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Opportunities in the airport pavement management: Integration of BIM, IoT and DLT

Antonia Pacios Álvarez, antonia.pacios@upm.es; Joaquín Ordieres-Meré j.ordieres@upm.es; Ángel Paris Loreiro, angel.paris@upm.es; Leticia de Marcos ldmarcos@aena.es

Abstract

This paper aims to explore different technologies related to digitalization in construction industry, with specific interest in providing added value to the whole lifecycle. The interest is, in particular, related to the airport industry, and a case study focused on pavement refurbishment has been selected. Instead of adopting the dominant approach, mainly related to the contract management and payment control throughout blockchain, the interest perspective of this paper is to provide value by enhancing the technical dimension of the interaction between those digital technologies. As a main outcome, a referential framework helping in integrate different stakeholders at any project phase will be proposed.

Keywords:

Smart construction; internet of things; automated systems; pavement maintenance management; pavement reparation reconstruction, resurfacing; Distributed Ledger Technology; Digital Transformation.

1.- INTRODUCTION

Due to the increasing number of passengers travelling, airports and smaller regional aerodromes have experienced a consequent increase in runway usage, accelerating the need for major maintenance. Maintenance at airports includes set of activities with continuous innovation to ensure safety, provide quality construction, and avoid excessive air traffic delays, which configures a complex system.

One of the characteristics of this complex system is the high number of interfaces and agents being involved; for each runway construction project the network of collaborations are set together and dismantled by the end of the project. The number of specialized node in such network (the number of companies being involved) is large, and the exchange of information is more frequent and relevant than before. To face failures or breakdowns in information exchange mean being exposed to relevant risks.

Airfield pavement basic functions are to provide adequate bearing capacity, good rolling qualities and good surface friction characteristics. Ease of maintenance, durability or sustainability are other requirements having increased relevance through time. Since the decision of resurface or rehabilitate should not been taken lightly, sufficient data to inform the decision-making process, from a number of sources, well in advance, should be obtained. These data can include those specific from the pavement conditions, as well as others, for example traffic forecast, weather forecast, budget, consultation with stakeholders among others (Tighe and Covalt 2008).

As in the general construction field, because of the economic crisis, the construction industry has faced a significant crisis, where network collaboration became a must. Generally speaking, the market is highly fragmented. The same happens at different services, like role of communications, document management and interoperability among them. Additionally, proper skills to integrate diverse software and hardware and systems to manage and communicate digitally is also required.

From the past ten years till now some of the limitations have been address. For example, some open standards for managing data have been adopted, as well as methodology for managing construction projects information assets. Objects are optimized for a limited set of parameters and domains.

Still several problems remain because of tools for project planning and business management are mature enough, but an integrating and scalable solution for all needed functionalities, for different type of projects, is not available (Shen et al. 2008). The ability to assess uncertainties, risks and the impact of failures is not mature, due to the limitations of available tools.

An automated project and maintenance management environment integrated across all phases of the lifecycle will enable all project partners and project functions to interconnect their systems, processes and equipment. This will drastically reduce the time and cost of planning, design and construction.

BIM alone, and now combined with DLT, is changing the construction system by promoting collaboration throughout the value chain, and enables accurate, well-informed decisions to be made through the lifecycle, as well as it brings the opportunity for integration of all those flows of digital information that can be related to geometric elements placed in such BIM model. Those changes are in the organization, agents involved, work flow, technology and management, and bring o**pportunities for construction digitalization and how may improve pavement management.**

Smart construction has different perspectives, including productivity (Kuenzel et al. 2016), but also safety (Li 2017) and site control (Pradhananga and Teizer 2013).

The main objective of this paper is to identify the opportunities that digitalization on construction field brings to the airport transport system, by adding additional trustworthiness to the relevant subsystem. In particular it will be illustrated through the optimization of data storage, use and transformation pavement maintenance program (Mäki and Kerosuo 2015). Section 2 makes a short review of the involved enabling technologies. Section 3 is devoted to present specific activities related to the airport pavement management, including all the life cycle. Section 4 proposed a BIM execution plan guideline for integration between APMS and BIM model. Section 5 is devoted to present the proposed framework enabling to use DLT technology as a technological layer enabling the integration of different sources, including object disposal (by means of BIM), referenced documents, IoT based sensor data streams, etc. Finally, the last Section is devoted to figure out the conclusions, as well as limitations and managerial implications.

2.- STATE OF THE ART

The main reason of this Section is to set the basics of the following technologies in the architecture/engineering/construction (AEC) sector: the BIM, IoT, integration technologies and DLT. When applied to aeronautical construction industry most publications is about airport terminals but not much research about airsite area was found.

2.1.- Deployment of BIM in AEC sector

Originally developed for architectural field, BIM applications to transport infrastructure projects still demands some research, particularly on fully interoperable standards, enable d asset management decision based on cost, risk and performance for the entire lifecycle, innovative solutions decisions designed to reduce disruption, etc. Since it is mandatory, a gradual introduction of the use of digital models is taking place. The adoption of BIM is a progression that implies levels of increasing capability maturity across technology, process and policy field. Most initial works with maturity level 2 do not benefit from the collaboration enable by level 3; integration with other technologies as for example DLT needs more networked and integrated forms as from Level 3 (Li et al. 2019).

BIM can be of crucial importance when applied in Operation and Management/Maintenance phases, since it might incorporate various discipline models. Domain/discipline systems integration according to (Shen et al. 2010) requires different perspectives, like:

a) Web-based systems, uses centralized information integration approach with a shares web server or a central database in the web service. Those are the most information systems deployed; may be adequate for daily construction project management but it is not sufficient to meet the requirements for a fully integration. In a complex project, for user-interaction, web servers are not only acting as repository of information, they must provide service and communication between disciplines.
b) Distributed objects/components, uses also a centralized integration approach. It has been widely used for the implementation of integrates systems, particularly for Distributed Object Standards.
c) Software agent technology was applied for integration before the web was available. It is best suited for applications that are modular, decentralized, changeable and complex. The advantage is to adapt to a dynamically changing linking.
d) Web services and semantic Web has been extensively used in e-business applications but less reported results have been found for architecture/construction field.
e) Integration of RFID and wireless sensor networks reduces the introduction of manual data; more automatized process. It is a well suited technology to help, during construction and maintenance phases, real time decision making processes. Also for monitoring progress feedback.

Understanding the importance to address users and technical needs, buildingSMART International Organization (bSI) created the “room concept” for assembling domain-specific user to focus on the identification, development and deployment of open digital standards that address particular needs and requirements. The Airport Room Roadmap Report declares that asset information management tools evidence problems that present challenges, as for example inefficient and uncompleted information exchange, speed up approvals, filtering big data, multi-tenant space management, long term planning needs, software application interoperability, etc.

2.2.- Use of IoT in the construction sector

IoT relates to all kind of things or devices in our working environment such as radiofrequency identification (RFID) tag, sensors, actuators,... that interact. First, supporting technologies are essential for information transmission; also, multiple sensors monitoring in real time should interconnect smart objects in a network via some application technologies.

In the last five years the interest of exploring the use of IoT alone or in combination with integration technologies has increase. Table 1 shows that the application of some type of digitization maintains an upward trend (the 2018-2020 period is shorter); even though not all research is included in the list, the tendency is of fewer studies on pilots or research projects of sensor integration with model. Meanwhile BIM technology has become popular, well explained since it is mandatory for public works in a large number of countries. If the research search is limited to linear infrastructure or pavement work, the number of experiences is much lower, still being a working topics with well stablish structure, regulation and the need of having a preventive maintenance program.

Table 1. Number of research focus on digital technology applications in construction. (Source: Web of Science)

	General construction (several disciplines)			
	2006/2009	**2010/2013**	**2014/2017**	**2018/2020***
Sensors				
Augmented reality	6	25	20	10

Point cloud/laser scanning	4	15	31	11
BIM + GIS	1	3	8	6
BIM + sensors	--	2	7	3
BIM + Point cloud	--	4	23	8
BIM + RFID	--	3	5	4
BIM + photogrammetry + laser scanning	--	1	1	1
BIM	4	78	521	181
IoT	--	4	15	21

*Half period of previous columns

2.3.- BIM and IoT integration

The potential of connecting BIM and IoT based data sources is still in early stages in the construction sector, although little bit more developed for building construction is almost absent for civil works. BIM models offer representation of the project at the component level by defining geometry, special location and many other parameters that were defined in each object (material, cost, manufacturer, etc.); it becomes a high fidelity operable data set of building elements, mostly a static information. IoT enhances this information providing real time information obtained from sensors at different operations phases, as for example, construction, maintenance, incorporating useful data for the life cycle evaluation. The data are time series streams from individual sensor. Both data sources may be accessed for example with manual interfaces or connection systems; however, integration is still needed of more research and application since more information available is from conceptual proposed models or prototype applications (Fang et al. 2016).

In the last ten year lots of resources were available to set open standards for BIM and IoT communication and a better integration of both technologies. From reviewed articles like (Tang et al. 2019) the following integration methods are outlined.

a) BIM tools APIs and relational database. BIM models can be exported into to a relational database; sensors data is stored and updated in relational database. A relationship between virtual objects and physical sensors is established. The main advantages are that model data could be exported to open data base connectivity format; all data are stored in the relational database; and, sensors data can be automatically updated in the BIM model. Main disadvantages are that not all model parameters can be exported, so limitations with the update. This method is adequate for simple BIM models and a limited number of sensors.
b) Creating a new query language, querying sensor data over BIM models or IFC models instead of using SQL. As limitations have that new query language that are not standardized may not be adopted, and to implement the new query language a corresponding platform need to be develop at the same time.
c) Semantic web approach. The integration of BIM and Semantic Web Technologies has the potential to meet the requirement to store, share and use heterogeneous data sets. This approach requires that BIM model and sensors data in a homogeneous format, Resource Description Format (RDF). Since most time-series sensors data are store in a structured relational database, duplication of data may happen when converting sensors data into RDF and it will be inefficient. It also requires knowledge of semantic web technologies and heavy data transformation. It is adequate for projects with various types of data sources.
d) Hybrid approach: semantic web and relational database. This approach brings two technologies together. The main points of that different data sources are stored in their

most suitable format and platform while achieving interlinking. This approach is the most promising integration method to facilitates IoT extended use on construction industry.

All cases will deal with the integration of three components: a) BIM servers as a data repository for building information, IoT device description, and other static data collected from software and models; b) Sensors, including continuous data time-series; c) then, the interaction method need also adopted.

2.4.- DLT in AEC Industry

Regarding another relevant dimension, which is the relationship between the construction industry and DLT, it is relevant to identify that some contributions have been made, considering blockchain as one specific implementation of DLT, like Li, Greenwood, & Kassem (2019) which propose a framework to provide a context. Benefits and expectations of both concepts have been also described in (Belle 2017; Turk and Klinc 2017).

In some of the scientific contributions (Li et al. 2019; Wang et al. 2017) the authors identify a major issue in construction to be the late payment of contract terms. Therefore, automated payments of fiat currency can be coded into smart contracts to protect contractors, subcontractors and the supply chain against insolvency from late payments. The smart contracts are extensions of the blockchain constructions, (blockchain v2.0) enabling to deliver value when specific conditions are met.

Li, Greenwood, & Kassem (2019) with the aim to analyses the current state of DLT in built environment and construction sector, resumes from literature review their potential uses. Several use cases were identified as for example: use of smart contracts; reformulating practice in the supply chain activities through tracking goods and services; maintenance and replacement insurance, and some others. Out of them the use for meeting regulatory and compliance requirements, clearly automated payments, and shared access to BIM stand out.

Although most of the papers have discussed the increasing trust and collaboration within the construction industry by integrating digital information with management and contracts, DLT is gaining traction from different type of industries as a way to increase the level of trust. Therefore, there is a school of thinking trying to emphasize the technical application of connections between BIM and DLT in construction, as for example:

- Supporting BIM trough smart contracts: launch tenders, archive documents, control model access and transactions.

- Verification of timing and source of the addition of components to a BIM model.

- Operational management using IoT connected devices and transaction environment of DTL to provide a BIM model in real-time.

- Intellectual property rights using for example DTL to prove ownership of particular BIM components.

This paper aims to contribute to this discussion, by bringing an additional use case where such technology links make sense, which is the control and supervision of road pavement and refurbishments at airports.

3.- AIRPORT PAVEMENT MANAGEMENT SYSTEM (APMS)

Airfield pavement basic functions are to provide adequate bearing capacity, good rolling qualities and good surface friction characteristics. Ease of maintenance, durability or sustainability are other requirements more in value with time. Since the decision of resurface or rehabilitate should not been taken lightly, sufficient data to inform the decision-making process, from a number of sources, well in advance, should be obtained. These data can include those specific from the runway pavement conditions, as well as others, for example traffic forecast, weather forecast, budget, consultation with stakeholders, among many others.

Airport Pavement Management System (APMS) is the decision support system related to technically and economically sustainable management strategies for maintaining the optimal conditions of the airport pavements in compliance with the provisions of current regulations and for a defined period. An APMS not only evaluates the current condition of the airfield pavement, but also predicts its future condition through the use of historic information and quality indicators. It will enable a user to store pavement condition and maintenance information into a database and use the resources to determine cost-effective solutions. In this way life cycle cost analysis can be made (AC 150/5380-7B 2014).

The main benefits of an APMS could be, as indicated in (Di Mascio and Moretti 2019):

- to encourage the creation of a computerized database to organize, store and consult data about pavements;
- to promote the monitoring of pavements and the systematic and objective assessment of the distress level;
- to predict the evolution of degradation, then to identify when the maintenance and rehabilitation interventions will be needed, the service life of maintenance and rehabilitation interventions, the interventions that show a rate of anomalous degradation evolution, the benefit/cost ratio of the works;
- to select and optimize the list of maintenance and rehabilitation works to be implemented in relation to the allocated resources;
- to allow systematic and documentable identification of the intervention needs, supporting the request for financial allocations;
- to allow greater flexibility and adaptability to changes both in financial assets and human resources.

The system is composed of objective and systematic procedures: inventory of the existing pavements (i.e. collection and retention of geometrical, technical, and mechanical data); monitoring of their performance, planning and scheduling maintenance and rehabilitation activities; evaluation of effectiveness and costs of maintenance activities to be performed as well as those carried out in the past. Figure 1 represents what must be contained in a APMS, with the inputs and output.

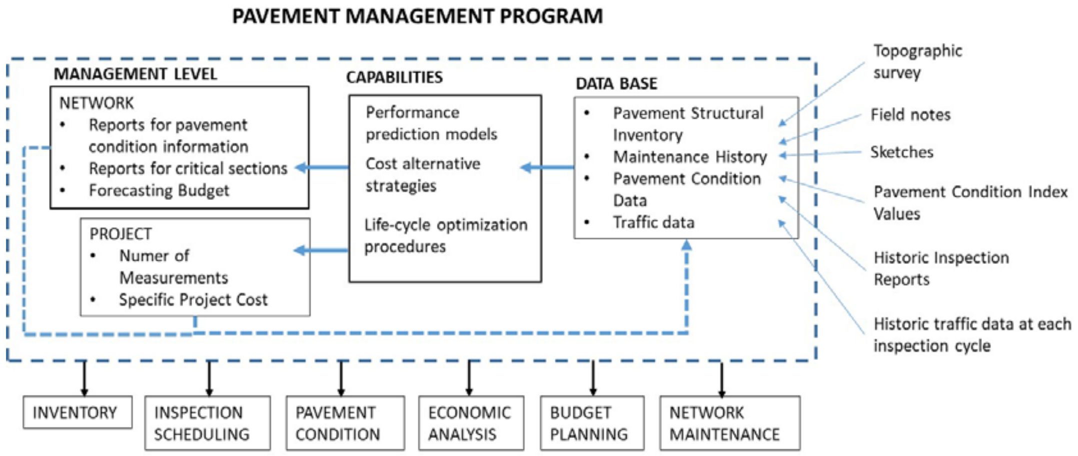

Figure 1. General scheme of APMS. Source: AC 150/5380-7B

Airports management bodies can use any of the existing software options as MICROPAVER, RICENT, Stereocarto, RAMBOLL, etc. Integration of existing APMS with airport BIM models is a challenge since, without losing system capabilities, an answer to the challenges identifies in Section 2.1 (better information exchange, speed up approvals, filtering big data, multi-tenant space management, long term planning needs, software application interoperability), should be provided.

The renovation of Barajas airport runway 18R-36L in 2015 has been used as a study case to better understand the high operational impact of works, the necessity to concentrate them in a single period, the resources available on site during construction, so the large amount of information and its complex interaction being handled simultaneously. All this information feeds the database of the APMS.

As for type of works related to construction phases, Table 2 resumes the relevance of information management for the types of works; All works are Operational and Safety Constrained (OSC) except the mentioned.

Table 2. Relevance of Information Management for the type of works

TYPE OF WORKS	NEW CONSTRUCTION	NEW CONSTRUCTION (NON OSC)	PAVEMENT REHABILITATION	SURFACE COURSE ENHANCEMENT	LOCATED CORRECTIVE MAINTENANCE	PREVENTIVE MAINTENANCE	ROUTINELY INSPECTIONS
INSPECTION	NA	NA	High	Medium	Medium	Low	Low
PROJECT	High	High	High	Medium	Low	Low	Low
DEPLOYMENT	Very high	Medium	Very high	Very high	Low	Low	Low
CONSTRUCTION	Very high	High	DUC	DUC	Low	Low	Medium
DEACTIVATION	High	High	High	Medium	Low	Low	Medium

NA. Not applicable; DUC. Difficult to use due to constraints

The BIM execution Plan proposed is based in three actions: BIM object definition and breakdown program management activities; automatic outputs verification; and, automatic continuous data input into the database.

4.- PROPOSED BIM DEPLOYMENT

The main objectives to integrate BIM are:

a) To facilitate decision-making in the design and construction phase, generating visualizations of models with the necessary information.
b) To guarantee the coherence and reliability of the different solutions provided by the experts of each discipline, facilitating communication between them.
c) To increase and ensure the quality of the construction process, improving the reliability of the work programming and the final construction documentation.

Major BIM requirements identified were: the information and documentation management; production of BIM-based project documents; analysis of information generated by BIM models.

4.1.- BIM Execution Plan

It should set the new organization by identifying the agents, team work, and the strategies for information management, communication, collaboration and BIM use.

BIM uses are (see Figure 2):

- Documentation 2D: Management and collection of documentation contained in the model (floor plans, elevations and sections of the models in a way that guarantees the coherence between them). Construction details are not considered.
- Measurements: Basic measurements obtained from the model through exported .txt files and imported into specialized software.
- Rendering: The 3D Model allows anticipate decision making and improves project understanding to all related agents since early stages. It allows also to obtain from the model photorealistic images and videos, or applications with virtual interaction.
- Coordination 3D: By making models for each discipline enables the reduction of interferences between elements.
- Planification 4D: 4D planning by model 3D with the added dimension of construction time, from bidirectional data exchange between specialized software and standard planning systems allowing, in case of possible modifications, to update and optimize.

Workflow must be adapted and new roles and responsibilities agents should be defined. Steps proposed to follow are:

- Verification of inputs.
- Structured data for construction elements following a widely used classification system, for example GuBIMClass, that allows to identify the construction elements by their functionality, their budget item and budget heading, and their work breakdown position (materials, templates, units).
- Organization of shared parameters.
- Organization of auxiliary files, models and their relationship.
- Shared coordinates, reference levels and axis. Clash Detection. The coordination model would integrate the discipline model in a new single model.
- Verification of deliverables or outputs.

The elements are represented graphically in the model as an object with specific and precise shape, size, location, orientation, tolerance and measurement. The model includes 2D and 3D parameters of building characteristic or construction systems, that provide constructive viability. It includes also, for its construction, accurate and necessary non-graphic information of the element. As it was indicated previously the classification system for the elements is the GuBIMClass. IFC for airports infrastructure works are currently in development. Although some properties can be directly defined within the schema of IFC model, other must be added.

To carry out the 3D coordination, a Coordination Model that integrates discipline models in a single model will be generated. Then, analysis and interference will be carried out and an attribute representing the difficulty or inconvenience that may entail will be incorporated to all the elements; in case of collision with any other that element should be modified.

Figure 2 presents the general scheme for BIM Execution Plan.

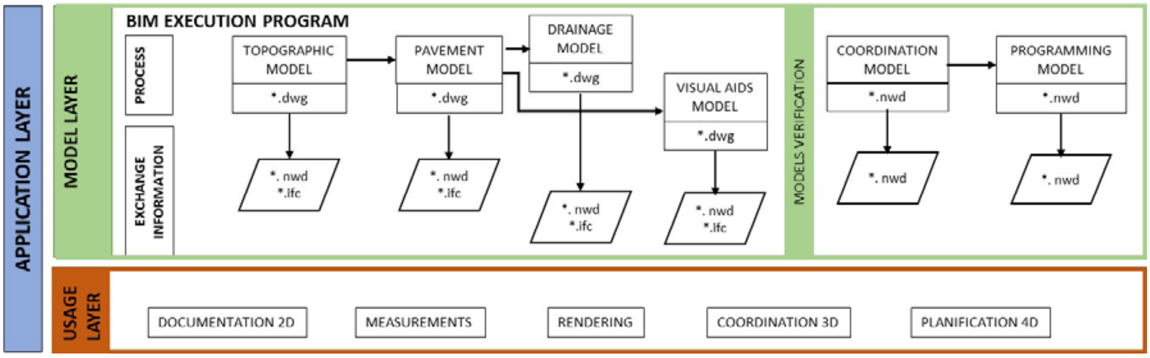

Figure 2. General scheme of BIM Execution Plan

Before submitting the models to the verification team, it is suggested that the modeling teams follow a quality control process. The verification will refer exclusively to compliance with the BIM requirements. It may be carried out by members of the BIM team or BIM management team (or by a third party). For elements it is subject to be verified reference, code, description, functionality, georeferenced, category or family. It has to be chased that most verifications will be automatic.

4.2.- APMs data base information

Over time, a monitoring system of airport’s response to traffic will require evaluation of many parameters, some quantitative (physical properties) and some qualitative (subjective characteristics). High performance measuring devices are used in order to minimize the number of vehicles and personnel involved in the surveys.

Most of data acquisition are obtained from pavement field survey; along with continuous registered data, field notes, pictures and sketches should all be imputed into the PMP. Precise pavement composition of each unit, historic traffics type, historic availability of non destructive test (NDT). With the advantage of getting all Repair and Maintenance activities digitalized, historic deterioration rates and knowledge generation could be used for futures work. The improvement for assessing pavement conditions is an essential first step; model for rating the surface condition will help to use funds most efficiently identifying the appropriate rehabilitation project (see Figure 3).

Focus on automated system to measure remotely with enough accuracy the runway surface condition parameters (on the scale of the area of operation) not many results were found. Most of the works has been related to research on linear infrastructures (Hurson 2004) or to identify remote sensing techniques as potential for pavement managers to assess large areas in little time (Schnebele et al. 2015).

Since no automated system exist to assess properties requiring visual inspection, some new research systems from other related physical characteristics may be explored. Mataei et al. (2018) proposed a system based on image processing method for visual inspection and, more recent research, to estimate de surface drainage. Elunai, Chandran, and Gallagher (2011) had previously propose a similar method to estimate the surface texture coarseness distribution from its edge profiles.

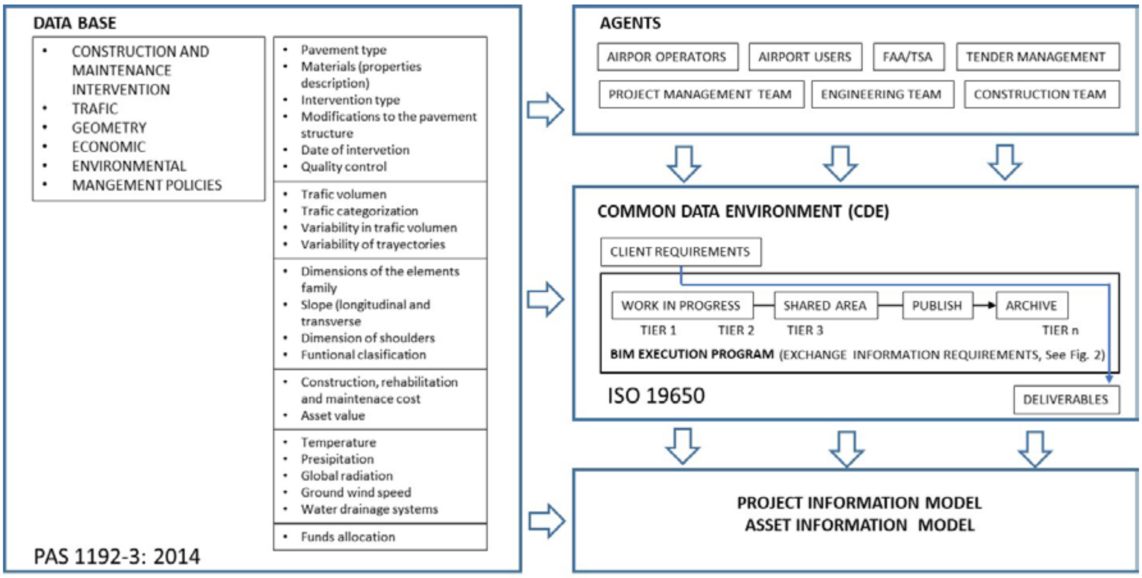

Figure 3. Integration of an APMS system in the BIM process based on de Oliveira 2013

A Common Data Environment (CDE) should be provided in order to maintain integrity and control of the data throughout the supply chain. The SHARED AREA is used to hold information that has been approved for sharing between organization and client or different companies. Accepted information data should be transferred to the PUBLISED area. This published area has two parts: one for file storage of data files, and other for data model and relational object database.

5.- FRAMEWORK PROPOSAL

What is also clear is that just up to the dimension 7D, all aspects are related to the construction of the building/infrastructure, but none is related to the remaining dimensions of the life cycle (Charef, Alaka, and Emmitt 2018). Indeed, during the construction phase itself, as there are different type of related documents, it becomes fairly unrealistic to imagine that all of them will be stored inside the BIM model. Instead our proposal is ***to have a dynamic, federated and potentially encrypted constellation of objects all of them related through a DLT database, able to track who was accessing any of those objects***.

In order to provide a comprehensive perspective, in general terms, both for the process and for the involved agents, the Figure 4 is provided, where the principal agents involved per phase, as well as the different digital products required. Therefore, during the design phase, and based on the vision and requirements provided by the owner and, probably by using different simulation models (energy consumption, structural design, etc.), a solution is finally developed, through the BIM model as well as all the technical documentation required to ask for the authorization for the solution from the proper public bodies, which should include the adequate insurance coverage. For the construction phase, maybe financial help will be required, where the business model but also the BIM one will be required to be presented. If the solution gets the approval, the construction phase starts, which involves the BIM usage to drive the technical implementation of the construction.

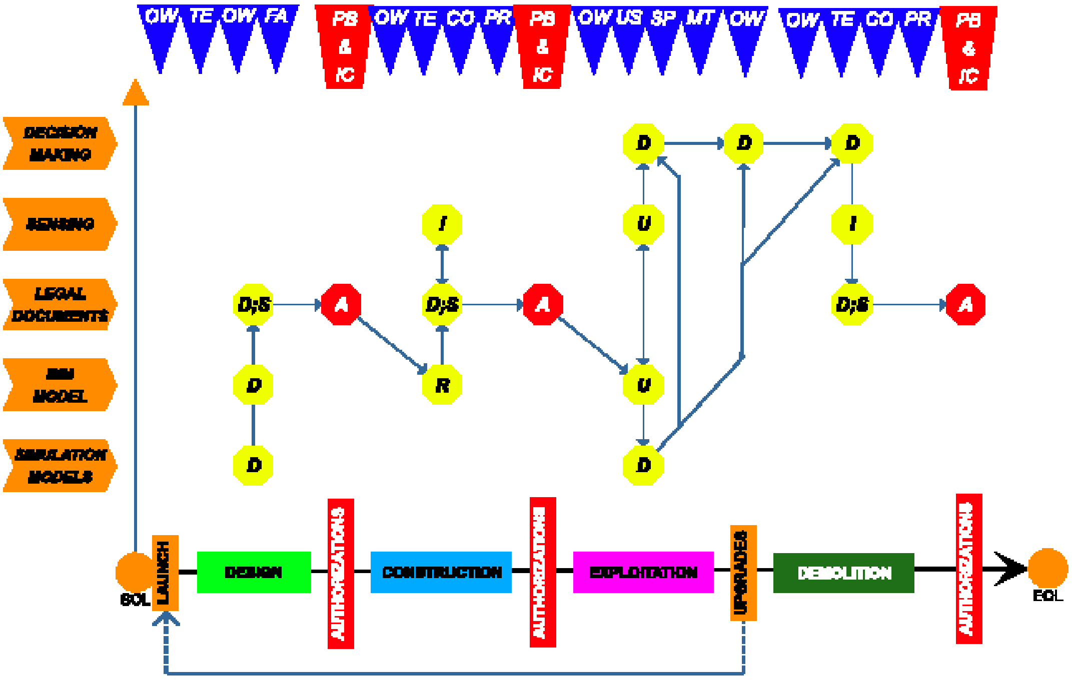

Figure 4. Reference framework connecting product phases along the X axis with type of digital elements along the Y axis and the agents on top. Notation: D=Develop, S=Submit, R=Rebuild, I=Install, U=Use, A=Approve. SOL=Start of Life, EOL=End of Life; OW=Owner, TE=Technical Staff, FA=Financing Agents, PB=Public Bodies, IC=Insurance Companies, CO=Constructors, US=Users, PR=Providers of Good & Services, SP=Service Providers; MT=Maintenance People, US=Users

Such framework is based on the agent's interaction depicted in Figure 5, which is also provided as matter of reference.

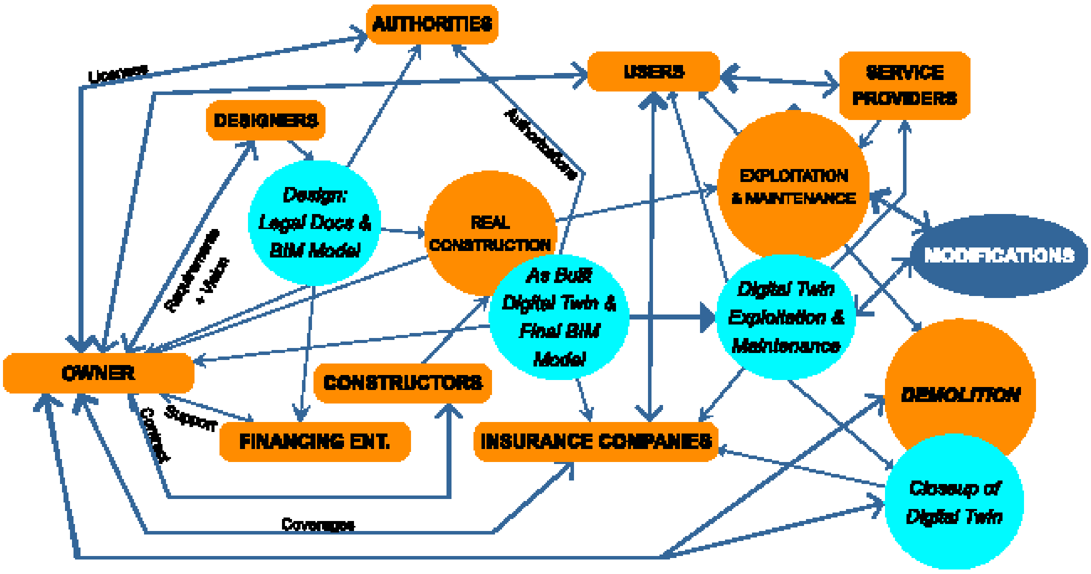

Figure 5. Interactions between agents around the construction, considering the different evolving states. Owner in our particular case is the operator of the infrastructure. Designers are responsible for phase0, contractors are those granted to carry out the field works. Users are airplane companies but also airport users. Authorities account for FAA, TSA, etc.

When the solution described above gets the approval, the construction phase starts, which involves the BIM usage to drive the technical implementation of the construction but also the Supply Chain Management as well as the selected sensing level decided for the usage of the product (buildings or infrastructure). When the upgraded BIM model, according to the decision taken during the construction phase, as well as all the required as-built documentation become ready, the authorization for services and exploitation happen. After its approval, the exploitation phase starts, which means that different agents, like the users appear, including potentially the ownership transfer process. However, because of the existing upgraded BIM model, and the live information provided by the installed sensors in accordance to the BIM model, different decision makers can utilize different tools, including simulation models to contribute to a better usage of the product. The usage can be complemented with maintenance, operational decisions, etc. Such operations can include at some point in time to start revamping of different elements or installations. Such events have been considered in the life cycle as a loop to the design step, covering obviously only the decided items. Finally, at the end, when approach the end of its life the decision making process will require the preparation of the legal documents, including the plan for dismantling it.

From the proposed framework it becomes clear that different agents will require different access levels to different digital elements. Indeed, it appears as evident that it will happen a continuous data production from different sensors that could benefit to different agents during their own decision making processes.

Therefore, in order to configure an actionable proposal the framework requires a complementary proposal of potential implementation for such combination of digital storage for very different elements, including digital models, as well as for live data, in such a way that enough guaranties for decentralized, privacy, trustworthiness, fare-less and support for the required dynamic behavior.

As different agents require different level of access in different periods of time, the proposed framework, as the general description of the interaction among those actors needs to be matched to an operational strategy able to facilitate such access. Therefore, either the owners of the construction product or its users will probably need get access to the legal authorization but, to grant traceability, probably other information like the constructive project or the models used into the design process or modification processes are also collected. From this perspective, different type of objects need to be stored, and different type of agents need to get access to different components.

To provide a convenient and flexible operational strategy enabling to handle relevant information, this paper proposes to store encrypted objects in a proper containing structure able to deal with such complexity level. Those different type of objects like BIM models (original, as built, upgraded, etc.), FEM models, documents, excel files, Pdf documents, etc., can be placed under a logic hierarchical structure. To support such containing structure, this paper proposes the adoption of the Experimental Directory Structure (Exdir protocol), that can be translated into the HDF5 format (Dragly et al. 2018) and (Krijnen and Beetz 2016).

The (Exdir), an open specification for data storage in experimental pipelines, amends drawbacks associated with HDF5 while retaining its advantages. Exdir, on the other hand, uses file system directories to represent the hierarchy, with metadata stored in human-readable YAML files, datasets stored in binary NumPy files, and raw data stored directly in subdirectories. On top of that, Exdir is not a file format in itself, but a specification for organizing files in a directory structure. Exdir uses the same abstractions as HDF5 and is compatible with the HDF5, which enables the usage of their open source tools.

When longitudinal information through time is considered, it can be stored either on the same Exdir container or in different ones depending on the responsible author in charge. It is easy to understand that any refurbishment to be made needs to take care of the original design, i.e. to consume the existing information in the Exdir container, but it needs to deliver the new documents describing the proposal and the changes finally made. Such new documents can be placed in the same Exdir container, when the author is the same than the first project or under a new one when they are different.

One of the critical aspects to provide convenient access to the information is to have a distributed database providing support to data access for different agents, with the convenient privacy levels. It is proposed to adopt the IOTA protocol, which was designed to be lightweight and serving for secure data communication between IoT devices. It differentiates itself from traditional blockchain-based distributed ledger (DLT) protocols by addressing two major pain points: latency and fees. IOTA does not utilize the concept of blocks and miners. Instead, all transactions that want to be added to IOTA's distributed ledger, known as the tangle, must validate two unconfirmed transactions on the ledger by solving a low-cost computational proof of work (Brogan, Baskaran, and Ramachandran 2018).

To keep the owner aware of the different containers, their location (URL with the storage of Exdir container), as well as the potentially different encryption keywords to access the individual components, it is proposed to be configured as transactions, encrypted, and being headed to the owner's IoTA wallet and finally sent to them through the tangle. Therefore, they always can have a centralized access to the information, through time. When convenient, the owner can either have direct access to the elements into the Exdir structure to disseminate with any relevant agent or just to inform him where the appropriate Exdir container is located, as well as the unencrypting keyword for accessing the specific document.

When someone with the proper access rights to the information needs to upgrade the information, the same approach will be implemented, and a new transaction covering the Exdir object for the updated information will be published and the corresponding encrypted transaction will be headed to the owner. If a transfer of property happen, the former owner needs just to send one transaction to the new one, by giving him the URL and keywords for each of the Exdir containers related to the construction object.

The second relevant aspect is to enable the collection and or usage for data being produced dynamically for the construction object during its life. In order to complement and properly provide support to the dynamic behavior of sensors, a digital structure of objects is needed. This is evident as the location of sensors, their characteristics and other relevant information is supported by the BIM model.

Fortunately, the same protocol can be used to handle data streaming from different sensors as well as from service providers of different commodities, as far as they want to implement such option. In this case, full traceability about what and when the usage of such services are provided, in addition to the cumulative figures on monthly bases, by using the Masked Authenticated Messaging (MAM). IOTA offers the MAM extension, acting as a second layer data communication protocol making it possible that sensors can broadcast encrypted, authenticated data streams being transmitted through the tangle as zero-value transactions. Such architecture can enable to introduce different monetizing approaches as potential agents interested in the data streams can subscribe to them, if the decryption keys have been given, in addition to the interested subscribers, which can send back to those smart sensors messages or instructions when convenient.

In this way, the proposed framework can support the different agent activities related to the whole life cycle of the airport pavement activities under control, including plans, daily activities, reports, tests, etc., where a relevant managerial dimension allows to grant access to the relevant stakeholders. All the records, covering every single phase, can be indexed by using the described approach, and when encrypted, the symmetric keys can be stored into smart contracts, to get them at safe, and releasing them when appropriate conditions are met.

5.- CONCLUSSIONS

This paper has proposed a framework able to integrate from a relational point of view the different stakeholders involved in the different phases of an airport pavement management, enabling to handling in an effective way all the relevant information regarding the works being carried out as well as the data streams from different devices and sensors involved in the process.

Although it is a step forward regarding the common way of managing these activities in most of the cases, a limitation is the lack of skills in all the stakeholders as well as the long ride ahead in order to establish a strong and highly standardized procedure conveying the different practices making it possible to enable the full exploitation of the information collected from different stakeholders during the process. To this end, it is envisaged an enormous potential benefit from the semantic description of the different objects in such a way that integration of information can be interoperated throughout automatic services.

The expectation in terms of management from these systems and services is to facilitate the regular exploitation of data through time, enabling more sustainable control processes and being more focused on adding value to the management chain and reducing effort in accessing and comparing information in a more manual approach. As just one example, these frameworks will foster the usage of predictive models and survival estimators for pavements according to what-if conditions related to weather, operations or both, which is hard to accomplish in an automatized way with the current systems of management.

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