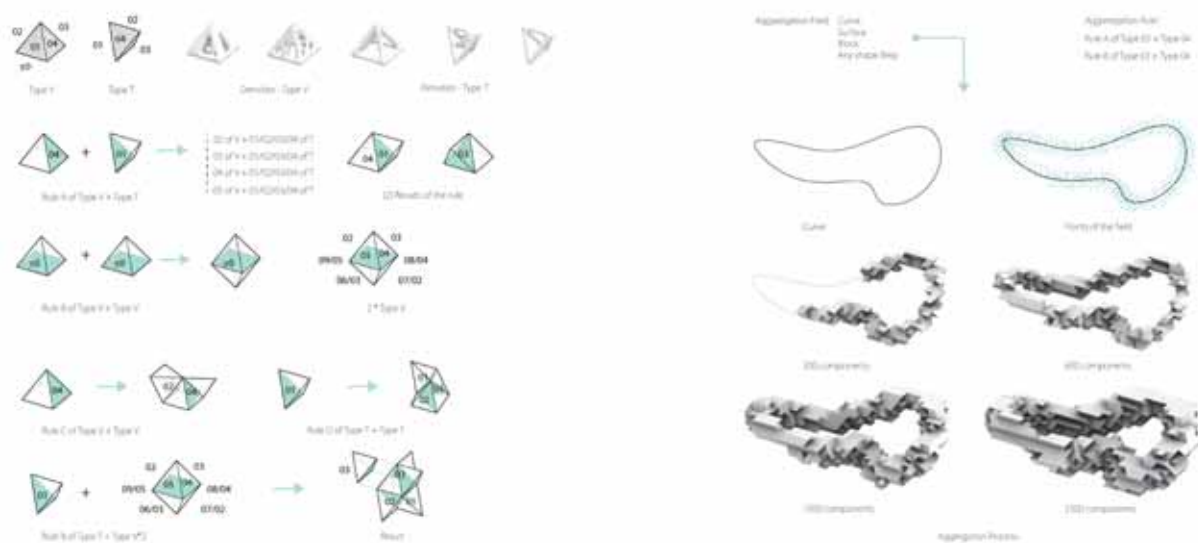


Figure 146. Generative Algorithm. Ceramics.

In the process of exploration, we focused on the geometries of tetrahedrons and pentahedrons because they offered more combinations in all three axes compared to orthogonal shapes. They could also be attached by all their faces. To establish the fabrication method, we conducted material testing and went through a trial-and-error process to develop a rigid and feasible substructure that could be removed during the firing phase. Nodes were placed on the corners of the polyhedrons to hold the sticks in place for each component. These nodes could be pulled away from both sides once the clay was dry. We created weaving patterns between the positioned sticks to form the faces of the polyhedrons, which were then covered in clay.

Each component had a digital representation of the clay applied to it to enhance the visualisation of the design. This was an essential part of the process because it

saved time and created a preconceived idea about how the component would turn out geometrically and aesthetically before proceeding to the physical manufacturing phase.

The tetrahedron and pentahedron were explored digitally because they could produce combinations that were possible in all three axes and could be attached by all of their faces. These combinations created more significant components that could grow into architectural elements. As seen in the combinations, the connected elements had varying densities, creating larger, more porous and denser components in some parts.

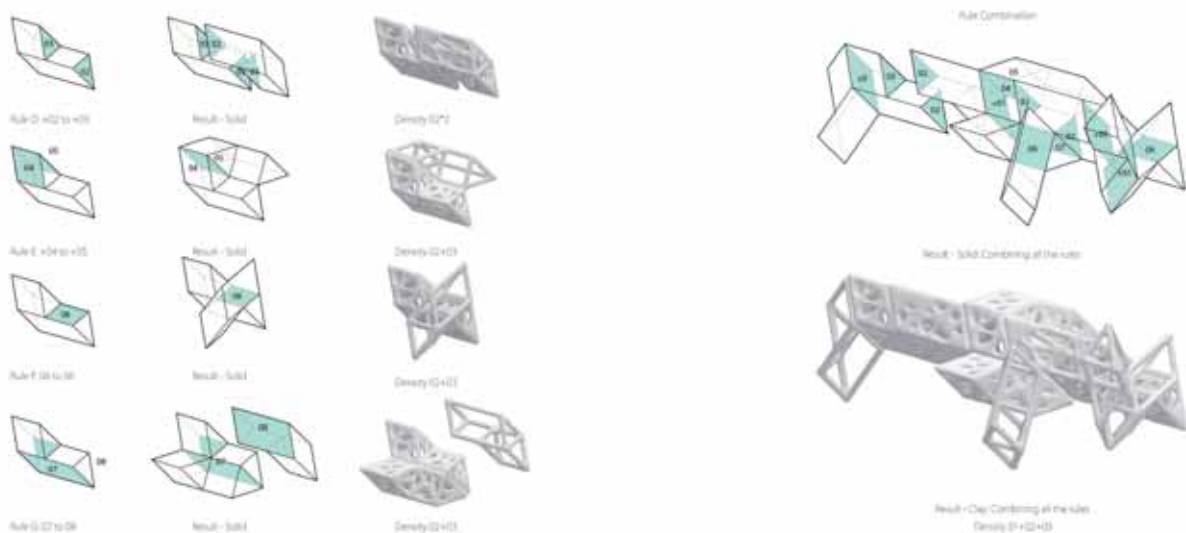


Figure 147. Generative Algorithm. Transition to architecture. Ceramics.

This approach was also applied in the tests carried out for architectural elements. Walls and facades were digitally developed, with some parts being more solid and others sparser, depending on how the light flowed within a space. Furthermore, the pattern and density studies produced both physically and digitally through catalogues were valuable for this part of the process. This is because the pattern and density of a single element greatly influenced the larger scale when populated.

The design could be controlled by the maker from the small scale of a single component to the larger scale of an architectural element, which is normally not feasible with conventional making-designing methods.

4.3.2. Augmented Approach

In the manufacturing section of the application, users can access an Augmented Reality simulation via their phones or Hololens. The simulation displays the component outline in space and provides guidance on where to place the sticks and nodes. Once the frame is assembled, weaving zones with lines appear, making it easy to follow the pattern with the rope. This simplifies the assembly process, making it quicker and more accessible, even for beginners. Once the user has assembled and woven the required number of components, they can collaborate with designated ceramist workshops to apply clay and glazes.

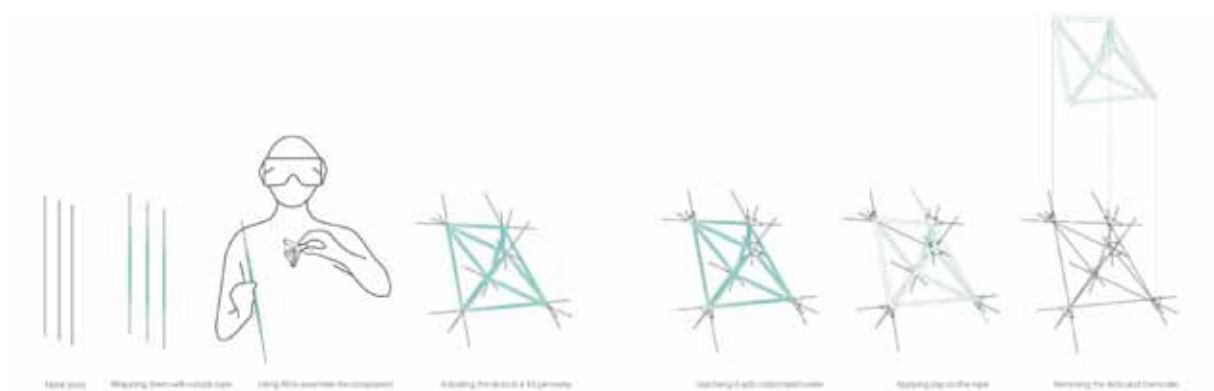


Figure 148. Augmented Manufacturing Sequence. Ceramics.

In the study conducted, the potential of computer vision to identify distinct weaving patterns was explored. These patterns were subsequently digitised, allowing them to be easily followed by users. The application design included a feature that permits users to select specific weaving styles in situations where multiple individuals work on the same weaving component, and variations in weaving techniques are expected due to individual intuition. This feature is particularly crucial in architectural contexts like facades, which require a certain level of consistency. The exploration was carried out using two approaches: one focused on movement tracking, while the other involved drawing curves on a tangible model with the assistance of Augmented Reality. In both cases, the aim was to digitise the information and integrate it into the app, ensuring that users could adopt their preferred weaving techniques seamlessly.

Object tracking, a domain within computer vision, focuses on following objects throughout consecutive video frames by associating them with a unique ID and positional parameters (Wang, 2018). To discern weaving motions, a uniquely coloured sphere was affixed to a rope's end. As this sphere moves, its coordinates generate the weaving curves. Nevertheless, this method faced challenges, notably potential obstructions by hands or the rope itself during weaving.



Figure 149. Augmented Manufacturing setup. Ceramics.

In the alternate approach, the faces of an object are digitally flattened to 2D, given that the application permits only 2D drawing on each face. Augmented Reality facilitates users in drawing weaving lines on a physical model via a smartphone. These lines are then transformed into curves within the design software and affixed to the digitally unfolded 3D model. This process empowers users to swiftly decide on their weaving style, instantly receiving its digital counterpart. The application provides a catalogue of nine foundational weaving styles for users to incorporate into their designs, and during the creation phase, AR guides users in weaving according to the chosen style.



Figure 150. User APP. Ceramics.

The research also explored the assembly of components both in the physical and digital spaces, with AR playing a pivotal role. The CeARamics platform's design facet uses a generative algorithm to populate digital clay elements. The algorithm's logic is grounded in custom rules encompassing geometry, connection points, and orientation details, dictating component type and placement for larger assemblies. These allow faster, more diverse assemblies compared to the basic types due to their multiple faces, yet they exhibited a 20% likelihood of altering growth direction due to geometric constraints. To introduce directional diversity, Type V and T were employed as transitional elements.

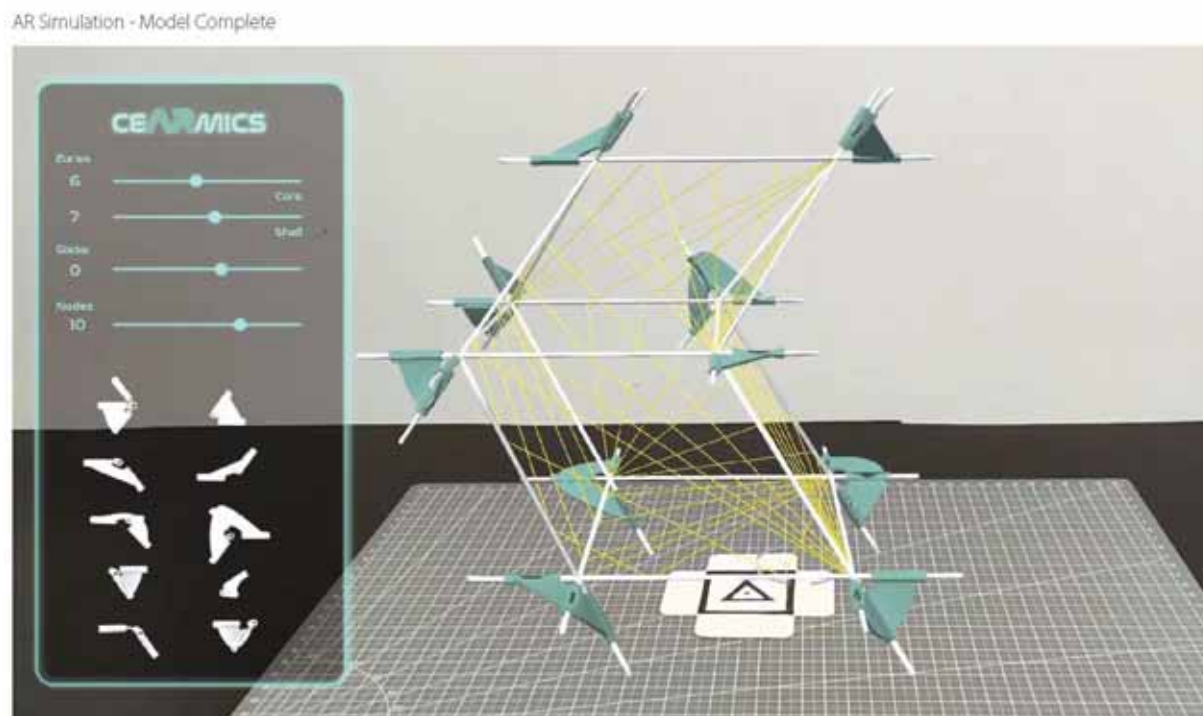


Figure 151. Weaving frame. Ceramics.

Ultimately, four distinct rule sets incorporating all component types were chosen, each generating unique design outcomes. For instance, wall generation results stem from varying aggregation rules. Designers can upload their geometric designs (surfaces, voxels) to the platform, which, based on the generative algorithm, overlays solid components. Utilising the WASP© replacement method, these solids can be swapped with digital clay segments of varying weave densities. This mechanism takes into account mechanical simulation and functionality. Depending on the designated space (public, semi-public, private), the clay segment's porosity is tuned. Regarding mechanical analysis, the component's force areas determine the clay modules used, ensuring a functional design.

The platform now allows users to choose from various weaving styles for their designs and then preview the glazed version by selecting a colour from the palette. Once the design is finalised, the application generates the parts, which can be manufactured by assigning them to manufacturers worldwide. These manufacturers will produce the clay elements while being guided by the application. After fabrication is complete, the components are shipped to the construction site, where workers can use augmented reality to view the digital aggregation within the real environment. This enables them to select a portion of the aggregation to assemble and begin construction. The platform is designed to be accessible on various devices, including Hololens, tablets, and phones. Manufacturers can view the aggregation in segments consisting of three different colours of solid components, each corresponding to a different density of components. These clay parts are used as a cladding system positioned on special panels that are attached to buildings, much like a curtain wall. It is important to note that the components themselves are non-structural. In case the edges of the components are too irregular due to the organic form that clay produces, they are sanded and smoothed to ensure they fit well and can be properly fixed on the panel.



Figure 152. AR Manufacturing configuration. Ceramics.

In the early stages of digital tool development, these tools facilitated individualistic handling, allowing users to process, modify, and share information independently (Carpo, 2011). However, with the onset of the 21st century, there was a convergence of design and production due to the advent of digital tools enabling generative, automated processes via information modelling and contemporary fabrication techniques (Carpo, 2011). Current technologies empower architects to oversee implementations digitally, fostering robust synergies across disciplines in the production process. Moreover, the evolution of digital architectural software emphasises its collective aspect, broadening its reach not just to professionals but also to provide platforms for citizen and community engagement (Carpo, 2011).

The digital age indicated a transition from mass production to mass customisation. This transformation introduced variability and incorporated expertise and societal engagement throughout its phases, leading to the creation of new shared ownership and authorship models. Central to this paradigm is the advent of open-source networks, enhancing interaction and promoting citizen involvement (Sanchez, 2017).

Regarding the CeARamics application's manufacturing aspect for construction, it was imperative to devise an approach for mass production. Instead of a centralised manufacturing model, we explored the potential of Augmented Reality in pioneering a distributed manufacturing ecosystem. Here, users are equipped with an AR-guided experience via their smartphones. Whether engaged by professionals, community-led workshops, or ceramic enthusiasts, the goal remains

consistent: championing a decentralised methodology that diversifies the production spectrum and democratises it. Essential assembly materials like nodes, sticks, and ropes are dispatched to users in a kit format. They only require their smartphones for operation, underscoring the system's accessibility and inclusiveness, given the lack of expensive equipment. Furthermore, recognising the potential for a global participant base in the fabrication process, the principle of shared authorship is evident. The result is a harmonious collaboration amongst diverse contributors, further reinforcing the ideals of a genuinely democratic system.

4.3.3. The Values Classification

The CeARamics project defines a prototypical approach to how the use of digital design and augmented reality can generate an environment where the participation of unskilled workers in the manufacturing environment is possible. Based on simple computational logic for a component-based system and an accessible platform to manage and manufacture ceramic elements, the project showcases one possible workflow that represents the potential of integrating digital design augmented reality and traditional manufacturing.

From the Digitalization Value, the project is based on the idea of components and combinatorial logic to populate spaces based on a series of parameters. The use of algorithmic logic in this manner supports a necessary digital approach, as the complexity of the multiple patterns, blocs, and parameters would be impractical without the help of computation. Likewise, the optimisation derived from the digital algorithm enhances the use of digital design that is complemented by the application of computer vision. In general terms, the project integrates several relevant technologies that all together facilitate the design and construction of the system. Particularly, the proposed digital platform as a core for the project reflects how relevant digitalisation is for this project and how beneficial it could be for every user related. Essentially, the positive use of technology towards a more accessible and adaptable system reinforces the Digitalization Value as one of the main elements of this research project.

From the Materiality Value, the exploration of materials like clay or hemp ropes to generate digital design components demonstrates that traditional materials are

compatible with the most computational approaches. The tactility and hand craftsmanship of the process also reinforce the role of the human within the manufacturing sequence, allowing for the intuitive distribution of the clay and the glazing. Also, the innovative manufacturing approach based on reconfigurable moulding facilitates a more flexible and practical new clay casting system that still allows for traditional firing. Together, they result in a reinterpretation of traditional clay making from a more modern, digitally focused perspective that promotes digital design while maintaining the material qualities and heritage of ceramic manufacturing.

From the Human Factor Value, the CeARamics project proposes a project where the participation of people in several forms is essential. On the one hand, the project emphasises handcraftsmanship through the manufacturing process, in which human intuition plays a significant role. Also, in this sense, the use of computer vision to record, archive and deliver weaving skills gives an extra level of significance to the craftsmanship value. On the other hand, the participatory platform proposed also encourages community participation and interaction. Likewise, the materiality of the project and its traditional spirit underline the humanistic scale of the project. The CeARamics project is, therefore, a relevant example of how digital and human can coexist and collaborate to produce valuable results.

From the Augmentation Value, the project proposes an innovative approach as it combines AR guidance for manufacturing and computer vision to record and archive craftsmanship weaving skills into a database. CeARamics proposes the idea that physical skills can be digitalised and then transmitted through augmented manufacturing guidance to allow unskilled workers not only to participate but also to perform based on a specific artist or crafters. This scenario facilitates the transmission of skills across the years and can preserve through digital means the knowledge and the value of people for future generations. Essentially, it creates an augmented source of heritage skills that can be preserved or distributed through the digital platform. Apart from the conservation and transmission of skills, the CeARamics project also explores a holistic augmentation for the manufacturing process that guides the user through the whole process with holographic guidance from the mould assembly to the weaving, the material distribution and finally, the component assembly. This comprehensive approach defines its augmentation value as an essential part of the research and the demonstration that modernity and tradition can be entwined through augmentation.

The integration between traditional making processes and materials and the preservation of heritage and traditional manufacturing knowledge is defined in this thesis as one of the main virtues that AR has to offer to the architectural world. In that sense, CeARamics explores a series of concepts that dwell deeply on this idea, showcasing very interesting results. From an archiving perspective, the nuances of handmaking and the individual characteristics of every artist were difficult to preserve as there was not a reliable frame to achieve this. By using Computer Vision and augmented manufacturing, this project aims to at least partially solve this problem by recording and archiving the data from each artist's techniques into a library that can be shared through the digital platform. Also, the participatory spirit of the manufacturing process proposed supports the idea of community and democratic access to the manufacturing and building processes. In that sense, this project establishes a deeply human-based project that integrates the latest technologies to achieve an interesting and promising balance.



Figure 153. AR Manufactured Block. Ceramics.

4.4. The ReBent Project

The project is initiated in the context of fast-paced digitalisation and a global housing crisis affecting regions all over the world. Smartphones and tablets have exceeded initial expectations in terms of their reach and influence. These devices are no longer limited to urban areas - even remote and underdeveloped regions are now benefitting from them. In India, for instance, the number of smartphone users doubled in just six years, surpassing the US (Newzoo.com). This surge in device usage opens up opportunities for modernising construction processes in distant and rural locations. Due to widespread smartphone adoption, local communities can leverage platforms that encourage community-focused workflows in construction. The WIKI House (2012) and AUAR projects in London (2018) demonstrate the potential of these platforms in promoting community-centric construction workflows.



Figure 154. AR Manufacturing App. ReBent.

Despite the potential benefits, access to modern construction methodologies remains a challenge in many underprivileged and remote areas. The lack of trained technicians is a significant obstacle, leading to limited design and building options (Auwalu et al., 2018). Technological augmentation through computational design platforms is a promising solution. These platforms simplify complex construction processes, providing user-friendly interfaces for non-technical users. Users can specify their construction requirements, and the platform's algorithms will suggest

the best approach. Such innovations empower users, bringing advanced design capabilities even to regions traditionally cut off from contemporary technology. Augmented reality is a transformative tool that provides real-time guidance to workers during construction (Goepel, 2019). AR-driven fabrication gives builders insight into a wider range of construction techniques, fostering innovative design in areas previously considered unreachable (Hahm et al., 2019).

Therefore, ReBent proposes a self-managed architecture through Augmented Manufacturing to improve access to better and more resilient architecture for remote and isolated communities. To achieve this, they suggest a concrete-based housing system that prioritises simplicity, adaptability, and low-skilled workers

4.4.1. Design Approach

The concept of bending deformation and force transfer to adjacent elements is fundamental to the structural design of many global architectures, indicating its widespread cultural familiarity (Lienhard et al., 2013). Bending-active structures are typically used to transform 2D compositions into 3D curves, as demonstrated by the AA Hybrid project's plywood structure, which balances analogue and digital factors (Lacone et al., 2020). However, these structures can exhibit unpredictable bending due to the material's resilience and the inherent elasticity law during active bending (Lienhard et al., 2013). Knippers bridged the gap between computational designs and physical models using the Iguana software to address these irregularities. Furthermore, Augmented Reality enhances fabrication accuracy by translating complex 3D geometries directly to real-world settings, eliminating potential errors from 2D translations (Goepel, 2019).

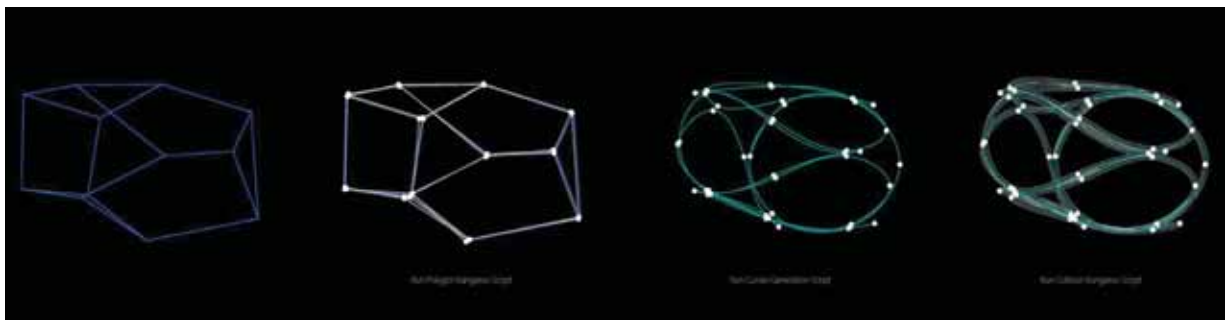


Figure 155. Bending simulation. ReBent.

This project explores the potential of Augmented Reality in simplifying the fabrication of active-bending structures, offering a self-reliant execution facilitated by holographic displays. The project innovates by utilising these structures to create liveable spaces and assessing their aptitude for long-lasting constructs, notably concrete moulds. The design introduces a pioneering mould system for constructing intricate, small-scale concrete structures that bypass the need for costly machinery, affirming its adaptability to various design intents.

Using a polygon system, the design offers a generative approach to positioning straight curves. Each curve links with an adjacent vertex in a singular closed bending cycle. The design approach pivots on polygons formed from 3D polyhedrons within a single voxel. Each polygon's straight lines are length-bound and connected via vector points and curve self-attraction. To ensure fidelity between computational simulations and physical models, bending behaviours are governed by tangents, prohibiting curves with unreplaceable closed angles. Recognising the challenges of large-scale constructs, the system integrates modular concrete pieces as moulds. These modular units symbolise segments of a more extensive entity, facilitating separate construction and on-site assembly, leading to structures of at least 1.85m in length.

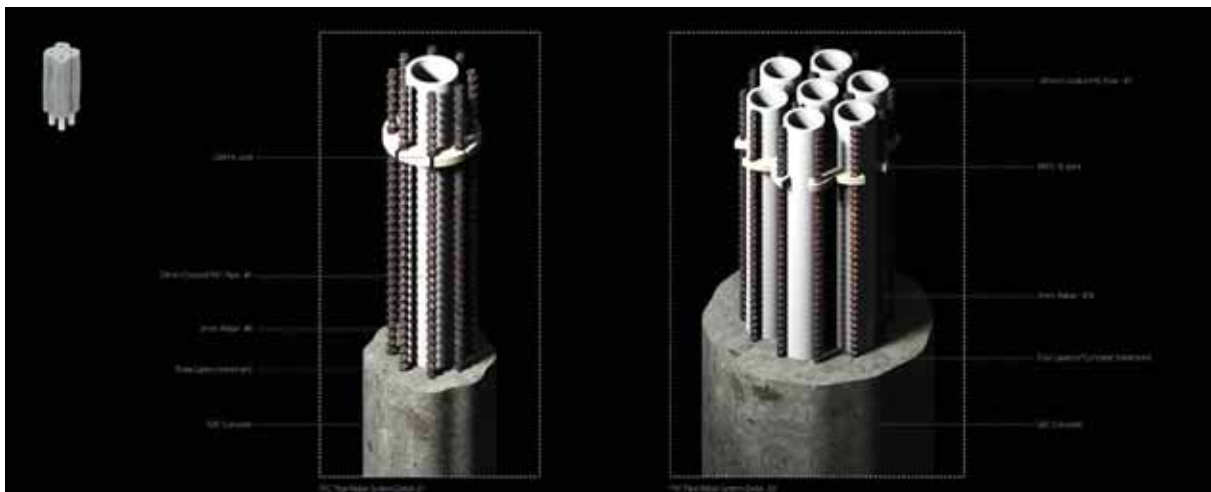


Figure 156. Concrete Casting System. Rebent.

A key goal is to harness universally accessible, local materials. Although PVC's eco-friendliness is debatable, its global availability and suitability for concrete spraying made it the material of choice for this prototype. However, future

iterations will consider sustainable alternatives like bamboo or natural fibre pipes. The selected 20mm hollow PVC pipes, inspired by Georgiou's 'God's eye' pavilion (Georgiou et al., 2014), were chosen for their flexibility and bending prowess.

The project evaluates active-bending's physical performance and structural behaviour to guarantee a seamless transition from digital design to tangible prototype, facilitated by the Grasshopper and Kangaroo Plug-ins. Discoveries indicated that higher displacement compositions necessitate added elements, cultivating a clustered pipe system. The structural simulations forecasted displacements for large constructs, enabling component adjustments for structural refinement. Enhancing stability was achieved by bundling pipes in vulnerable areas and reinforcing the future concrete with steel rods, connected via 3D printed TPU brackets, bolstering formwork rigidity and easing concrete application.

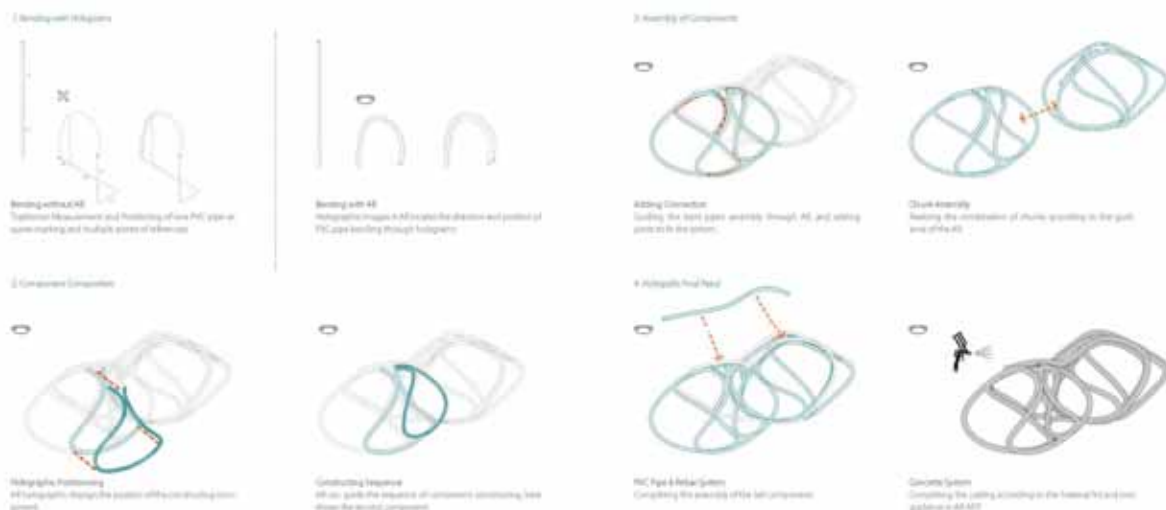


Figure 157. Generative Sequence. Rebut.

Initial explorations assessed various concrete mixes for their adherence to PVC pipes. The Glass Fiber Reinforced Concrete (GFRC) emerged as the optimal choice with its inherent malleability from fiberglass components. To address adherence challenges, glue was sprayed onto the pipes. The study found that the number of layers is proportional to the geometry's bending stress, necessitating at least three layers for basic shapes and a minimum of five layers of GFRC for complex areas.

4.4.2. Augmented Approach

The project goal was essentially to promote access to enhanced housing and incorporate local communities. To accomplish this, the project developed a customised software application in Unity© that is optimised for Hololens and reinforced by the Windows Mixed Reality Toolkit (W-MRTK), designed for Augmented Manufacturing.

The Microsoft Hololens application is a user-friendly construction sequence that seamlessly processes design logic, translating it into actionable building data. Upon launch, users are presented with a home screen offering the choice to start a new project or continue an existing one. The AR interface transitions to a streamlined menu that presents a comprehensive project overview, including construction details, such as element quantities, fabrication procedures, and assembly guidelines.

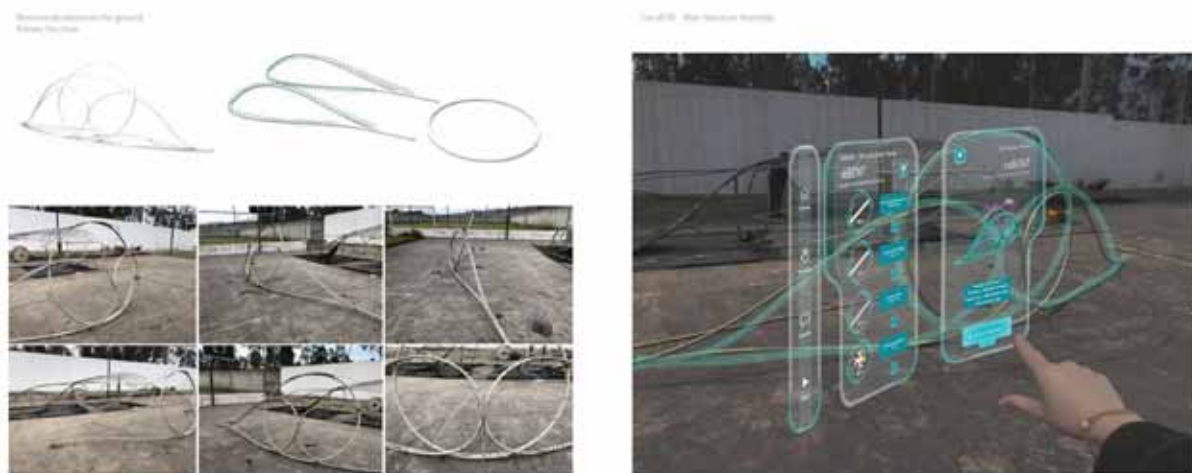


Figure 158. AR Manufacturing. Bending process. Rebut.

Thanks to the intuitive display, users can systematically plan and sequence each assembly phase with prior knowledge of the required elements and their variants. The immersive holographic visuals serve as interactive guides, walking users through each step. Users can engage with these holograms, matching them with corresponding pipes, thus integrating a real-time evaluation mechanism. The application enables users to revisit previous steps, visualise the end assembly, or jump to different phases, catering to the need for iterative design changes.

The AR platform revolutionizes the construction of intricate concrete structures by being astutely adaptive, handing over operational and construction control to the user. It negates the old-school dependency on printed blueprints or continuous laptop consultations.

The platform trial and prototype construction were conducted in Quito, Ecuador. The pavilion design branched out with wings on either side, featuring a robust central core. This geometry was deliberately complex, intended to showcase the system's adaptability. For ease of assembly, the design was segmented into three major parts: one roof and two walls.

Remarkably, a group of five individuals, none of whom had prior experience with the technology or construction in general, managed to build the 7m by 2m prototype in merely two days, dedicating five hours each day. Their primary guide was the AR visualisations.

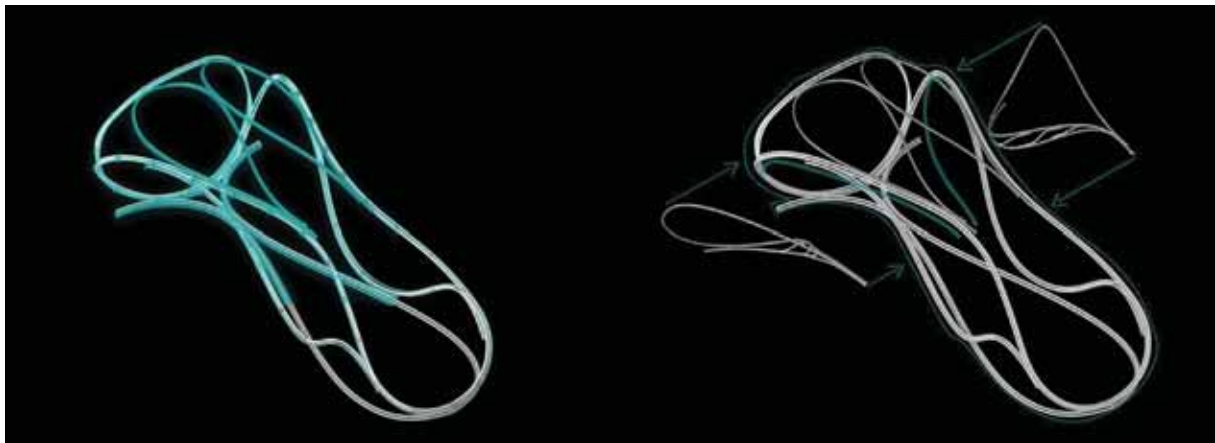


Figure 159. Quito Prototype. Re bent.

The initial structure was sectioned into three primary components constructed at ground level. AR visual aids then determined the assembly, orientation, and casting sequence, ensuring optimal stability. With only a single Hololens device at our disposal, we turned to Fologram®, a Grasshopper® plugin for AR, and two other devices, an iPhone X and an iPad Pro.

The team was diverse, comprising local volunteers with no ties to the architectural or construction fields. Those leading the AR directives laid out ground markers indicating where the pipes would bend. Following this, the others would compare their bending work with visuals on the iPad, ensuring accuracy. Even with

meticulous preparation, there were inevitable discrepancies, particularly at the joints. The design had to be adapted to combat excess wobbliness in the structure. After this adjustment, the prototype's foundation, a skeleton of PVC and rebar, was systematically coated with GFRC to finalise the structure. The resulting model was a faithful representation of the design and a sturdy, functional entity. The novelty was that first-time builders achieved this level of success.



Figure 160. Quito Prototype. Assembly Process Rebut.

Fologram© was a fundamental tool, especially when on-the-fly adjustments to pre-set components were needed. For instance, some components didn't support the pavilion's stability as anticipated. Thus, real-time modifications and swift

implementations became crucial. While the pavilion's final measurements deviated slightly from the blueprint, about 0.21m in length and 0.08m in height, the Hololens app proved instrumental. However, it had its constraints. Modifications to a pre-set design took longer within the app than anticipated. Additionally, there was a marginal discrepancy in precision between the Hololens and the other devices, attributable to Hololens's superior camera and sensor array. While both were effective, the Hololens, with its heads-up display, outperformed handheld devices in terms of convenience during assembly. Notably, the assembly was executed at night to avoid the sun's glare obscuring the holograms. As a result, the prototype demonstrated the capabilities of the system and the viability for inexperienced users to participate in the building process.



Figure 161. Quito Prototype. Concrete Spray. Process ReBent.

4.4.3. The Values Classification

The ReBent project represents many fundamental aspects of the idea of augmented architecture. It uses the potential of the technology in several ways, from design to manufacturing. If analysed from the Craftsmanship Value perspective, the project promotes the idea of an enhanced concrete formwork system. Although the building process is not a traditional method, it embeds the design of craftsmanship by exploring the possibility of intricate concrete geometries. Likewise, it favours the idea of using structural elements in a decorative way without compromising

performance. From a pure manufacturing perspective, the project reinterprets traditional mould-making for concrete and modernises it using technologies like 3D printing to endure adaptability. In this sense, it is important to mention that the geometry explored during the research project was intentionally intricated to prove that the system would allow for great flexibility and use the full potential of the bending concept.

From the Digitalization Value, the project generally represents a clear paradigm of transforming natural behaviours into algorithms to define design rules. In that sense, the project uses a complete approach where the user just defines basic parameters, and it is the system that delivers the final design through iteration and recalculation. Also remarkable is the fact that algorithmic logic also plays a significant role by defining buildable components and elaborating at the same time the correct sequence for the expected bending result. As a result, It embraces a fully digital design approach where human participation is minimal.

From the Materiality Value, the project proposes an interesting approach. It uses a widely available material with a determinant role in construction, like concrete, but from a different perspective. It proposes its mixed use with PVC as a lost formwork and a higher, more efficient version (GRFC) to facilitate the participation of unskilled workers in the process. On the same line, the material strategy facilitates flexibility and adaptability for a very resilient material. Also, the use of hollow PVC as the formwork works in a direction that makes a traditionally complicated process accessible and simple. Also, the fact that all the elements used are easily accessible and common embraces the idea of self-managed architecture.

From the Human Factor Value, Rebent defines several areas where intuition and improvisation skills play a determinant role. On the one hand, the assembly, although guided, will be affected by unpredictability from the materials and weather conditions, which requires the human to fine-tune every piece to achieve the final result. Along the same line, the concrete spray requires some intuition to correctly fulfil all the areas since the final concrete behaviour tends to be temperamental. Finally, The system based on bending rods is also inspired by vernacular techniques that draw from traditional knowledge, embedding the project of heritage human scale. The project, in that sense, is transversally connected with human labour intuition and traditions without losing its digital origin. It embraces a full collaboration between the computer and the user.

Rebent serves as an example of how augmented architecture can be approached for different scales and materials. It uses a fully digital design strategy that combines a more crafted building process to achieve housing scale. The augmentation plays a fundamental role, as its guidance is paramount to achieving the algorithmic shapes and the right assembly sequence for optimised bending performance. Therefore, this case study summarises how augmentation can transform industrial architectural materiality into vernacular forms and techniques using computational design.

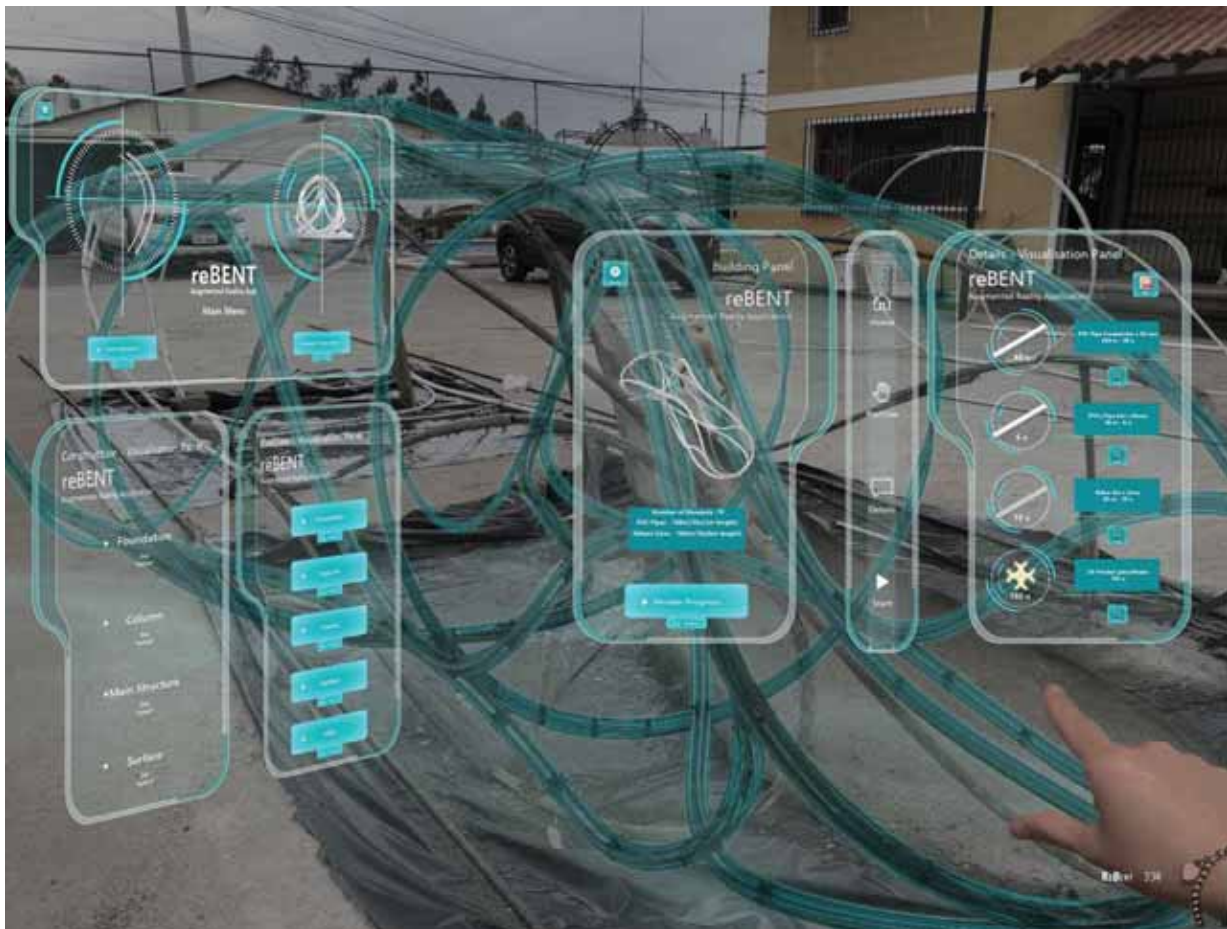


Figure 162. Quito Prototype. Accuracy Test. Process Rebent.

4.5. The FlowMorph Project

The FlowMorph project aims to answer a unique design question that revolves around the idea of Mixed Reality Assisted Manufacturing for complex geometry. The project proposes an MR+Simulation workflow using a CFD solver to explore a specific material, Polycaprolactone (Polymorph). The goal is to assist the exploration of the material in the production of an artefact by heating and reshaping the plastic. The research focuses on creating organic structures called 'Skeleton' and 'Tentacle' by using a combination of specific digital simulation methods. The CFD application explores aspects of the human-geometry interaction in the form-finding exercise overlaid on the physical reality. This process takes advantage of the cognitive aspects of MR and allows designers to intuitively explore a solution space by ad hoc play with the fluid simulation and adjustment of options. This augmentation in the making process affords intuitive exploration in interlaced making and designing - an enhanced reflection in the design practice. The increase inspires research in new design tools and practices, and the goal is to confront the complexity of using digital and physical protocols to explore the use of adaptive 'unexpectedness' of the digital generative design. In this particular project, the plastic used leads to the investigation of a wide variety of plastic applications in highly digitalised design. Therefore, the project seeks a possible taxonomy of random glitches in this workflow. In fact, the project presents a survey of the current state of the art of MR and CFD-assisted manual fabrication, deriving a design exercise and elaborating on the outcomes to propose a road map for future applications of mixed reality in the design-by-making and craftsmanship.

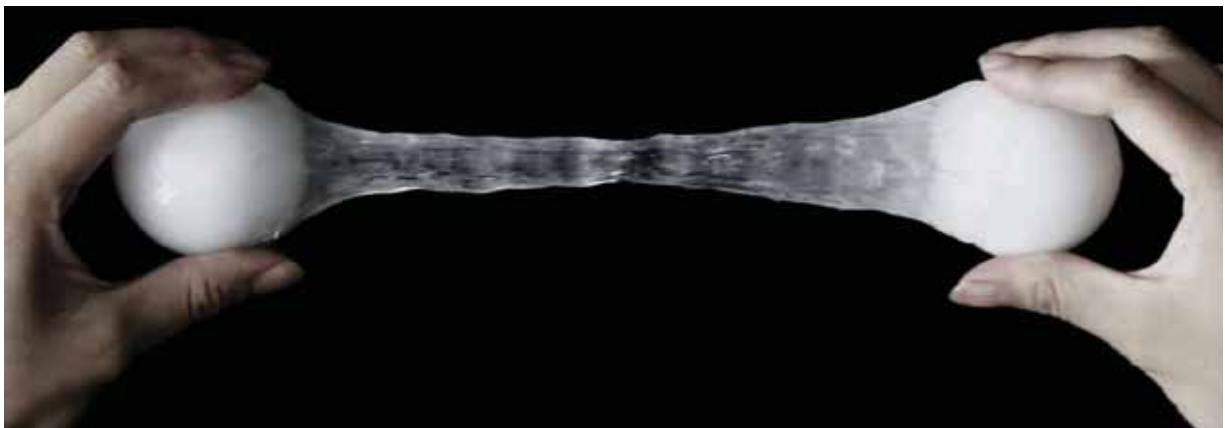


Figure 163. Thermoplastic Stretching. Flowmorph.

4.5.1. Design Approach

To fully leverage the benefits of human-machine collaboration, the concept of generative computation has been introduced. This approach allows computers to aid in designing and decision-making, especially when it comes to shapes and geometries. However, working with computational design tools can be mentally taxing. The complexity of parametric modelling is increasing exponentially. Generative computation is revolutionising the design process by allowing computers to play a more active role. This approach offers creative potential in designing structures that humans may not be able to imagine, let alone manually design.

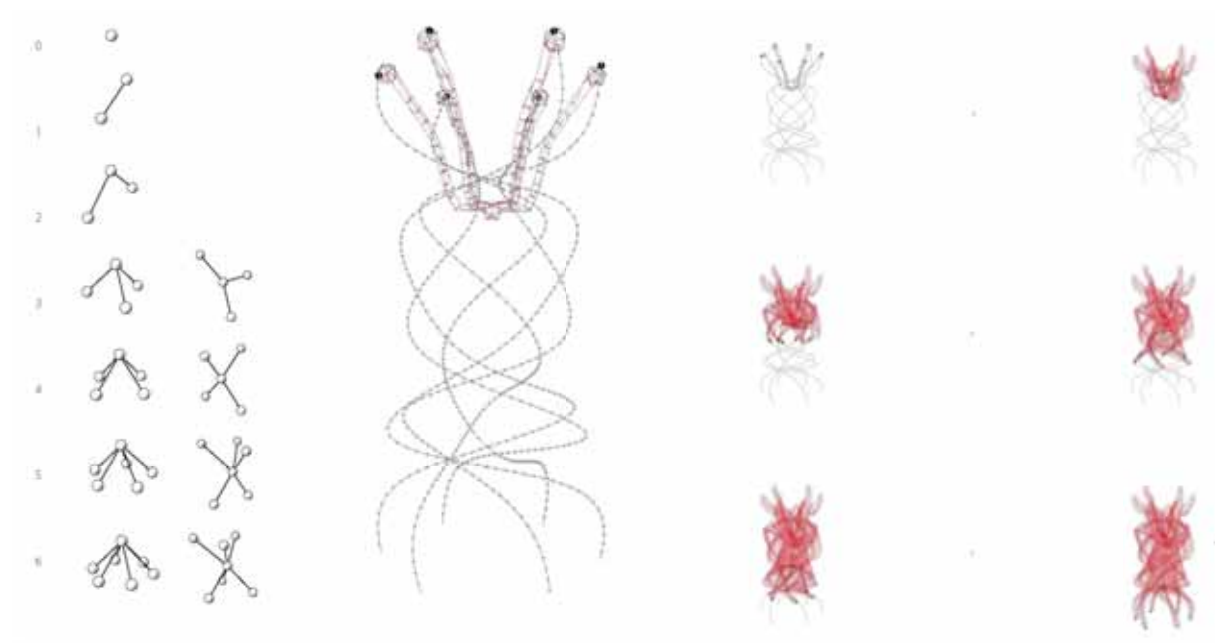


Figure 164. Jellyfish Algorithm. Flowmorph.

The simulation is based on the flexible behaviour of plastic material. A spring particle system algorithm was used to create this simulation, which generates unique and complex 'Jellyfish-like' outcomes from a simple geometry. The workflow of the simulation involves setting multiple structural paths and forces within a boundary box. A component moves along these paths and duplicates itself based on the physics of the algorithm. The structural path determines the direction

and rough shape of the outcome. However, lock points have been set on the paths to allow for the selection of locked or unlocked points. The simulation has several external forces, including gravity, wind, speed, and bouncing behaviour. To maintain control, a component that is as simple as possible has been set up. These constraints allow for a wide range of options, resulting in more varied and unconventional geometric outcomes.

In order to generate more useful simulation outcomes, we employed fluid dynamics as an additional approach. We created a 3D fluid container with an embedded vector field and applied various forces, such as gravity, turbulence, radials, and air, to the fluid engine. These external forces affected the fluid engine's vector field, making the generative process more complex and rich. The outcomes were influenced by the resolution of the vector, timing, location, and strength of the forces. Visualising the outcomes was a direct result of the forces applied to the vector field.

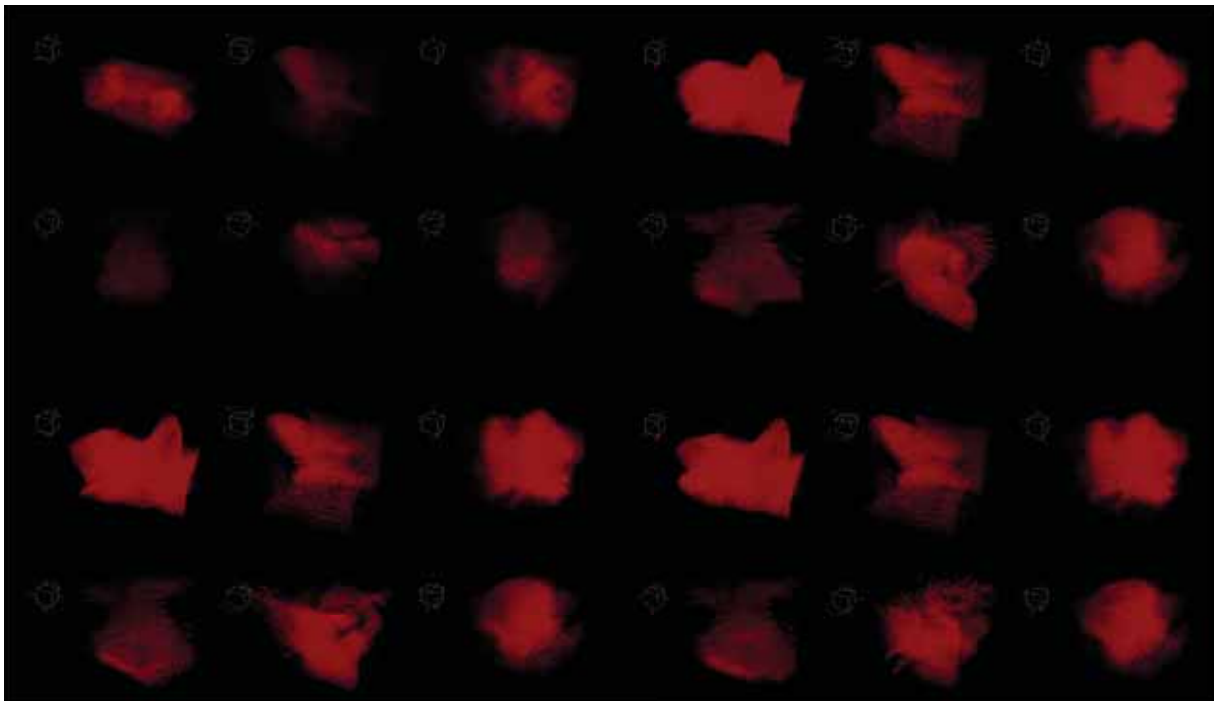


Figure 165. Vector Field. Flowmorph.

Intricate and interesting vector fields were produced, which were thought to provide an interesting guide for geometries for their structure. Additionally, the use of external forces by the fluid engine enabled the consideration of controlling

the generation of shapes through human interaction via gestures using Augmented Reality devices. As shown in the image, interaction with applied external forces is naturally allowed, such as using the arms to generate the design gesture.

To better understand interactive design, various methods of recognising human gestures were explored by the team. Initially, they started by tracking colour, which enabled them to draw a line based on the movement of a white colour component. The team also aimed to determine how the computer could detect their actions and provide the next step. To track the component, they established markers. Once a component was assigned to one of the target positions, the grey marker turned green, and other potential positions around it were shown in red. The process was repeated when another component was attached to the red markers.

Gradually, the team developed gesture recognition into a drawing routine performed by the user's hands to implement a more seamless interaction. This method was based on the AR device's tracking capabilities to detect specific hand gestures. The curve drawn by the hand gesture was directly deployed as a 3D mesh in modelling software. This system shows the possibility of interactive design where human gestures can influence the design itself.

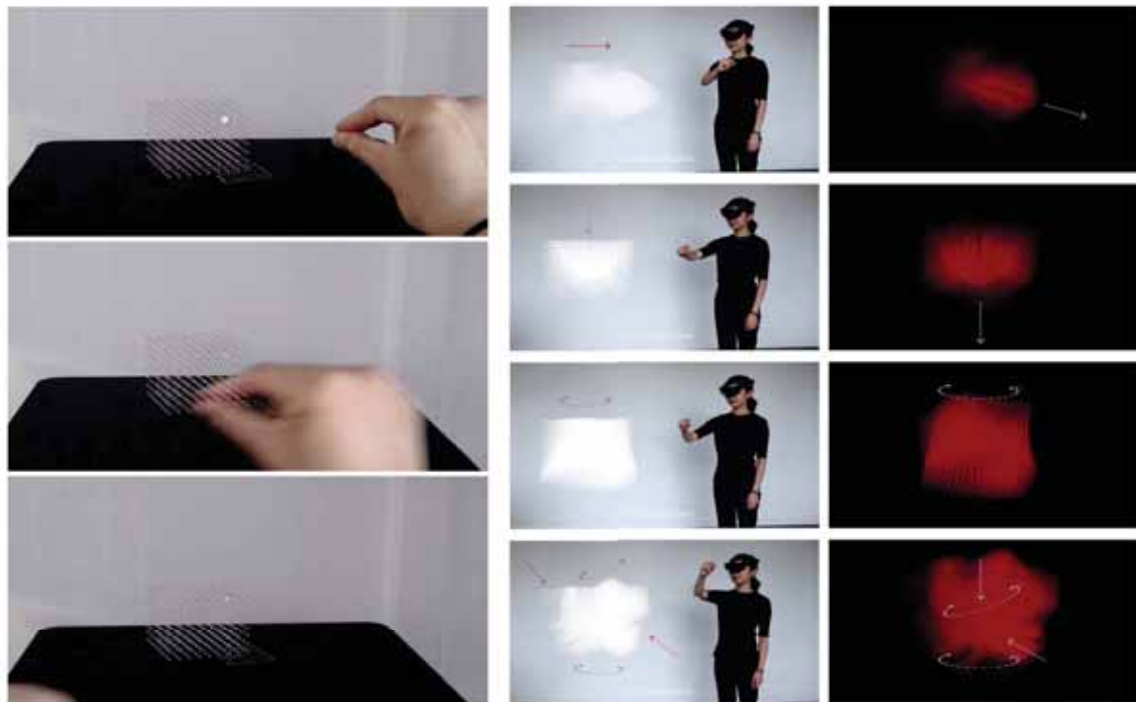


Figure 166. Augmented Design. Flowmorph.

Preservation of the directionality of the resultant vectors is deemed important when generating a vector field. To achieve this, a geometry logic is needed to draw the directionality and materialise it as a physical outcome. For the material to be stretched by connecting each sphere one by one, a 3D grid that can grow and adapt itself to the directionality is required. Various types of 3D grids were studied, and it was concluded that a pyramidal grid was the most feasible option for the design. It can adjust and deform itself based on the directionality of the vectors.

To implement this design, a computing workflow method was developed. After generating the vector, it is converted to a mesh with the same topology as the vector field. Then, the pyramidal grid system is deployed based on the scale and resolution of the topology. This process can be applied to any vector field design, allowing for the creation of a functional structure.

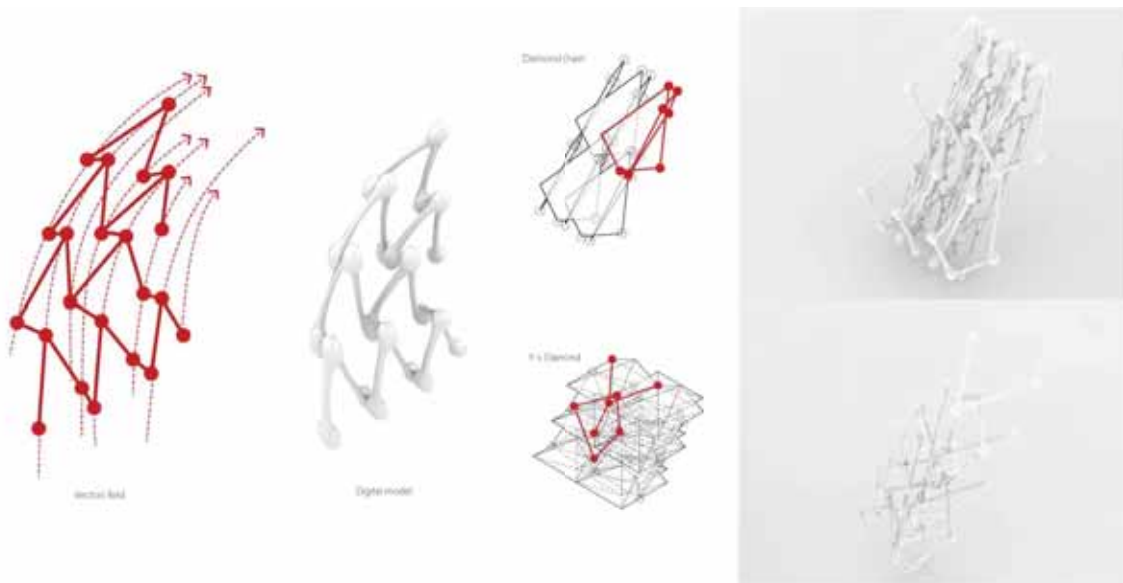


Figure 167. Component Generation. Flowmorph.

4.5.2. Augmented Approach

Over the past few decades, it has been realised that digital fabrication, including CNC, 3D printing, and robotics, has enabled the exploration of design variation and innovation of form and functionality. Mass-customization has been proven effective for most fabrication, particularly for products requiring high precision with little tolerance level. However, digital fabrication processes usually come at a higher cost and are not able to handle high tolerance or intuitive on-demand decisions. Additionally, dealing with fabrication that requires delicate craftsmanship is challenging. To address this issue, the human-machine relationship must be reconsidered. Machines are suitable for handling repetitive, heavy, dangerous, and precise work, while humans excel at handling delicate crafts, adapting tolerances, and making intuitive decisions.

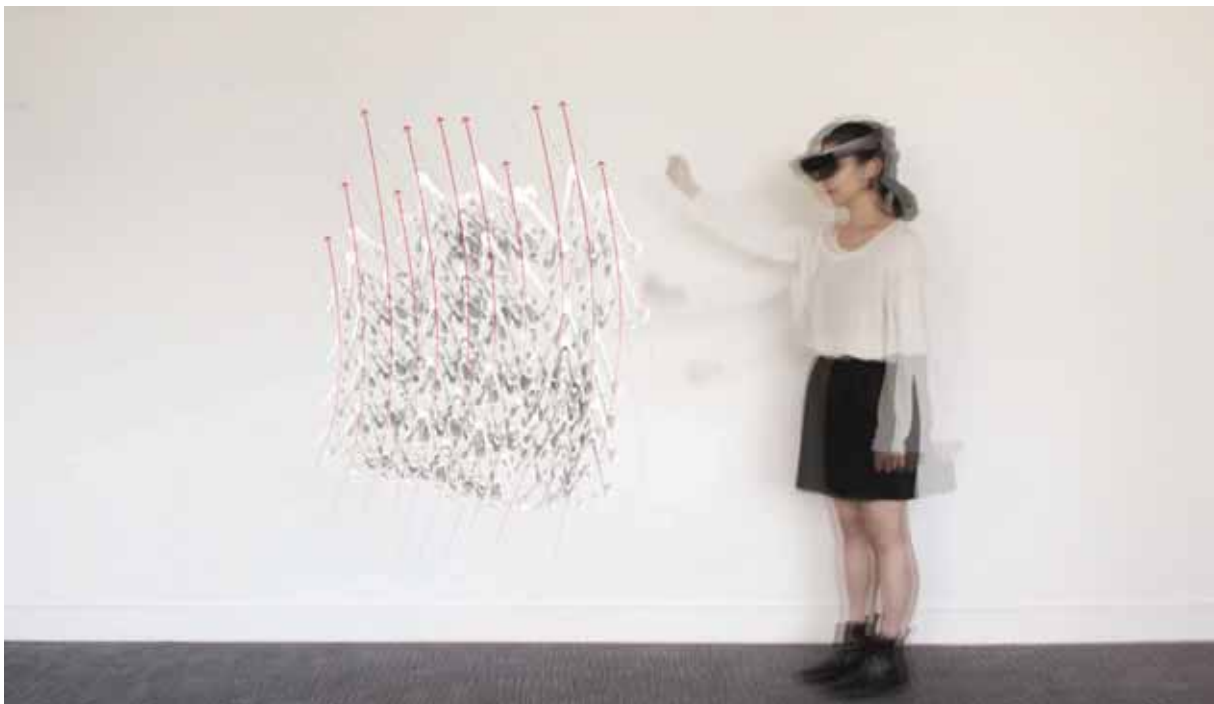


Figure 168. AR Interaction. Flowmorph.

The design research explored materials and crafting techniques that can benefit from the strengths of both humans and machines. It was discovered that plastic is a low-cost, strong, flexible, and elastic material that is also malleable with craftsmanship. After numerous tests and trials, a "stretching" action was decided

to be used for the production of physical models. Thermoplastic was used, which can be melted under certain temperatures and easily modified until it cools down. This technique relies on craftsmanship, allows for high tolerance, and is free to accumulate in multiple directions. This gives a high degree of freedom in exploring shapes and geometries.

The research focused on the role of human intuition in the manufacturing process. By combining human intuition with the behaviour of materials, a manufacturing technique was developed that uses plastics. Plastics were chosen due to their unique relationship with digital fabrication and their versatility for human interaction. There are numerous examples of research on plastic 3D printing and robotic spatial printing, such as AI build (2018) and Branch Technology (2018).

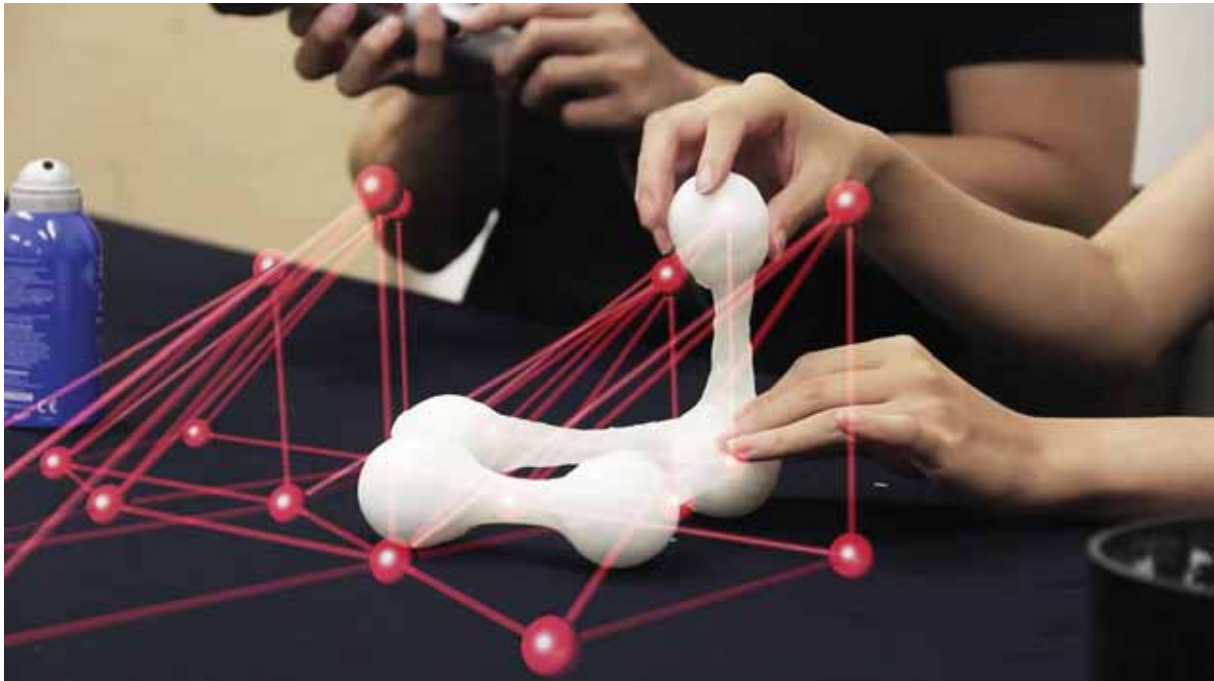


Figure 169. Component Making. Flowmorph.

Robotic 3D printing has been shown to be a significant improvement over traditional 3D printing when it comes to dealing with plastic behaviour, which is good in tension and stretching rather than accumulation. However, expensive computing, precise calculation of continuous tool paths, and temperature control during printing are typically required for robotic stretching. A method has been developed to naturally overcome these issues, allowing plastics to be freely formed in any direction, even from challenging positions. There is no need for heavy

computing to study the tool's path, and the method can freely change the size and length of the stretched segments. It also allows for intuitive changes and adjustments at any time, before, during, or after fabrication. The method is adaptable to analogue mistakes or failures, unlike highly robotic fabrication processes.

The furniture design underwent feasibility testing after several studies were conducted. A generative workflow was used to create a series of chairs, and the chairs were subsequently catalogued. One chair in particular was selected for further development. The pyramidal grid was applied to ensure proper scale and resolution, resulting in a final chair design featuring unconventional geometry generated by fluid behaviour. The manufacturing process was tested and improved based on user experience as part of furniture scale experimentation. Generative design and AR technology combined demonstrated immense potential for interactive experiences.

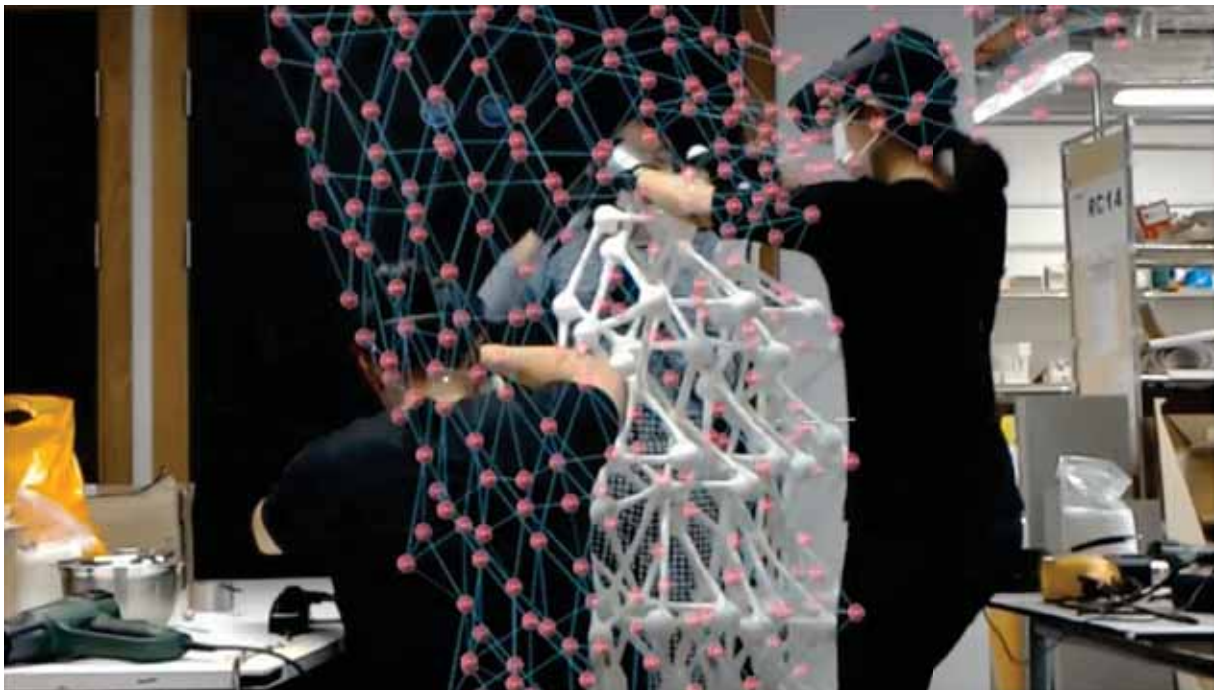


Figure 170. Final Prototype assembly. Flowmorph.

The AR device used for fabrication was designed to be user-friendly for all makers. An initial fabrication trial was conducted to determine the necessary 3D model and information. The trial found that a simple hologram guiding the maker was sufficient, rather than deploying all the details of the 3D model. The small

prototype was fabricated only with a hologram of simple lines and points representing the structure. The process of making is simple, and anyone can learn with guidance. The unique design language can be maintained by stretching between spheres.

The fabrication process for the final piece began based on studies. The final piece measured 2.1 meters in height, 1.6 meters in width, and 1 meter in depth. It took 50 hours to complete the construction, which involved three makers. During the construction, one or two makers wore AR devices and directed the others by pointing out the location of spheres or building the basic structure. The makers without AR devices worked on the rest of the structure, which didn't require hologram guidance. The fabrication process was pretty fast, even though some makers only joined the making process on that day. Before starting fabrication, they were instructed on how to use the material, and the conceptual principles were explained. This fabrication method is universal regardless of the user's skill level, making it one of the most beneficial aspects of this experience. However, there are some drawbacks that need to be addressed, such as the limitation of the distance between the makers and the model due to the size of the AR device's window. When a maker is too close to the object, it may be hard to see the hologram, which can limit convenience. Additionally, if several makers wear AR devices, the location of holograms may differ slightly depending on the device, creating a tolerance problem. However, these technical issues can be easily addressed by the human factor in manufacturing. Augmented fabrication provides new design and fabrication methods.



Figure 171. Final Prototype. Flowmorph.

4.5.3. The Values Classification

FlowMorph proposes an interesting hybrid approach that combines a completely hands-on manufacturing process with a very innovative and radical material proposal. The project lies on the idea that new materials can be used through traditional techniques to find new architectural languages. Its Design logic is based on digital simulations combined with the simplicity of the material system, resulting in an innovative proposal that could be easily used as a basis for further research in plastic manufacturing and augmented manufacturing in architecture. Overall, the project presents a system aiming towards smaller or furniture scales but still challenges the design's creation.

From the Digitalization Value, FlowMorph explores a fully digital methodology where a series of algorithms are in charge from a bottom-up strategy to deliver the final design proposal. The sequential logic of computational design defines and refines a geometry that results in an efficient and adaptable geometry. The project embraces a simple particle strategy that enhances fluid geometry exploration and reinforces the idea of component manufacturing. FlowMorph, in fact, represents the digitalisation value in a very positive way that balances a fully automated generative system that also allows for human interaction and fabrication.

From the Materiality Value, the use of plastic represents an interesting approach as it demonstrates the possibility of adding new materials to the traditional catalogue. Also, its thermal properties enhance the idea of traditional manufacturing as it can be handled in simple ways with minimal equipment. Another interesting aspect of this material choice is its life expectancy. As an inherently soft material, it is designed to last a limited amount of time, favouring a more fluid space creation. At the same time, recyclability and reusability result in a very sustainable material use. The aftermath is that the materiality value is well sustained as, on the one hand, its ingenuity helps for a simple use while caring about its CO2 footprint, particularly for plastic material.

From the Human Factor Value, Flowmorph proposes an interesting take as it not only allows for the “Human Glitch” but also expects and embraces it. Using a simple, accessible building system that requires zero previous skills allows for a very human-intuitive manufacturing process where improvisation fits and that, in many cases, is required as the unpredictability of the material favours it. Also, the fact that the whole system relies on hand-making and human vision reinforces the

idea of human participation in the manufacturing sequence. Also relevant to mention is the possibility of interacting with the computational algorithm, which includes an interesting alternative view of how the human can connect with the machine and the algorithm. As a result, the project represents an intrinsic human value as it is positioned as an essential part of the system.

From the Augmentation Value, the project implements the AR technology in an integral way, from design to fabrication to assembly. In that sense, it showcases how augmentation can be introduced as a structural tool enhancing every traditional part of the architectural process. Additionally, combining a heavy digital emergent approach with a very intuitive human manufacturing process reinforces its value, showing how it can seamlessly merge tradition and modernity. It actually defines what augmented architecture can be and what its potential is in manufacturing and design.



Figure 172. Architectural Speculation. Flowmorph.

5. Discussion

The continuous and widespread evolution of technology is a powerful force in today's society, impacting various fields and opening up new opportunities in professional and academic areas. As technology advances, it influences society's structures, dynamics, and aesthetics, as seen in architecture and design. This evolution is driven by the pursuit of efficiency, functionality, and novelty, resulting in fundamental changes in how society operates and interacts. Technological progress reflects social needs and aspirations, serving as a catalyst for change that drives human development and creates new paradigms and opportunities in design and architecture.

Among the different technologies that have emerged in recent years, augmented reality represents a particularly transformative and disruptive innovation. AR represents a synthetic environment in which digital and physical elements are seamlessly integrated, providing users with an immersive and interactive experience that transcends traditional spatial and perceptual boundaries. It settles a new scenario where the overlapping between what is real and what is digital dissolves and promotes and supports the concept of Extended Realities.

AR does not operate in a vacuum but is deeply embedded within and responsive to broader social contexts and dynamics. Its adoption and integration among the fields of architecture and design reflect and contribute to a broader technological and social co-evolution process in which technology and society mutually shape and inform one another's development and trajectory. Looking through the lens of augmented reality, we can understand how technological advancements influence social shifts. This impacts not just the physical and visual aspects of our surroundings but also how people perceive, experience, and engage with space and location.

AR introduces unprecedented opportunities and challenges within the environment of architecture and design. It enables architects and designers to visualise, manipulate, and experiment with spatial forms, structures, and materials in real-time, developing a dynamic and iterative design process that is highly responsive to both aesthetic and functional considerations. Furthermore, AR provides a powerful medium through which architects and designers can communicate and collaborate with clients, colleagues, and the broader public, facilitating more informed, participatory, and democratic approaches to the design

and planning processes. It has the real potential to shift the current linear workflow for architecture into a more rhizomatic, interconnected and collaborative environment, inspiring a new way of working and creating in the field of architecture and design.

As seen in the industry through projects like XYZ, the introduction of AR technologies can improve complex processes such as technical installation and surveying. Its application not only facilitates faster and more accurate construction of intricate buildings like data centres but also helps in saving money by reducing errors and inaccuracies that typically result from traditional drawing and visualisation methods. This approach can be extended to other areas, such as on-site precast assemblies or formwork making. It is anticipated that this technology will be integrated into mainstream workflow in the near future. However, the impact of AR is not limited to the industry and traditional building techniques. The use of a mixed virtual-real environment will influence the built environment as a whole. Design, participatory processes, urban experiences, historical context, and digital immersive design will all play a significant role in the future use of Augmented Reality.

The goal of this thesis, as mentioned before, lies in the definition of how we could understand the role of Augmented Reality in architecture and design, how it will impact the manufacturing and craftsmanship industry, and how, as a result, the building industry will change and adapt to it. In order to achieve this, this thesis first defines a historical frame that situates this technology within the three main topics that affect the automation field, the augmentation field, and the craftsmanship field.

In terms of settling the base for the discussion, if we see the evolution of craftsmanship, it is possible to identify a pendulum trend that drives its popularity and intrinsic value connected to contextual technological evolutions. In that sense, it is possible also to see how its value as a “minor” art has followed these variable trends. In connection to higher consideration times, the names of creators were devoted and praised, while in less valued times, creators were blurred into the mass of artisans and crafters. An evolution of this paradigm came with the Industrial Revolution, where automated manufacturing changed the view on craftsmanship and added the new “handmade” versus “machine-made” controversy. As a result, the ideal of craftsmanship shifted towards a precious object status where the “handmade” has a “soul” or uniqueness. At the same time, industrially made products lack it and promote the homogenisation of society. Although this

idea has been repelled by the work of industrial designers and top-quality products, the barrier between automation, technology, and artisanry is still present at some levels. The inclusion of a mixed technology like AR could open the door to new alternatives to implement technology, particularly digital design, while keeping the “handmade spirit” in the final product. Consequently, the use of AR as a medium to in actuality innovate on traditional craftsmanship has the opportunity to create a desirability factor to power and maintain its popularity and demand.

This new framework aims to preserve and transmit traditional techniques and styles, preventing complete automation takeover. A key issue is the transmission of labour and skills in relation to the connection between augmented manufacturing and craftsmanship. The high cost and time-consuming nature of craftsmanship pose significant challenges, making it relevant to use augmented reality to ease these issues. Digitising skills and archiving them for easier access can help facilitate labour supply, while holographic guidance connected to digital models can improve efficiency. These advancements can streamline processes, reduce the need for physical documentation, and make the industry more accessible through three-dimensional, intuitive models. Computer vision's archival capabilities further contribute to the preservation and transmission of craftsmanship heritage.

The industry is currently facing a significant challenge due to a shortage of skilled labour and trainees. This issue is particularly critical as the knowledge and expertise of artisans are not being passed down to the next generation, leading to a gradual loss of valuable skills. This situation is crucial when analysing and predicting the future of artistry and craftsmanship, affecting the chances of survival for these professions.

By using augmented reality, young people can gain hands-on training in a virtual environment, allowing them to explore complex techniques and crafts without the need for physical materials. This makes learning more accessible, engaging, and interactive. For example, AR can mimic traditional craftsmanship processes such as woodworking or metal forging, providing real-time feedback and guidance to users, making the learning process more intuitive and less intimidating.

Moreover, AR can enhance the creative aspect of these industries. Younger generations are often attracted to careers that allow for creativity and customisation. AR can facilitate dynamic design processes by enabling users to

visualise and manipulate designs in real-time, fostering a sense of innovation within artisanry and manufacturing. This approach not only modernises traditional methods but also encourages creative expression, appealing to the younger workforce.

AR also promotes collaboration and social engagement, as it enables young artisans and manufacturers to work alongside skilled mentors remotely, allowing them to develop relationships with experts while learning from anywhere in the world.

By integrating AR into the artisanry and manufacturing sectors, these industries can modernise their image, making them more attractive to a generation that thrives on technology and creativity while preserving traditional skills.

One potential solution is the recording, archiving, and transmission of manufacturing skills through the use of Augmented Reality and cloud technologies. This provides a new alternative that can compensate for traditional workflow and allow for a wider audience. Delocalising knowledge and using a cloud-based system could be fundamental for preserving these arts. Additionally, the accessibility to this knowledge could also help underdeveloped communities thrive by providing industrial opportunities that would otherwise be limited.

Increasing the opportunities for people to obtain skills may help areas with severe shortages of skilled labour improve their numbers and subsequently foster local progress and development.

If we focus our sight on the architecture industry, both ideas are also relevant to maintaining artisanry as part of the equation. Apart from the fact that AR can be used for very technical procedures in architecture, its use at a lower level, on the level of craftsmanship, is also very valuable. Architecture suffers, in this sense, the same problems that artisanry does. Although automation and industrial production are the primary sources of elements in architecture, there is still a demand for bespoke crafted parts that can add a sense of uniqueness to the building in the same way hand-making does for artisanry. Therefore, architecture is not immune to the same issues and risks that the craftsmanship industry as a whole faces, so similar solutions can be implemented to alleviate this situation.

Augmented reality is still in its early days as a mainstream technology for craftsmanship. Both hardware and software need improvement in order for the capabilities mentioned here to exist and succeed. The artisan industry is traditionally very conservative and resistant to innovation, priding itself on

manual labour and unique products. Shifting this paradigm will require a sensible approach, and AR will need time to address all possible issues to achieve this goal. If the current trends continue and attract more makers to the technology, it's possible that it will eventually be accepted as a tool that blends digitalisation and manual craftsmanship while preserving the artist's "soul" in the final product. To achieve this, AR needs to become more accessible and practical, supported by cloud technology and user platforms.

Regarding automation, Augmented Reality should be considered as an ally rather than a rival. Automated manufacturing can be viewed as a component of a larger chain that integrates both automation and manual labour, depending on the task at hand. This can involve utilising prefabricated components, handcrafted components, or manual labour as needed. CAM technologies like CNC milling or 3D printing can be combined with Augmented processes to achieve either more complexity or alternative results, promoting, in any case, a more interesting final product. Also, the digital core of both technologies allows for great compatibility from the design to the final assembly. In that sense, AR means a better integration with automation than a potential competitor. Like other technologies, it is more a matter of selecting the right technology through the right use for the right intent than anything else.

Augmented Reality is a valuable tool that can enhance the performance of automated manufacturing, particularly for mass customisation. Mass customisation involves sorting and assembling different objects, which can be quite complex. In the automation industry, normativity and homogenisation are crucial factors in simplifying processes and programming. By combining digital design and augmented manufacturing with automation, the complexity of mass customisation can be reduced. Incorporating human intuition and intelligence can significantly overcome the challenges posed by the non-uniformity of parts and help achieve better results in the manufacturing process. A human worker guided by an AR device can easily adapt and follow basic instructions to assemble similar but different parts. This concept can also be applied to the assembly and the finishing or preparation of the CAM-made components. The use of augmented reality in combination with automation enhances both and can solve issues while allowing for a better workflow, efficiency, or design. Even the human factor can be added to the process as parts can be finished by humans and AR, allowing for unique finishing or combining fully hand-made components that create a balanced mix between the "soulless" and the "handmade".

The manufacturing industry faces significant challenges in terms of improving quality and efficiency, which cannot be solved without the integration of automation. It is crucial to continue developing these technologies while also integrating digital design. Incorporating augmentation into the equation can enhance the industry, allowing for development that improves quality and results while maintaining traditional manufacturing qualities. Therefore, combining augmented manufacturing and automation can help both technologies reach their maximum potential.

Automation has played a fundamental role in modern industrialisation by improving the quality, quantity, and efficiency of products. This is also true in architecture, where prefabrication has revolutionised the way we build. However, mainstream architecture is currently suffering from homogenisation, and the inclusion of augmentation in architecture can help prevent this. It can lead to a more creative and digitally connected manufacturing environment where artisans can take their traditional place and be enhanced by automated manufacturing. Furthermore, the idea of a collaborative workflow involving both humans and robots to accomplish a task results in an intriguing and innovative alternative. Precision and efficiency can be achieved simultaneously with adaptability and human intuition. This could pave the way for a completely new approach to manufacturing and even a new language, as the outcome would be a seamless hybrid that blends automated manufacturing and craftsmanship.

The Augmented Age is defined not only by Augmented Reality technology but also by an entire family of different technologies. Artificial Intelligence, Machine Learning, Computer Vision or mechanical skill-enhancing hardware will be part of many different ways of the labour fabric and mainstream society. Humans will enhance their performance in multiple ways, but augmentation will not be restricted to this area only. Augmentation will also play a fundamental role in our day-to-day experience, affecting the way we as humans interact and even how we perceive the urban environment.

This thesis mainly focuses on the concept of augmented skills and cognitive processes. However, it is crucial to consider all possible scenarios, ramifications, and challenges that a fully immersive society could bring. The risk of a fully simulated society is real, and to discuss, predict, and prevent this scenario, we need to approach the matter meaningfully and sensibly.

When we consider where this technology should go and how it should affect our lives, we need to establish that the new environment should propose fair and democratic access. The community should have the power, and institutions or corporations should not be the only ones in control. The digital environment and the neutrality of the internet should be enforced and reinforced to create a healthy Extended Reality. This environment should support the freedom of information and action within the limits of the common law. Otherwise, there is a risk of amplifying the subsequent problems that big tech platforms are already facing. These problems include censorship, political biases, fake news, digital human exploitation, and restricted access to fair and accessible information.

Augmented Reality offers exciting opportunities for craftsmanship and manufacturing but also presents significant challenges and ethical concerns. When AR overlays digital information onto physical spaces in urban areas, privacy concerns arise due to potential surveillance risks and data privacy issues. Individuals may inadvertently expose personal data as AR devices capture and analyse their surroundings, blurring the distinction between public and private spaces.

The digital divide is another critical challenge. AR can democratise access to knowledge by providing immersive, remote learning opportunities, but it may also worsen existing inequalities. Developed regions with advanced infrastructure can take full advantage of AR technologies, while underdeveloped regions may fall behind, deepening economic disparities. Moreover, older generations may struggle to adopt these technologies, widening generational gaps in skill acquisition and access.

Cultural implications become particularly complex when traditional crafts are digitised and augmented. AR has the potential to preserve endangered artisanal skills, but it also risks commodifying and oversimplifying cultural practices. Craftsmanship, which is often deeply rooted in local traditions and identities, may lose its authenticity when transformed into a digital format. The nuanced knowledge and soul of handmade craftsmanship might be diluted as these practices become more easily replicated and distributed in augmented forms. This raises questions about the preservation of cultural heritage versus its commercialisation in a digital age.

From the perspective of this thesis, it is crucial to establish clear rules governing the recording, storage, and delivery of information, particularly when it comes to

traditional cultural heritage and skills. Issues such as colonisation, cultural biases, and gender discrimination are highly relevant and must be addressed in the platform environments where archiving takes place. To ensure fair access and distribution, as well as the recording of these skills, the platform environments must provide fair systems for generating data that do not exploit people, accessible interfaces that allow for inclusion, and account for different disabilities that users may have. Moreover, the information must be delivered in a way that is not restricted to developed countries, as one of the primary goals is to revitalise decaying communities.

It is essential to thoroughly evaluate the social impact of any new technology to ensure its positive adoption by society. This evaluation should consider all possible implications, from purely technical to social or philosophical implications. Extended Realities have the potential to profoundly change parts of our society, so a deeper and more meticulous consideration is required.

Regarding hardware and software, augmentation tools have the potential to enhance both cognitive and physical skills. Although these technologies are currently in their early stages, there is a clear path of improvement that we can predict. Hardware and software will continue to progress and achieve the goals that are expected from the speculations.

Physical augmentation involves various considerations, with mechanical exoskeletons being a crucial component. These devices are already aiding in industrial tasks and are anticipated to enhance the abilities and quality of life of industrial workers across various industries and workplaces. Exoskeletons can boost a worker's precision and strength and enable individuals with motion disabilities to perform previously impossible tasks. When integrated with other technologies, such as automation, exoskeletons have the potential to enhance and streamline assembly lines and industrial processes. It is expected that humans, exoskeletons, and robots will be fully integrated in the near future, resulting in a more diverse and efficient process driven by digital tools and executed through a seamless chain of automated and hardware-assisted tasks.

Cognitive augmentation is set to revolutionise the manufacturing industry by making use of visual assistance, computer vision, and AI technology to optimise workflows. With the help of AR, workers will have access to real-time information that will enhance the connection between the design process and the manufacturing process. This will seamlessly integrate digital design with physical

product creation. Additionally, the thesis mentions that workers will have more accessible and flexible training and skilling opportunities, thus expanding the pool of available skilled workers. This will enable workers to perform tasks without extensive training, and skilled workers will be able to perform more complex and precise tasks than before the advent of augmentation technology. The real-time use of AI can have a valuable impact on complex tasks since decision-making can be assisted by trained intelligence to provide better results. In addition, when combined with computer vision, AI can predict problems or prevent accidents by having a wider awareness of the surrounding environment. As an expected result, augmented workers will be able to perform better and safer, increasing the overall productivity in all industries.

In terms of artisanry, craftsmanship and architecture, the revolution through both physical and cognitive augmentation will have a noticeable impact, as both industries are heavily affected by a shortage of workers, particularly skilled labour. Augmentation can simplify tasks that are difficult or require complex media to be performed. It can assist with tasks such as formwork assembly, reinforcement assembly, or heavy component transportation, making the worker's performance safer and faster. Whether physical or cognitive, augmentation can also establish a stronger connection between digital models and manufacturing processes. As mentioned in the thesis, this can help preserve traditional arts like carpentry or forging and integrate them seamlessly with computational design and mass customisation approaches.

Augmented Reality has the potential to bridge the gap between tradition and innovation in architecture, design, and manufacturing. By seamlessly integrating digital tools, automated processes, and manual craftsmanship, AR creates new opportunities for creativity and collaboration while also preserving cultural heritage and artisanal knowledge. However, these technologies also present significant social and ethical challenges, such as ensuring equitable access, protecting privacy, and maintaining cultural authenticity. Addressing these issues requires careful governance and inclusive design. Despite these challenges, the potential of AR to tackle labour shortages, enhance skill development, and combine automation with human expertise is undeniable. When used alongside other emerging technologies like AI, machine learning, and exoskeletons, AR can provide a more comprehensive approach to industrial processes, promoting efficiency, personalisation, and a renewed appreciation of craftsmanship. Ultimately, realising these benefits depends on a conscious effort to create fair digital

environments, empower communities with new skills, and ensure that human creativity, diversity, and cultural values remain central to our augmented future.

5.1. Author's Position:

This thesis presents a comprehensive evaluation of the possibilities that Augmented Reality and, in general, the integration of architecture into Mixed Realities could ultimately offer. As this topic exists within a rapidly evolving environment at the time of writing, some ideas or concepts have developed and even completely expired during the elaboration of this text. Others, conversely, have been reinforced and extended. Particularly since the surge of AI technologies in recent years, there is a clear trend indicating significant changes across all industries, including architecture. We are witnessing increasing automation in drawing and project planning, aided by MLL models in design. The profession is, in some ways, at risk of losing its unique fusion of creativity and engineering. Preserving the human factor in the industry is essential if we want to protect architecture from becoming a generic producer of inhabitable spaces and cities. In that sense, the importance of Augmented Reality is considerable, as it is a technology that directly bridges the physical and digital worlds.

Although this thesis seeks to be as subjective and partial as possible, a reasonable bias is anticipated as it is a part of human behaviour, even in the most scientific environments. As part of these conclusions, the author considers it essential to establish his position and define his personal opinion on this matter. This aims to be an exercise in transparency and clarity, as the following lines hope that the reader can better understand the mindset from which all these ideas are generated. At the end of the day, this thesis has a very strong conceptual component and aims to establish ideas rather than merely describing data. In a way, it seeks to serve as an early manifesto about architecture in the context of mixed realities.

The first position the author will define is his vision of digital technology and its implementation in architecture. Generally speaking, the implementation of digital technologies has been positive for architecture, as it has clearly expanded our possibilities for design. Without digital architecture, we could not have many of the exceptional buildings that have been developed over the past twenty years. Additionally, digital technologies have, in many ways, democratised access to the industry for many smaller players, as they have allowed for more efficient

workflows that were previously the domain of large companies. However, this implementation has its downsides; for instance, technologies like BIM have promoted a more predefined design approach, resulting in an increasing homogenisation of architecture, particularly in housing and retail. This dual-sided situation, where digital technology fosters creativity while simultaneously promoting homogeneity, is why the author adopts a very cautious approach regarding how we should continue to implement and engage with mixed realities and AI environments in the future.

When examining the Mixed Reality environment, it becomes evident that there are many promising opportunities for the continued development of this industry. The significance of this technology and its impending integration into our society highlights the urgency for architects to adopt and incorporate it effectively. Mixed Reality will necessitate the design and development of spaces that exist not only in the virtual realm but also interact with the physical world in innovative and unforeseen ways. Therefore, it is crucial for architects to engage with this technology. To remain relevant, designers must push the boundaries of their field and stay at the vanguard alongside other participants. The architectural paradigm will inevitably need to evolve, as physical spaces will no longer be the only form of space we consider. The principles of architecture must adjust to accommodate a hybrid environment that addresses both reality and virtuality with equal expertise.

This shift is particularly important, as digital design and technologies related to Mixed Reality should be integrated into the early stages of architectural education and become a fundamental part of every architectural office's daily operations. Embracing digital design and these emerging technologies will be essential for the survival of the profession, especially as automation continues to transform the traditional construction industry and streamline standard design workflows. To thrive in this new era, architects must embrace change and adapt to the evolving society that is on the horizon, regardless of personal preferences.

Regarding Augmented Reality, its role will be essential in the transition to a hybrid environment, as it serves as the perfect interface to connect both physical and digital spaces. Although this thesis focuses on the influence of craftsmanship and artisanry on this technology, AR will also be fundamental to experiencing the "phygital" built environment. It is important to recognise that digital entities will populate our cities and spaces, and architects should play a significant role in their development and design. The training we possess in understanding and proposing

spatial experiences should extend to the upcoming Mixed Reality scenario. While this technology and these types of experiences are still in their early stages, we can already glimpse the future.

For several years, users have been able to experience early instances of this new form of architecture and built environment through smartphones and other portable devices. Increasingly, we see all sorts of games and events using the city as a playground. With the evolution of smart glasses and similar hardware, this trend is expected to grow in a relatively short timeframe. As a result, it is conceivable that at some point in the near future, the distinction between reality and virtuality will be completely integrated, allowing for a seamless transition between the two for users.

When focusing on this thesis topic, the manufacturing process will likely follow a similar path regarding adoption and accessibility. In fact, it is plausible that it will be integrated even faster, as the complex equipment required does not differ significantly from other tools currently used in manufacturing, particularly in the building industry. There are already examples of augmented reality being used to track progress and compliance in construction projects through portable devices and QR codes. Additionally, AR can visualise potential conflicts when installing complex systems within a building. Virtual Reality and Augmented Reality have been utilised for years as visualisation tools for clients, allowing them to visit a plot and see the future building through this technology. In terms of the core aspects of the construction process, AR will facilitate tasks like steel reinforcement assemblies for concrete. Furthermore, as mentioned in this thesis, the use of AR in construction will enable non-specialized workers access to more tasks, serving as a medium to guide them through complex processes with minimal previous training.

Additionally, AR has the potential to enhance precision, achieving a higher level of supervision and quality control on-site and on demand. The seamless integration between digital and physical environments in the building industry also presents an interesting opportunity to coordinate human and robotic labour. A shared digital environment could effectively direct actions for both parties. Simultaneously, computational and digital design will encounter fewer obstacles, as the complexities of various assemblies or processes can be addressed through real-life guidance from AR devices and their optimised workflows. Augmented reality in the building industry is likely to have a positive impact, allowing for improved operational processes and more democratic access to various tasks.

However, we must also exercise caution; if not properly regulated or used, it could lead to outcomes we as creators should avoid. Just as AI can homogenise design, leading to identical buildings, the automation of manufacturing and construction processes could result in standardised materials, techniques, and finishes. In this context, the role of craftsmanship and artistry is crucial, serving as the key to preserving uniqueness in the architectural landscape.

The craftsmanship and artisanry, which serve as the main theme of this work, represent a critical area where the implementation of Augmented Reality can play a fundamental role. Traditionally, these arts have taken a conservative approach to adopting new technology; however, it is essential for these professions to embrace new techniques. The refusal to accept technologies like 3D printing may hinder their progress in the long term, as they will struggle to adapt to emerging trends.

I personally agree that the "human factor" offers inherent value, giving a unique quality to every object. Nonetheless, I understand that this uniqueness can manifest in various ways. Therefore, it is important to recognise that the inclusion of digital technologies can positively impact the craft, enabling results that may not be achievable otherwise while still allowing crafters to add their personal touch. Moreover, technologies like 3D printing can sometimes produce a "touch" similar to traditional methods, especially when used with materials like clay or FDM production; the resulting components may exhibit slight variations influenced by material properties and environmental conditions during production. Similarly, utilising AR to create handmade pieces does not diminish the value of craftsmanship; rather, it enhances the possibilities for design and material applications. As described in this work, AR can integrate digital design with manual crafting, preserving the "human factor" throughout the making process. Additionally, it can serve as part of a broader strategy to record and preserve processes and traditional techniques for future generations. Augmented Manufacturing should be understood as a technology that can enhance the craft and keep the profession relevant and alive. However, this technology is not free from potential challenges. When implementing these ideas—especially when used as a source of knowledge—it is crucial to respect the traditional rights of individuals to own their heritage. Ensuring that traditional techniques are not commodified and that information is shared respectfully is vital.

Furthermore, these technologies are intended to help artisans thrive, not to serve as a means of mass production that replaces local labour. We must adopt an

approach that advances the industry while remaining fair and conscious of cultural heritage and environmental considerations.

The integration of augmented reality and other digital technologies into architecture offers a significant opportunity to broaden the creative possibilities within the profession, make complex workflows more accessible, and preserve valuable craft traditions. However, it also highlights our duty to protect the uniqueness of architectural expression and the cultural heritage embedded in time-honoured techniques. By combining human craftsmanship with the precision and guidance provided by digital tools, we can ensure that the “human factor”—the essence of originality and artistry—remains central to our built environments. Striking this careful balance will enable architecture to maintain its distinctive identity while evolving in a sustainable and equitable manner as we navigate this transformative era of mixed realities.

6. Conclusions

The incorporation of Augmented Reality technology in architecture and craftsmanship has brought about a new age of design, manufacturing visualisation, and interaction, which has the potential to fundamentally change traditional methodologies and workflows. This thesis conducts a methodical study of the effects of AR applications in these fields, with the aim of outlining their impacts on enhancing design processes and promoting a more direct engagement with craft. This work utilises a rigorous methodological framework, combining empirical research with theoretical analysis to explore how AR tools facilitate a more immersive and intuitive approach to architectural design and craftsmanship.

The study cases provided in this work define a series of experiments conducted to explore the potential advantages and disadvantages of using augmented reality in architecture. The intentional selection of a catalogue of traditional materials in architecture is also part of the methodology that settles the study framework. By analysing concrete, wood, metal, ceramics, and plastic, the principal and most used materials are evaluated, and a comprehensive view of the possible uses of augmented reality can be given.

Along with the study cases, using the values system as a methodology to understand the study cases adds to the holistic approach necessary to measure the possible impact of AR technology on the built environment. In that sense, although not quantifiable, the values serve as a checklist of areas of relevance for the understanding of the topic. They define qualities that are valuable and desirable for the architecture and craftsmanship of the future.

However, all the projects used as study cases do not live in a vacuum but are surrounded by a very novel and dynamic environment that can rapidly change and deem obsolete some ideas. Particularly in the technological area, it is expected that noticeable progress will occur in the coming years, so affirmation related to these aspects is firmly based on knowledge created during the experiment. Moreover, due to this same factor, some of the ideas that comfort the conclusion have a speculative nature, as the pace at which this technology evolves requires thinking in that sense.

The findings of this thesis should be regarded as a critical comprehension of the subject rather than an absolute mathematical truth. The research cases present a multifaceted perspective on the matter that takes into account three main concepts that define the impact of technology - craftsmanship, automation, and augmentation. These ideas are evaluated to draw a conclusion on how AR technology will affect them and, consequently, the architecture industry's manufacturing process. The results, therefore, are arranged in relation to these three topics and substantiated by the Values criteria to form tangible knowledge that can illustrate and speculate about the future from a solid academic perspective.

6.1.Result 1: Craftsmanship and Augmented Manufacturing.

One of the main purposes of this thesis is to evaluate the impact of Augmentation technology on manufacturing processes. It explores the use of holographic guidance, projections, and on-screen guidance as alternatives to traditional physical drawings or scaled-down models. These digital solutions offer interactive and dynamic documentation, making information more accessible to non-professionals and individuals without drawing reading training. Augmented representations can provide live guidance and are responsive to the user's surroundings through computer vision. Ultimately, these advancements can shift guidance materials from static and passive to active and interactive.

The emergence of augmented reality brings forth new possibilities that can help address existing issues in the design profession while simultaneously creating new opportunities for enhanced collaboration between clients, designers, and manufacturers. In that sense, the study cases presented in this thesis exemplify some of these possibilities by addressing new approaches to traditional materials through computational design and Augmented Manufacturing.

A connecting factor that supports this angle is the fact that all the study case prototypes were developed by users with no previous manufacturing experience or training. In a matter of weeks, they were able to master these materials and achieve physical tests by using AR. This fact demonstrates that, at the very least, AR technology can be used as a more efficient way of training new craftspeople and delivering a more hands-on learning process.

It's important to note that traditional materials such as wood, clay, concrete, and metal were used in these experiments. Augmentation techniques are not limited to new materials; they can also be combined with traditional materials and techniques. Projects like Diffusion and Mindcraft employed common techniques such as forging and steam bending, which are commonly used in manufacturing and craftsmanship. Even CeARamics, while taking a more innovative approach, still incorporated traditional processes using stoneware clay and manual weaving methods. These examples show how AR can be seamlessly integrated with traditional and heritage techniques while also opening up opportunities for new materials and approaches in manufacturing. Human value is preserved whether the goal is to maintain traditions and heritage in craftsmanship or to innovate with new materials and manufacturing techniques.

In terms of architecture, the case studies Difussion and ReBent take a more direct approach, proposing techniques that go beyond decoration and focus on structural behaviour. This is interesting because both projects address areas where the shortage of skilled labour has a significant impact. The case of the Diffusion project goes beyond traditional forged metal joinery by suggesting that traditional metalworking tools can be digitised and integrated into the Augmented Manufacturing process. This enables people without metalworking skills to access these techniques, thus widening the pool of scarce metal workers. Moreover, the assembly process can be extended to rebar assembly or metal structure assembly. The ReBent project goes even further by addressing two main issues in concrete construction: sustainability and access to skilled formwork manufacturing labour. In terms of sustainability, the ReBent project uses Augmented Reality to change the approach to formwork making, thereby reducing wood waste and adding flexibility to concrete casting. The use of AR in both cases not only allows untrained workers to perform complex processes but also leads to more optimised versions of traditional construction material techniques.

In terms of craftsmanship skills and preservation of heritage techniques, the proposal by CeARamics demonstrates some of the potential of this technology, particularly with the growth of computer vision technology. The project presents the idea of recording skilled artis weaving styles and then storing them in the cloud and having them ready to be delivered through the platform via AR guidance to the final crafter. Although not the main goal of this project, this idea proved that the recording of skills is something possible and a way to preserve knowledge through time. This represents a promising concept as one of the reasons for the

decay of some craftsmanship areas is connected to the lack of disciples from the next generation.

Lastly, and looking at new possibilities, the direct connection from digital design to less traditionally manual-made materials has the potential to enhance craftsmanship and manufacturing. The flow morph project, as the main example from the study cases, proposes an alternative approach by combining a material like plastic with handmaking techniques. In that sense, a material that is mainly used in automated industrial processes and 3D printing moves towards a more human-sensitive area where automation is replaced by computer-assisted human intuition. This concept reinforces the value of materiality while at the same time settling the human value as the centre of Augmented Manufacturing.

The results related to craftsmanship and manufacturing are crucial for understanding the impact of augmentation technologies on the future of architecture. The seamless integration of these techniques presents a new scenario where traditional skills can be not only preserved but enhanced. Both traditional and new materials offer a wide range of opportunities for the future of architecture and craftsmanship. Additionally, the preservation and passing on of skills could help prevent the loss of traditional knowledge and skills, which are important for our culture and traditions.

6.2.Result 2: Automation.

The implementation and increasing use of automation in architectural manufacturing and craftsmanship is not only positive but necessary to adapt to the shifting and shrinking workforce supply. Automation may appear as a competitor to craftsmanship and artisanry, but if used sensibly, it can be a strong ally. It can improve and optimise processes, enabling the profession to make the best use of resources and costs. Augmentation technology can play a fundamental role as it bridges the gap between hand-made and machine-manufactured products. For instance, CAM manufacturing can be converted into AR-assisted manufacturing, which offers a way to translate digital design into products. For example, from the CAM perspective, in a typical case, the robot follows a numerical code to perform a series of tasks that will manufacture the digital product. From the AR perspective, an AR platform and hardware interface can guide a human with a

high level of precision to perform the same tasks and movements prescribed by the CAM logic but done by hand. Both options result in similar objects that comply with the digital design to the desired standard. However, the CAM-made object will always be identical to the previous and next. At the same time, the AR-made model will be slightly different due to the inherent variability of human accuracy. This difference could be a positive or negative factor, and its correct use will be up to the designer or maker to make sense of it. Additionally, the complete integration of digital language in both techniques can facilitate a more streamlined collaboration between machines and humans. In essence, both compatible technologies can help improve quality efficiency and digital integration while avoiding the loss of uniqueness or human labour in manufacturing processes.

The thesis study cases explore the impact of automation and how it can be combined with Augmented Reality. They focus on areas where automated manufacturing cannot achieve the same level of outcomes as those provided by human intervention. Some aspects of these examples are already based on automated techniques such as 3D printing, which enhances the results or becomes necessary for fabrication. Two projects, ReBent and CeARamics, use 3D-printed joinery to achieve the necessary formwork. In the case of ReBent, the plastic brackets used to attach the rods to the PVC core are part of the computational design and adapt to different necessities across the structure, changing the shape and disposition of hooks and thicknesses. The following text is a response regarding material and performance optimisation. In this case, unique brackets are produced using a PLA printer for the prototype. For CeARamics, a similar approach is taken, but the 3D-printed brackets are reusable across the AR for multiple system components. Both projects rely on automation to some extent to reduce costs and optimise the process. Material manufacturing aside, automation is used to produce the mentioned pieces, allowing for a more adaptable and intuitive assembly system.

From the complementing perspective, Difussion Mindcraft and FlowMorph exemplify the capacity of handmaking to outperform automation in some particular cases. The complexity in the assembly and in the making of these projects promotes the use of human crafting as the programming and the intelligence necessary for the production would be excessive and impractical. In the case of Difussion, the secondary components could be produced by automated processes in rod bending machinery, but the twisted joinery and the posterior assemble would present an enormous challenge as both require a high level of

intuition and adaptability to correctly perform the task. The unpredictable behaviour of forged metal and the natural deformation of the pieces during the cooling would render the task almost unreachable, at least for the current level of robotic technology. In fact, the unpredictable material behaviour in these three examples is the principal scenario where the human has, at this time, a clear advantage against the machine. The project Flowmorph, in that sense, is the most defining case as the behaviour of the thermoplastic during the stretching process is completely unpredictable, and continuous adjustments were required to match the holographic model during the manufacturing process. Human intuition was essential to overcome these challenges and successfully produce the prototype.

On the assembly logic, the project Mindcraft and, up to a level, Difussion, represent another area where the human performance guided by AR technology has a competitive advantage over the analogous automated process. Particularly, for the Mindcraft process, the assembly of the different sections into which the prototype was divided required a very particular non-linear sequence. That meant that some of the slats were located using either previous slats as a reference or interlocking the new slats in between previous slats. This task, together with the natural spring back of the wood after the steam bending procedure, required an active use of human intuition to adapt the new components to the deviation and connect all components as expected. A similar but less determinant situation was also observed while manufacturing the Difussion prototype. The natural deformation of the metal, both after cooling or caused by the spring back after the cold bending, caused a series of minor inaccuracies a robot could not solve while the human could quickly react to overcome them.

Some parts of the manufacturing process could have been carried out by machines to improve the synergy between humans and machines. For instance, in the game Mindcraft, the metal frame was digitalised and integrated into the augmented reality logic. However, it could have been possible to replace this task with robots or other automated machines, which would have improved performance and accuracy. Nevertheless, human skills would still have been required to fix the slats correctly. The combination of both techniques presents an interesting area for further research.

After analysing the presented case studies, it can be concluded that automation and augmented manufacturing are compatible technologies that, when combined in a sensible way, can enhance each other's results. The potential of these technologies to improve performance and preserve a certain level of human touch

can benefit the architectural and craftsmanship industries. They can provide a more digital and efficient approach while maintaining the heritage of human labour and craftsmanship. However, this field still needs further development, as there are not enough tested examples of the combination of both technologies to be fully implemented into the mainstream industry.

6.3.Result 3: Augmentation.

Throughout history, technology has evolved to augment human capacities in various forms. The emergence of Augmented Reality technology has introduced a new form of augmentation that bridges the gap between the physical and digital worlds. This technology enables a complete connection between the two domains. From a manufacturing perspective, the significance of AR technology becomes apparent. Its implementation can enhance the performance and efficiency of builders and craftspeople in multiple ways. AI can be used to optimise building processes. At the same time, physical augmentation tools such as exoskeletons and AR can be utilised to revolutionise the future performance of the workforce and, therefore, the building and manufacturing industries. Through the study cases exposed in this thesis, there is a clear set of results that address mainly the idea of augmented reality for making and building tasks. However, the entirely digitally generated elements and the interactive design were also an area of interest as they cover other forms of augmentation.

In construction, projects use different techniques for making and assembling components. Four projects - Difussion, Mindcraft, CeARamics and Rebut - employ a similar logic. They first make the components and then assemble them using AR guidance, proposing prefabrication based on AR guidance that produces sections or components, which are later assembled. However, the case of FlowMorph is slightly different, as component making and assembly are the same tasks. This project uses a continuous 3D printing-inspired logic, resulting in a monolithic building with no visible joinery or panelling despite being made up of many elements. These two approaches show that traditional methods can be combined with augmentation and that more innovative ideas can also be implemented.

Upon conducting a deeper manufacturing analysis, it was found that Flowmorph stands out from the rest in a relative sense. The difference lies in the fact that

Flowmorph doesn't require any additional materials or tools. The project is entirely built by hand, with the aid of augmented guidance. This presents an interesting concept as it has an innovative approach by dealing with new materialities and geometries while also drawing from vernacular techniques such as adobe building. In the case of the other four, the situation within the current building industry is more defined. Still, a small difference between the four can also be found. While Rebent and CeARamics face a more revolutionary making technique, Difussion and MindCraft remain inside a more conservative crafting approach.

In the case of Rebent, they use a traditional material like concrete but adapt it to a more modern digital understanding. They propose the removal of traditional formwork as well as a higher level of optimisation through pre-bent components that act as a lightning-lost formwork and form-finding system. A similar concept is the one developed by CeARamics, where the AR is used to assemble a three-dimensional formwork for clay dipping. This challenges the traditional casting or sculpting methods. Also, due to the complexity of the components, the AR helps to assemble the overall façade wall. In both cases, the outcome is a design that incorporates digital techniques to enhance its value while maintaining the importance of human value at the core of the manufacturing process. Additionally, materiality plays a crucial role as both explore new ways of mould-less casting.

Alternatively, both Diffussion and Mindcraft have similar intentions that are based on traditional techniques. Mindcraft uses steam bending, while Diffussion uses cold bending and forging. The interesting aspect here is that augmentation demonstrates that a fully digital design based on agents can be translated into traditional making seamlessly through the use of AR. Although both projects explore highly complex aesthetics, the use of traditional methods serves as a demonstration that, in the same way, AR can be used to integrate new languages to achieve more traditional results. In that sense, the concept of conserving heritage through AR is also demonstrated, at least to a certain extent.

Outside Augmented Manufacturing, the study cases also present other forms of augmentation. The Flowmorph and Mindcraft both present an augmented interactive AR design system where the user can interact through AR with the generative agents to define and improve the design. This adds to the idea of human touch but from a digital perspective as the autonomously generated design can be participated by humans. For the Rebent project, the augmentation comes from two different areas. On the one hand, the project uses computer vision to record and define bending qualities to obtain data to generate virtual models empirically. This

data is then used for the second stage, where the user can generate interactive AR simulations to visualise the natural material assembly of a predefined shape. The CeARamics project heavily uses computer vision to record and rationalise weaving styles and patterns that are stored through a digital app.

All these different alternatives of augmentation add to the overall goal of enhancing the current capabilities that can be used in non-augmented processes. In all cases, the augmentation provides access to better and deeper integration with the digital side, more advanced manufacturing results, and better data acquisition and management. They also serve to consolidate the idea that augmentation can both provide more advanced skills to trained users and basic to advanced skills to the untrained workforce. Digital augmentation for manufacturing is still in its early years, but as demonstrated by the study cases, there is a significant potential to be released. Traditional techniques and new techniques have a space within this technology to grow, and future labour will have access to a new level of fabrication based on more data, more optimisation and more accessibility for the user.

6.4. Comments on the results.

This thesis thoroughly investigates the potential of Augmented Reality technology in the fields of architecture and craftsmanship. It highlights how this technology has the ability to transform design, manufacturing visualization, and interaction, and revolutionize traditional workflows. Through empirical research and theoretical examination, this analysis has shown how AR enables a more immersive and intuitive approach to design and craft, enhancing traditional methodologies and workflows.

Through a meticulous examination of AR applications across various traditional materials such as concrete, wood, metal, ceramics, and plastic, a spectrum of both opportunities and challenges has been unveiled. The compatibility of AR with these materials validates its adaptability to traditional practices and its potential to innovate and extend the boundaries of architectural design and craftsmanship. The study cases underscore the role of AR in democratising design processes, enabling individuals without prior manufacturing experience to master complex materials and techniques, thereby nurturing a new generation of craftspeople.

Furthermore, the integration of AR with traditional craftsmanship practices and its convergence with automation technologies presents a nuanced narrative of coexistence and mutual enhancement rather than competition. This synergy between human touch and machine efficiency encapsulates a future where craftsmanship is preserved and evolved, fostering a blend of heritage and innovation.

However, the dynamic and rapidly evolving nature of AR technology, coupled with the speculative nature of some of the findings, necessitates a cautious interpretation of the results. The thesis acknowledges the provisional character of its conclusions, inviting ongoing inquiry and adaptation as technological advancements continue to unfold.

The findings of this thesis underscore the pivotal role of AR in shaping the future of architecture and craftsmanship. As we stand on the cusp of a technological renaissance, it is imperative to recognise that the integration of AR into traditional practices is not merely an option but a necessity to address the evolving demands of the industry. However, it is also crucial to approach this integration with a measured and thoughtful perspective, acknowledging the speculative nature of

certain conclusions due to the rapid evolution of technology. As AR continues to mature and its applications broaden, its potential to enrich the architectural and craftsmanship landscapes will undoubtedly expand, heralding a future where tradition and innovation coexist in harmony, propelled by the transformative power of Augmented Reality.

References

In an architectural thesis, the bibliography is not just a formality but a crucial component that supports the credibility of the research. The selection of authors within the bibliography is crucial as it demonstrates the depth and breadth of the investigation. A well-curated bibliography serves as a roadmap that guides readers through the research's thoughts, theories, and practices. It reflects the researcher's thorough engagement with the subject, demonstrating an awareness of its historical context, current debates, and emerging trends.

The choice of authors is an essential part of the process as it directly influences the direction and validity of the thesis. The authors and works included should be purposefully selected, ensuring they contribute meaningfully to the thesis' objectives. A diverse range of voices and schools of thought should be represented, ensuring a comprehensive and multi-faceted approach to the research question.

It is important to recognise that not all references carry equal weight or relevance. Primary sources are invaluable in providing direct, unfiltered insights. Secondary sources offer interpretation and analysis, aiding in situating the primary evidence within a wider academic context. Tertiary sources are less critical in a research-intensive document like a thesis. The bibliography should reflect a balance between historical foundations and contemporary discourse, ensuring that the thesis is rooted in a rich historical context while remaining relevant and forward-thinking.

In summary, the bibliography in an architectural thesis is much more than a list of references; it is a strategic compilation of sources that collectively support and enhance the research. The meticulous selection of authors and types of references is essential in crafting a thesis that is not only academically robust but also reflective of the diverse and dynamic nature of architectural discourse.

This bibliography has been meticulously curated and divided into three sections, each serving a unique purpose in the architectural discourse of this thesis. The multidimensional approach adopted in the study encompasses a broad spectrum of perspectives and disciplines.

The first section, "Thinking Authors," focuses on the deeper layers of sociopolitical and philosophical thought that underpin the thesis. These authors have been carefully chosen for their profound contributions to our understanding of the complex interplay between society, space, and architecture. Their works not only present theoretical ideas but also challenge and expand our perception of the built environment in relation to human experience and societal structures. The inclusion of these thinkers is crucial as they provide the ideological framework that shapes the thesis, enabling a rich exploration of architecture's role and impact in a broader socio-cultural and philosophical context.

The second section, "Technology Authors," is dedicated to unpacking the state of the art in augmented reality technology, a key focus of the thesis. The authors featured here are at the forefront of technological research and innovation. Their works offer insightful analyses of current technologies, their capabilities, and their future trajectories. This section is not only a repository of technical knowledge but also a critical examination of how these technologies can be harnessed within the field of architecture. The insights gleaned from these authors are instrumental in evaluating the potential of augmented reality to revolutionise architectural design, visualisation, and interaction.

The third and final section, "Academic Authors," is the foundation of the thesis. This collection consists of scholarly works that provide empirical evidence, historical context, and critical analysis, grounding the thesis in a solid academic foundation. These authors contribute significantly to the thesis by validating the arguments and hypotheses presented. Their research and findings offer a necessary layer of academic rigour, ensuring that the thesis is conceptually innovative and methodologically reliable. The inclusion of these academic works ensures that the thesis is anchored in well-established knowledge while also contributing to ongoing scholarly discourse.

Together, these three sections of the bibliography create a rich base of knowledge containing theoretical, technological, and academic perspectives. Each section complements the others, creating a holistic and comprehensive foundation for the thesis. This organisation reflects a deliberate and strategic approach to research, ensuring that the thesis is a well-rounded and thoroughly substantiated piece of academic work.

Thinking authors.

Daniel Bell

-Bell, D. (1973). The Coming of Post-Industrial Society: A Venture in Social Forecasting. Basic Books.

Daniel Bell was a prominent American sociologist, writer, and professor who gained recognition for his extensive research in post-industrialism, information society, and cultural analysis. Born in 1919, Bell's intellectual journey spanned several decades, during which he significantly influenced sociological thought. He is primarily known for his groundbreaking work "The Coming of Post-Industrial Society," where he analysed the transformation of economies from manufacturing-based to ones centred around information services and knowledge. This work anticipated many aspects of contemporary society, including the rise of a service-oriented economy, the importance of theoretical knowledge, and the impact of technological advancements. Bell's diverse interests, including the sociology of science, education, and forecasting social and cultural trends, positioned him as a key figure in 20th-century sociological thought. His works remain relevant in discussions about the challenges and complexities of modern societies.

The identification of the socioeconomic areas and their potential problems and evolution is fundamental to defining the framework to understand the influence of digital and XR technologies and how they can change and evolve society. Its work is essential as is used as the main guidance to define the thinking methodology of the thesis.

Mario Carpo

-Carpo, M. (2011). The Alphabet and the Algorithm. MIT Press.

-Carpo, M. (1992). The digital turn in architecture 1992 - 2012. John Wiley & Sons.

-Carpo, M. (2017). The Second Digital Turn: Design Beyond Intelligence. MIT Press.

Mario Carpo is a renowned architectural historian and theorist with expertise in the history of architectural theory and digital design. His work explores the relationship between architectural design, technology, and cultural history, with a particular focus on the digital era. Carpo analyses how digital technologies are transforming the practices of architectural design and the production of architectural knowledge. Carpo is known for critically examining the implications of computational design and digital fabrication in architecture. His notable works include "The Alphabet and the Algorithm" and "The Second Digital Turn," where he discusses the evolution of architectural design in the context of digital technologies. Carpo's research spans from the Renaissance to the present, providing insightful analyses of the impact of technological innovations on architectural form and theory. As an educator and prolific writer, Carpo has made significant contributions to understanding the intersection between digital technology and architectural practice. He is an influential figure in contemporary architectural discourse.

In this sense, the influence of Carpo's work is of great relevance as it not only defines the context for digital architecture and its connection to traditional arts and styles but also serves as the translator of the "Search, do not Sort" concept into the architectural environment. This constitutes a valuable contribution as it sets the base for a whole new methodology of augmented architectural practice.

Jean Baudrillard

-Baudrillard, J. (1988). Simulacra and simulation. University of Michigan Press.

Jean Baudrillard was a French sociologist, philosopher, cultural theorist, and writer. He is widely recognised for his profound and often provocative analyses of contemporary society and culture. Baudrillard's work delves deep into consumerism, media, and technology and their impact on modern life. He is best known for his concept of "simulacra and simulation." Baudrillard argued that reality has been replaced by a system of signs and symbols in the postmodern era. This has led to a world where it is difficult to distinguish between the real and the simulated. His work "Simulacra and Simulation" illustrates this idea and has been influential in the fields of sociology, media studies, and philosophy.

Baudrillard's other significant contributions include his theories on hyperreality. This is a condition where the distinction between reality and a simulated copy becomes blurred. He also explored the concept of consumer society. Here, consumption defines social structures and values. Baudrillard's critical views on the impact of mass media and the commodification of culture have made him a central figure in contemporary cultural criticism. Despite his passing in 2007, Baudrillard's work continues to be a subject of interest and debate. It offers a penetrating critique of modern society's complexities and contradictions.

The concepts of hyperreality and simulation define many of the positionings of this thesis in a relevant manner. The evaluation of ideas like systematic skills and digitalised human knowledge from this perspective is paramount to understanding the impact of augmented reality and the metaverse in architecture. Baudrillard's work then situates itself as a keystone for the philosophical thinking of this work.

Gilles Deleuze

-Deleuze, G., & Guattari, F. (1987). A thousand plateaus: Capitalism and schizophrenia. University of Minnesota Press.

Gilles Deleuze was a highly influential French philosopher who made significant contributions to a wide range of disciplines, including philosophy, literature, film, and psychoanalysis. Born in 1925, Deleuze's work is known for its complexity and exploration of novel concepts in metaphysics, ethics, and aesthetics.

Deleuze's philosophy is characterised by its emphasis on concepts like difference, repetition, desire, and becoming. He is well-known for his critique of traditional notions of identity and representation, advocating instead for a philosophy of difference and multiplicity. His collaborative works with psychoanalyst Félix Guattari, particularly "Anti-Oedipus" (1972) and "A Thousand Plateaus" (1980), are groundbreaking texts that offer a radical rethinking of philosophical, political, and psychoanalytic theory.

Deleuze's solo works, such as "Difference and Repetition" (1968) and "The Logic of Sense" (1969), are also highly regarded for their originality and depth. His ideas have profoundly impacted contemporary thought, particularly in fields like cultural studies, literary theory, and the arts. Deleuze's work continues to inspire and challenge scholars and thinkers across the globe, making him one of the most significant philosophers of the 20th century.

The concept of Rhizome and the definition of order are significant in this thesis, both from a thinking perspective and internal structure. This thesis structures different aspects of post-modern thinking and creates a multifaceted approach by interconnecting concepts. Moreover, the different topics evaluated in this thesis interconnect and interfere with them. Deleuze's ideas are then a seminal part of this work, and even though it is not the most cited, it is the model that defines the backbone of the thesis.

Zygmunt Bauman

-Bauman, Z. (2000). Liquid Modernity. Polity Press.

Zygmunt Bauman was a renowned Polish sociologist and philosopher widely recognised for his insightful analyses of modernity, globalisation, and the dynamics of contemporary society. Born in 1925, Bauman's work profoundly influenced the fields of sociology, philosophy, and cultural studies.

Bauman is best known for developing the concept of "liquid modernity," a theory that describes the contemporary era as characterised by constant change, uncertainty, and the dissolution of traditional structures and norms. In this fluid state, individuals face challenges related to identity, relationships, and societal roles, as traditional frameworks are no longer reliable guides.

Bauman's unique approach to sociology, combined theoretical depth with a keen observation of everyday life, made him one of the most important social theorists of the late 20th and early 21st centuries. His work remains highly relevant in discussions about the nature of modern societies and the challenges they face.

The ever-changing society and the influence of media technologies in these processes had a relevant role in defining the idea of the platform society and the knowledge transmission through XR technologies. In this sense, Bauman Liquid Society serves as a measuring tool to comprehend the potential impact of these technologies.

Michio Kaku

-Kaku, M. (1999). Visions: How Science Will Revolutionize the 21st Century. Anchor.

-Kaku, M. (2011). Physics of the Future: How Science Will Shape Human Destiny and Our Daily Lives by the Year 2100. Anchor.

-Kaku, M. (2014). The Future of the Mind: The Scientific Quest to Understand, Enhance, and Empower the Mind. Doubleday.

Michio Kaku is a renowned theoretical physicist, futurist, and popular science communicator known for his work in making complex scientific ideas accessible and engaging to the public. Born in 1947, Kaku is a co-founder of string field theory, a branch of string theory that he has significantly contributed to developing. Kaku's work primarily revolves around the universe's fundamental forces, theoretical physics, and the future of humanity. He is an advocate for the search for a unifying theory in physics, often discussing the potential of the elusive "theory of everything," which aims to unite the four fundamental forces of nature.

Kaku is also known for his optimistic outlook on technology and the future, often discussing topics like space colonisation, artificial intelligence, and the potential advancements in science and technology that could shape the future of humanity. His ability to communicate science to a broad audience has made him one of the most influential and well-known figures in the field of science communication.

Kaku's unique vision of science, technology, and society is of great relevance for this thesis in order to understand, speculate, and predict how XR technologies will change society. Its theories about the evolution of augmentation, the future of labour, and the use of artificial intelligence define an interesting framework that this thesis uses as a reference to elaborate on the technological possibilities that XR brings to the architectural environment.

Brett King

-King, B. (2012). Bank 3.0: Why Banking is No Longer Somewhere You Go, But Something You Do. John Wiley & Sons.

-King, B. (2016). Augmented: Life in the Smart Lane. Marshall Cavendish International.

Brett King is an influential figure in the realm of financial technology and a respected futurist renowned for his insightful predictions and analyses of trends in the banking and finance industry. An Australian author, speaker, and entrepreneur, King's work is centred around the intersection of technology, finance, and the future.

King's influence as a futurist is most evident in his ability to foresee and articulate how digital innovation and emerging technologies are reshaping the financial sector. He has been a vocal proponent of the idea that traditional banking is undergoing a fundamental transformation, moving away from physical branches and towards digital and mobile platforms. His books, such as "Bank 2.0," "Bank 3.0," and "Augmented: Life in the Smart Lane," are testament to his foresight, discussing the evolution of consumer behaviour in finance and how technologies like AI, blockchain, and mobile banking are driving changes in the industry.

King's blend of expertise in finance, technology, and future trends makes him a pivotal figure in understanding the trajectory of the financial services industry and its adaptation in a rapidly changing digital landscape. His work informs current practices in the sector and shapes thinking about the future of money, banking, and consumer interaction with financial services.

The relevance of this author lies in his unique vision as a futurist, particularly in his understanding of technology implementation and user adoption. His theories about the future of XR, the labour workforce and the proposal of the "Augmented Era" are keystones of this thesis from a technological thinking perspective. King's ideas on the subject are highly significant.

Gilles Lipovetsky

- Lipovetsky, G. (2005). *Hypermodern Times*. Polity.

Gilles Lipovetsky is a well-known French philosopher, sociologist and writer who gained prominence for his works on postmodernity and modern culture. Born in 1944, Lipovetsky conducted extensive research on topics such as hypermodernity, individualism, and consumerism in modern societies. His influential works include "The Empire of Fashion" and "Hypermodern Times", which examine the changes in human behaviour and society due to the increasing influence of modern consumer culture and media. Lipovetsky's insightful analyses of trends, fashion, luxury, and the cult of individuality have made him a significant figure in the fields of sociology, philosophy, and cultural studies. His ideas often reflect on the paradoxes of contemporary life, where the pursuit of individual happiness coexists with widespread societal challenges.

Its role in this thesis is essential as it defines one of the main ideas for developing the concept of the augmented society. Its definition of Hyperreality and the role of the technology in the evolution of the society and the economy settles a definitory situation that needs to be understood and contextualised within the metaverse environment.

Sherry Turkle

-Turkle, S. (2011). Alone Together: Why We Expect More from Technology and Less from Each Other. Basic Books.

Sherry Turkle is an esteemed American professor, psychologist, and author renowned for her extensive research on the interface between technology and human psychology. Currently a professor at the Massachusetts Institute of Technology (MIT), Turkle's work predominantly explores the impact of digital technology on human relationships, self-identity, and communication.

Her research delves into how the digital age, especially the advent and proliferation of the internet, social media, and mobile technology, is reshaping the way individuals interact, form relationships, and perceive themselves. One of her key arguments is that technology, while connecting people in unprecedented ways, also fosters a sense of isolation and superficiality in human interactions.

Turkle's notable books, such as "The Second Self: Computers and the Human Spirit" and "Alone Together: Why We Expect More from Technology and Less from Each Other," offer profound insights into the psychological and social consequences of living in a digitally interconnected world. In these works, she examines the complex relationship between people and technology, questioning the long-term effects of a digitally saturated lifestyle on human empathy, intimacy, and emotional well-being.

A pioneer in the field of digital culture studies, Turkle's work is highly influential and widely respected. Her critical examination of technology's role in society raises important questions about the balance between our online and offline lives, urging a more reflective and conscious engagement with digital technologies.

From the sociology perspective Turkle's work represent an essential reference to elaborate the ideas regarding the effects that digital media technologies and now Metaverse represent for the future society. Also her positioning towards culture, heritage and homogenization is of paramount interest to articulate the defining socio-economical ideas of this thesis.

Technology Authors.

Gwyllim Jahn

-Jahn, Gwyllim. (2022). Mixed Reality Fabrication. 10.13140/RG.2.2.24824.42244.

-Jahn, G.,Newnham, C.,van den Berg, N. (2020). Collaborative Fabrication In Mixed Reality In: Data, Matter, Design: Strategies in Computational Design, Routledge, New York, United States

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-Jahn, G.,Wit, A.,pazzi, j. (2019). [BENT] In: ACADIA 19: UBIQUITY AND AUTONOMY Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture, Austin, Texas, 21-26 October, 2019

-Jahn, G.,Newnham, C.,Hahm, S.,Pantic, I. (2019). Steampunk Pavilion In: Tallinn Architecture Biennale Installation Competition Tallinn, Estonia

-Jahn, G. (2018). Allbrick Feature Wall In: Now Awards Launceston, Australia

-Jahn, G. (2018). Woven Steel Pavilion In: CAADRIA (Conference on Computer-Aided Architectural Design Research in Asia) Beijing, China

-Jahn, G.,Newnham, C.,van den Berg, N.,Beanland, M. (2018). Making in Mixed Reality. Holographic design, fabrication, assembly and analysis of woven steel structures In: ACADIA // 2018: Recalibration. On imprecisionand infidelity. Proceedings of the 38th Annual Conference of the Association for Computer Aided Design in Architecture, Mexico City, Mexico, 18-20 October, 2018

Gwyllim Jahn is a prominent figure in the field of architectural design, best known for his groundbreaking work in digital fabrication and computational design. As one of the founders of Fologram, Jahn is leading the way in integrating advanced technologies into architecture. His primary focus is on combining digital technology with traditional craftsmanship, by using tools like augmented reality, virtual reality, and computer-aided design to improve architectural design and construction. Under Jahn's guidance, Fologram has developed tools that blend digital modelling with hands-on construction, enabling more complex and precise

architectural designs. Jahn's work highlights the role of emerging technologies in boosting creativity and efficiency in architecture, especially in bridging the gap between virtual design and physical construction. His contributions are significant in shaping the future of architecture, advocating for the use of innovative new technologies to transform building design and construction.

Jahn's work is crucial not only for defining the current state-of-the-art but also for his role on the Fologram team, which is essential for research on AR manufacturing. Jahn's parallel agenda at RMIT is a constant source of influence and inspiration, and his research is contributing to advancing the concept of Augmented Architecture.

Mark Billinghurst

-Billinghurst, M., & Duenser, A. (2012). Augmented reality in the wild. In Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems (pp. 33-36). ACM.

-Billinghurst, M., & Duenser, A. (2012). Augmented Reality in the Classroom. Computer, 45(7), 56–63.

-Billinghurst, M., & Kato, H. (2002). Collaborative mixed reality. In Proceedings of the First International Symposium on Mixed and Augmented Reality (pp. 261-284).

-Billinghurst, M., Clark, A., & Lee, G. (2015). A survey of augmented reality. Foundations and Trends® in Human–Computer Interaction, 8(2-3), 73-272.

Wagner, D., Billinghurst, M., & Schmalstieg, D. (2006). Handheld augmented reality in education. In International Conference on Computer Graphics and Interactive Techniques: SIGGRAPH 2006. ACM.

Mark Billinghurst is a renowned researcher and pioneer in the fields of augmented reality and human-computer interaction. He has made significant contributions to the development and application of AR technologies across various domains. His work primarily focuses on enhancing interaction with digital content and interpersonal communication through intuitive and interactive AR interfaces. These interfaces have made digital information more accessible and engaging in real-world settings.

Billinghurst has a strong academic background and has worked with prestigious institutions as an educator and researcher. He explores the application of AR in education, communication, and gaming, and developed the influential open-source library, ARToolKit. Known for his research in collaborative AR systems, he enables multiple users to interact in shared digital environments. As a visionary in augmented reality, he has significantly advanced the field and influenced interactions with technology in the digital era.

Billinghurst's contribution to AR and XR environments is vital for this thesis and the field's evolution. His work with the ARToolKit and research on AR pedagogy has established a foundation for knowledge transmission and accessibility. His role is key in defining the 'Search don't sort' model for manufacturing skills.

Matias del Campo

-del Campo, M. Manninger, S. Sanche, M. Wang, L. - The Church of AI—An examination of architecture in a posthuman design ecology. Proceedings of the 24th CAADRIA Conference, 2019

-del Campo, M., & Leach, N. (2022). Machine Hallucinations: Architecture and Artificial Intelligence. John Wiley & Sons.

del Campo, M. Evoking Through Design: Contemporary Moods in Architecture, John Wiley & Sons, 2017, 136 p.

- del Campo M, Leach N. Can machines Hallucinate architecture? AI as design method. Architectural Design. 2022;92(3):6-13.

-del Campo M, Carlson A, Manninger S. Towards Hallucinating Machines - Designing with Computational Vision. International Journal of Architectural Computing. 2021;19(1):88-103.

Matias del Campo is a renowned architect and designer celebrated for his innovative use of computational design techniques and modern architectural theory. His work explores the impact of artificial intelligence, robotics, and digital fabrication on architectural design, resulting in complex, organic structures that merge technology with aesthetic appeal. Del Campo challenges traditional architectural norms with his futuristic designs and is also active in academia, sharing his insights through lectures and workshops on the role of emerging technologies in architecture. His visionary approach positions him as a key figure in shaping the future of architecture in the digital era.

The recent writings and viewpoints of Rosenberg, coupled with the research of del Campo, are the primary sources for understanding the field of AI architecture. Del Campo's extensive research into this technology and its integration with design is crucial for comprehending how AI can revolutionize and alter the process of design. This can also lead to a shift in the traditional roles of Designer and Client. In this thesis, his influence is evident from the perspective of Augmented Architecture, Augmented Society, and the Value System.

John Frazer

-Frazer, J. (1995). An Evolutionary Architecture. Architectural Association.

John Frazer is a trailblazing figure in architectural computing and generative design, known for his significant contributions to architecture through his innovative use of computational and evolutionary design. His work mainly revolves around developing generative design systems using computational techniques, allowing architectural designs to evolve in response to environmental changes and user needs. Frazer's approach deeply embeds digital technology into the architectural design process, redefining traditional concepts of building design and construction.

As an influential academic and educator, Frazer has played a key role in shaping the perspectives of new generations of architects and designers. He has held various academic roles in prestigious institutions, focusing on teaching and researching advanced computational methods in architecture. His teachings and writings have been pivotal in popularising the concept of generative design and advocating for the integration of digital tools in architectural creation.

Frazer is celebrated for his forward-thinking vision, advocating for architecture that is dynamic, adaptable, and technologically integrated. He promotes a design philosophy that views buildings as evolving entities, responsive to their surroundings and users, rather than as static structures. His visionary approach positions him as a leading figure in the field, pushing for a future where architecture and technology are seamlessly interwoven.

In the context of this thesis, the work of Frazer has had a significant influence as one of the most relevant pioneers of digital architecture and the implementation of new technologies. His approach to practice and research has greatly contributed to shaping the current state of the topic. It is important to note that his work and influences for the thesis go beyond the listed publication as he is one of the main foundations for understanding digital technologies, as well as automated and autonomous processes.

Branko Kolarevic

-Kolarevic, B. (2003). Architecture in the digital age: Design and manufacturing. New York, NY: Taylor & Francis.

-Kolarevic, B., & Klinger, K. (Eds.). (2008). Manufacturing Material Effects: Rethinking Design and Making in Architecture (1st ed.). Routledge. <https://doi.org/10.4324/9781315881171>

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Branko Kolarevic is a well-known architect, educator, and researcher who is highly regarded for his expertise in computational design and digital fabrication in architecture. He has made significant contributions to advancing architectural theory and practice, particularly in the integration of innovative technologies into the design process. Kolarevic's work focuses on using computational methods in architecture, from the initial design to the fabrication of building components. He advocates for the use of digital technologies to transform traditional architectural practices, encouraging experimental and integrative approaches to design and construction. A significant element of his work is the use of computer-aided design (CAD) and computer-aided manufacturing techniques, which enhance precision, flexibility, and efficiency in architectural projects. His research and teachings examine the potential of these technologies to create novel architectural forms and promote sustainable building practices.

Branko Kolarevic has significantly impacted academia and influenced a generation of architects through his teachings and publications on parametric design, digital fabrication, and new technologies in architecture. He is celebrated as a visionary for pioneering digital technologies to create innovative and sustainable designs.

His extensive research on digital and augmented manufacturing is crucial to this thesis, and his teaching methodology plays a key role in advancing the field. As a pioneer in testing these technologies in architecture, his contributions are invaluable.

Paul Milgram

-Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems, 77(12), 1321-1329.

-Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1995). Augmented reality: A class of displays on the reality-virtuality continuum. In Proceedings of the SPIE, Telemanipulator, and Telepresence Technologies (Vol. 2351, pp. 282-292). SPIE.

Paul Milgram is a renowned researcher and academic recognised for his contributions to human-computer interaction, particularly in augmented reality and mixed reality. His work focuses on the interaction between humans and complex technological systems. Milgram is notable for developing the "Reality-Virtuality Continuum," a framework categorising the mix of real and virtual environments. This concept is crucial for understanding and evolving AR and mixed reality technologies, highlighting a spectrum from entirely real to fully virtual environments.

Milgram's interdisciplinary research, blending psychology, engineering, and computer science, has significantly advanced our understanding of how people interact with environments that merge physical and digital elements. This work has been pivotal in enhancing the design and usability of AR systems.

Beyond his research, Milgram has made substantial contributions through teaching and mentoring in the academic community, influencing future technologists and researchers in human-computer interaction. His pioneering efforts have profoundly impacted the development of interactive technologies and continue to shape the progression of AR and mixed-reality applications.

Milgram's role as a pioneer in the development of the XR environment is of significant importance to this thesis. The work he produced in defining the XR environment is used in various ways throughout the thesis. Moreover, his contribution to the early hardware industry completes the state of the art and the history of this technology.

Louis B. Rosenberg

-Rosenberg, L. B. (1992). The use of virtual fixtures as perceptual overlays to enhance operator performance in remote environments. Technical Report AL-TR-0089, USAF Armstrong Laboratory, Wright-Patterson AFB OH, 1992.

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Louis B. Rosenberg is a highly respected American inventor, entrepreneur, and researcher known for his significant contributions to virtual reality (VR), augmented reality, and human-computer interaction. With a strong background in engineering and computer science, he has played a crucial role in advancing interfaces and interactive technologies. Rosenberg is particularly recognised for his early innovations in VR and AR, notably inventing the first functional augmented reality system in the early 1990s. This landmark development set the stage for many contemporary AR technologies.

Rosenberg has significantly advanced our understanding of complex systems, artificial intelligence, and collective intelligence. His work focuses on enhancing human decision-making through innovative systems that combine human and AI for problem-solving. As an entrepreneur, he has founded several companies, contributing to fields like VR, AR, and human-computer interaction. His visionary inventions continue to influence the development of immersive and interactive technologies.

As one of the pioneers of AR technology, Rosenberg's work is essential not only for defining the current state of the art but also for informing the technological approach of related research. Furthermore, he has become a prominent figure discussing AI, addressing both the risks and potentials associated with this technology. His insights are vital for the content of this thesis and extend beyond the references included in the bibliography.

Jose Sanchez

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- Sanchez, Jose (2023). [Social Realism in the Age of Simulation](#). *IAAC Bits 10– Learning Cities: Collective Intelligence in Urban Design*. Actar D, Inc. P. 139.

Jose Sanchez is an architect and game designer who specialises in the intersection of architecture and interactive design, specifically in the field of architectural gaming. His work focuses on exploring how gaming can influence and reshape architectural design and urban planning. He creates interactive platforms and games that encourage user participation in design, promoting a collaborative approach to architecture and urban development. Sanchez's projects merge digital technologies with architectural concepts, showcasing how gaming mechanics can address real-world design issues.

One of the most notable achievements of Sanchez is the creation of "Block'hood", a video game that challenges players to think critically about ecological and urban systems. This reflects his approach to using gaming to educate and engage the public in sustainable design and urban ecology. Sanchez's interdisciplinary approach combines technology, social participation, and environmental consciousness. He is involved in teaching and research, sharing his game design and architecture knowledge. His groundbreaking work in architectural gaming is highly regarded, having advanced the integration of interactive and participatory methods in architectural practice and education. His work is a unique fusion of architecture, gaming, and sustainability, providing fresh insights into how we interact with and comprehend built environments.

Sanchez's work establishes the framework for the platform architecture from a thesis perspective. His research on participatory methods for designing urbanism and manufacturing is fundamental to understanding how a cloud-based system could function. Projects like Common' hood demonstrate how distributed XR-based manufacturing systems can be approached and their potentials and problems.

Academic Authors

The list of academic authors is diverse and extensive, covering a range of technical and historical experts, along with statisticians. Their work serves the purpose of outlining the historical framework of craftsmanship, from traditional methods to modern automation. The authors have provided a strong foundation for the ideas presented in this thesis. However, unlike the other sections, this list lacks specific authors who offer guidance on particular topics. Although this section is not focused on specific authors or lines of thinking, it does not mean that some authors retain a more relevant role than others. These authors have helped construct a data-driven narrative on several topics contained in this thesis. Their extensive research and work in these areas have been fundamental in understanding the past and the present, and therefore speculate about the future.

David Autor and Damon Acemoglu's work is highly significant in the fields of sociology and labour theory. They have focused on analysing the impact of technology on the skilled workforce. Andrew McAfee is also an important reference in this area as he helps to understand the potential outcomes of changes in the labour market caused by technology.

Glenn Adamson is the primary technical and historical reference for the study of craftsmanship history and analysis. His work helps to understand the evolution of this practice and the changes it has undergone throughout history.

Jonathan Bowden and Martin Campbell-Kelly's team, including William Aspray, Nathan Ensmenger, and Jeffrey R. Yost, provide expertise on the history and current state of computing technology. These two works were fundamental to elaborate the historical and technical knowledge reflected in this thesis.

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- Fikouhi, S. is the founder of ARki, an augmented reality platform for architectural visualization. Details about her work can be found on the ARki platform's official website or in related app store publications. ([ARki App](#)).
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