

Cultural heritage management from traditional methods to digital systems: A review from bim to digital twin

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Abstract. In each phase of work, the client should be able to analyze, assess, and manage project quality according to their specific needs. Traditionally, this verification and control process is manual, relying on drawings, images, and renderings to evaluate design quality and alignment with client expectations. However, when requirements change, it becomes challenging to ensure the project still meets the client's demands. Digitization processes enhance collaboration between contractors and designers through analysis and control tools that facilitate data sharing and ensure compliance with specifications. Despite the lack of traditional management data making, it difficult to quantify economic benefits precisely, digitization coupled with facilities management (FM) has proven advantages. Real-time access to complete and accurate information optimizes activities and saves time otherwise spent searching for necessary data. The research aims to review the evolution of building heritage management from traditional methods to digitization systems, highlighting the key differences these new systems bring to existing buildings, whether historic or simply old.

1 Introduction

The energy consumption required for the production and transport of building materials as well as for heating, cooling and lighting of buildings are all significant contributors to carbon emissions. Air pollution, climate change and the depletion of natural resources are all environmental problems caused by this excessive carbon footprint. In addition, the global population is expected to increase in the coming decades. This will increase the demand for housing and energy.

Carbon-consuming activities can be significantly reduced by increasing the lifespan of existing structures and infrastructure. Retrofitting buildings to increase energy efficiency and using sustainable materials during construction can help reduce carbon emissions and reduce the environmental impact of the building sector. Therefore, to meet the growing demand for housing and energy consumption, retrofitting existing structures and infrastructure is crucial. The built cultural heritage (BCH) offers a unique opportunity to

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create sustainable solutions to address the problems created by urbanization, population growth and climate change. When we talk about built cultural heritage, we refer to buildings, landscapes and infrastructure that have architectural, cultural and historical significance and are valued by communities for their symbolic meaning.

2 Literature review

Every building, regardless of its type, whether existing or new, requires constant care to ensure high-quality operation. The management of the building determines this care. The functionality and appearance of buildings (their structures and the technological equipment housed in them), as well as the preservation of their design parameters throughout their life cycle, are mainly influenced by appropriate use and regular quality maintenance, which are an integral part of facility management.

Throughout the world, the term Facilities Management (FM) refers to everything from property management, financial management, change management, human resources management, health and safety, contract management and maintenance to construction and engineering services, as well as housekeeping and service delivery. The spectrum of FM is therefore fascinating as it encompasses a wide range of activities from cleaning to corporate real estate operations (“Facilities Management - Evolution and Importance,” n.d.).

2.1 Facility management: briefly history

Price asserted that FM origins derive from the role of caretaker or superintendent of a building, who is primarily concerned with the maintenance, cleaning and security of tenants. [1,2]

Price further explained that due to the growth in the complexity of buildings and the significant costs associated with their operation, it has become necessary to introduce both tactical and strategic management functions. This has led the discipline to rise to the level of other support activities such as human resource management and information technology. [1,2] Although FM's prediction of becoming “part of the language of business by the end of the century” has not been fulfilled, it continues to attract increasing attention. [3] Thus, Price argued that facilities management has difficulty in correctly defining what it is and where it is going. The question is why FM is still strong and growing day by day in today's world of service-oriented business management. [1,2]

Earlier facilities were more modest and few physical resources were available for maintenance. Business equipment was simple, the Internet was not widely used, databases were limited to individual computers, networking was limited to telephones and the mode of communication was more focused on physical meetings. But the 20th century brought significant changes.

Cabins are replaced by cubicles and sophisticated modular furniture systems are available. Shared facilities are an accepted phenomenon, life is networked and the Internet becomes a key infrastructure. The way modern business operations are conducted is influenced by the transformation of workstations into technologically advanced work IDs. New problems arise for the workplace and its management. As working life has become more complicated but highly efficient, customers begin to demand more support. This was the moment when FM became popular but above all became an important function for the company.

FM has a development of about 38 years in the USA when it was first recognized as a specialized business function. The following is a chronology of its milestones (“Facilities Management - Evolution and Importance,” n.d.).

- 1978: The Facility Management institute (FMI) was formed

- 1980: The National Facility Management Association (NFMA) was organized in the U.S
 - 1982: The idea of FM Integrating Functions evolved
 - 1986: IFMA released first official Statement of Facility Management
 - 1987: The Japan Facility Management Promotion Association (JFMA) was established
 - 1991: IFMA defined 8 competencies as areas a facility practitioner needed to be experienced in
 - 2009: A new global job tasks analysis defined 11 core competencies
- Nowadays, FM has become much larger and now includes buildings, staff and business centers.

2.2 Facility management: general aspects

Almost two thirds of the total life cycle cost of a building comes from facility management activities. [4]

The definition of Facility Management, as given by the IFMA website, the most authoritative association on the subject, and the UNI standard, is as follows:

- IFMA – “Facility management is a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology”.
- UNI EN 15221 – 1:2007 – Terms and definitions – “Integration of processes within an organization to maintain and develop agreed services that support and improve the effectiveness of its primary activities”.

These definitions are very broad and can easily include strategic, analytical and managerial elements, defining an all-encompassing scope, far from being just an operational role. However, they focus on activities limited to the built environment, ignoring the impact that the facility manager as a consultant could have on the design and construction phases of the building.

"Facility management is the practice of coordinating the physical workplace with the people and work of the organization. It integrates the principles of business administration, architecture and the behavioural and engineering sciences." [5] FM is a multidisciplinary approach that incorporates individuals, locations, procedures and technologies to ensure the efficiency of the built environment. FM encompasses maintenance management, energy, space, resources, building performance, control management, sustainability management, emergency management and other building management activities. However, still making use of 2D drawings and traditional facility management systems, FM managers find it difficult to obtain details [6,7].

Facility management responsibilities depend on the sector and size of companies. Facility managers are responsible for a wide range of facilities. The main role of managers is to manage a variety of activities, such as property management, capital projects and planning, occupancy and space management, lease administration and accounting, and work experience. In addition to the activities mentioned above, there are also significant ways to improve skills in each area that will help the manager realize his or her plan. Firstly, this involves ensuring efficient operations, creating an environment that supports productivity, finding and adopting technological solutions, ensuring compliance with regulations, reducing energy consumption costs, reducing risks to employees and equipment, and reducing the carbon footprint of the real estate portfolio [8].

The financial value of facility management is clear. The second highest cost for an organization is real estate, and good facility management can save up to 30% of expenses [9].

Research by McKinsey & Company states that most projects are 80% over budget and 20 months behind schedule. Up to 45% of the total project cost can be saved by using capital project management technology plans [10].

3 Digitization of cultural heritage management: from BIM to DT

AEC-FM is in the middle of the fourth industrial revolution, a period of inevitable digital transformation [11].

It is well known that heritage management and conservation require time and energy. Much is done every day to preserve the integrity of the built heritage and prevent it from deteriorating. The documentation, study and conservation of the built heritage has become more technologically sophisticated over the last decade, which has led to a greater diversity and complexity of information sources. The collection of data from drones, electronic distance measurement (EDM), 3D scanning, global positioning systems (GPS), photogrammetry (terrestrial aerial, etc.), data structuring (CAD, BIM, GIS, etc.), geographic information and data dissemination (CAD, BIM, GIS, etc.), has helped to create digital representations of the built heritage, which allows for more efficient planning, predictive maintenance and strategic management. Otherwise speaking, heritage digitization has provided not only a visual representation of heritage, but also a technological solution to effectively manage heritage conservation [12,13].

3.1 Bim for the management of the cultural heritage

BIM was initially developed for new construction with the aim of increasing competitiveness in the construction industry by reducing construction costs and time and avoiding a significant number of errors during construction. This complex and collaborative process enables more effective management of all the information associated with a site during its life cycle. At the beginning of a project, a complex digital 3D model composed of intelligent elements is built, constantly updated, and used as a platform to exchange information with all stakeholders to achieve these goals [14].

Over the past few years, a great deal of research has focused on the potential of BIM to meet the needs of heritage conservation professionals. This research has shown that, once integrated with highly detailed documents, BIM can be used in a conservation project.

One of the new technical breakthroughs in efficient heritage documentation and management is the implementation of the BIM technique in 3D geometric modelling with the integration of physical, functional and semantic features [15].

Murphy was the first to present the idea of HBIM. He described it as “a new solution whereby interactive parametric objects representing architectural elements are constructed from historical data, these elements (including details behind the scanning surface) are accurately mapped onto a point cloud or image survey” [16].

Actually, the main difference between BIM and HBIM (heritage building information modelling) is the creation of the digital model at the beginning of the project. The former requires a digital representation of the current condition of the site based on a complete and accurate survey, historical research and on-site observations, while the latter requires the design of the entire model from the sketch phase onwards [17].

Then, by modelling them in 3D, linking them to any related data and assigning them properties and attributes, a digital library of all the building elements that make up the monument is created. In addition, a digital model of the HBIM process can be created by mapping the building elements onto the point cloud to incorporate additional information on geometry, material and characteristics.

The data are organized and integrated into a digital model, which can be used on a platform where stakeholders can work together to manage the data. To keep the model up-to-date and always provide a clear understanding of the evolution of the site, additional datasets will be progressively integrated together with the different phases of the asset life cycle (design and research, construction, management and operation, conservation, etc.). The structuring of the HBIM model and the centralization of data ensure that all information related to the asset will be digitally preserved in the event of the disappearance of the physical object.

However, it is important to bear in mind that value assessment acts as a crucial link between preliminary investigations and the subsequent phases of a conservation project, such as design, construction, operation and maintenance. It also plays an important role in the development of conservation strategies. Only when compared with other data such as the legal status of heritage sites and their current situation, statements of significance can have a significant impact on the development of such strategies (pathologies). With this in mind, efforts should be made to incorporate these parameters into the HBIM process so that the conclusions of the initial surveys and value assessments are linked to the later phases of the heritage structures' life cycle (design, construction, operation and management, etc.).

3.2 DT for the management of the cultural heritage

HBIM is becoming increasingly used in heritage conservation and it is proposed to develop a DT with the integration of HBIM. [18]

The digital twin concept and its principles are increasingly being used to facilitate facilities management and optimize operational efficiency at both the building and city level. The most difficult phase in the life cycle of the built environment is facilities management, which requires the integration of the operation of multiple systems and a combination of the management of human and system functional activities in order to meet the requirements of sustainable living. As the circular economy is being considered, facilities management is a crucial factor in taking initiatives that show sustainable development among existing buildings.

Heritage management is more challenging than general facility management activities. Two of the main problems for heritage conservation are predictive maintenance and monitoring of heritage performance. Consequently, these are the main problems for heritage facilities management that require digital solutions.

Researchers have made many efforts to prove that DTs can solve problems in the sector. However, they are still limited to a few pilot projects in civil engineering [19]. However, researchers and practitioners agree on the crucial role that the DT paradigm could play in the AECO domain, particularly in improving the growth of sustainable management of built assets.

A variety of scenarios need to be examined to assess the ways in which real-time data exchange can be successfully used in the context of built heritage conservation (BCH). It should be noted that historic buildings can suffer damage and degradation over centuries. In contrast, exceptional events such as earthquakes or hurricanes have a low probability of occurrence but can have significant consequences for the economy and society.

While authorities and governments make great efforts to safeguard iconic buildings, this method is not economically viable on a large scale due to the large number of historic buildings in cities, particularly in Europe.

The definition of a DT becomes impractical when quantitative data, such as material properties and a complete geometric description, are difficult to obtain. Therefore, the development of digital tools and numerical models that can simulate a variety of scenarios, perform a significant number of calculations in a short period of time and take into account

the variability of certain parameters is the most rational application of the DT paradigm. Computational results need to be stored and analysed to create engineering graphs and decision-making tools for a rational approach. These predictive tools should be integrated with non-destructive testing (NDT), using these semi-probabilistic models to optimize economic resources for retrofitting design and structure testing.

To achieve the full potential of DT in BCH conservation, additional research and innovation opportunities need to be pursued. These include the creation of a methodological framework for the implementation of a structural DT, the creation of a systematic comparison between DT and HBIM concepts to clarify their differences and connections, the development of DT as a computational model for simulations and predictions, and the increase of practical implementations in the field of structural engineering and BCH conservation.

The correct implementation of the DT paradigm with the use of its essential features would be essential not only for the BCH digital documentation problem, but also for the entire preservation planning process. Indeed, the use of DT as a computational model and for the analysis and interpretation of data with probabilistic tools would enable the implementation of targeted preventive preservation strategies.

3.2.1 Digital twins

Many times, the concepts of Digital Twin and BIM are confused. The main task of BIM is to expand the 3D model of an object in the real world, while a Digital Twin emulates what it reflects.

What can the Digital Twin do for the construction sector? Before answering this question, we need to understand what a Digital Twin is. There are many definitions of this term as it is used by a variety of industries (e.g., aerospace, marine, offshore and aerospace). However, in 2019, the CIRP, Encyclopedia of Production Engineering, provided a definition of the term Digital Twin that seems to satisfy most situations in which it is used: "A digital twin is a digital representation of a unique active product (a real device, object, machine, service or intangible good) or a unique product-service system (a system consisting of a product and a related service) that encompasses its selected characteristics, properties, conditions and behaviors through models, information and data within a single or even across multiple life cycle stages." [20].

The use of models to represent reality is nothing new in engineering. In the 1967-1972 Apollo program, NASA built physical 'twins' of spacecraft. [21] However, the creation of virtual replicas in digital computer space was only possible in the last quarter of the 20th century.

Many people, attribute the Digital Twin concept to Michael Grieves, who gave a presentation on product lifecycle management in 2002 [22,23,24]. Grieves showed all the essential components of a Digital Twin model in his presentation: the real and virtual object as well as the collection and processing of data between digital copies and physical assets. Grieves' initial definition was a 'conceptual ideal for product lifecycle management'. Later, Grieves changed it to "Mirrored Spaces Model" and then renamed it 'Information Mirroring Model'. Finally, in 2011, Grieves collaborated with NASA's John Vickers in an article and used the term "Digital Twin" [20].

However, research has recently addressed the common misconception that a digital twin cannot exist without a physical object [25]. Whether a digital model is designed to become a physical product with a physical counterpart is the main criterion, according to Grieves, for determining whether it is a Digital Twin. In this case, Grieves offers an excellent example. We cannot make a Digital Twin a physical object.

4 BIM vs DT in the management of the cultural heritage

Unlike other sectors, the implementation of DT in civil engineering has been influenced by the pre-existence and widespread adoption of the BIM paradigm, particularly in the operation and maintenance (O&M) phase of modern buildings. However, it is common for the literature to overlap DT and BIM technologies [26-29]. Although DT has become a buzzword in the construction industry, its fundamentals and applications are still unclear.

Typically, BIM can only provide static data about the built environment and cannot automatically update the data in real-time models without having additional data. [11] The integration of real-time sensing data and static information provided by BIM models has become possible with the advent of the Internet of Things (IoT), which is defined as the interconnection of sensing devices that can enable the exchange of information between different platforms [30].

Intelligent tools allow real-time environmental data to be visualized and analysed in BIM models, and BIM models to be automatically updated according to the state of the building in real time. For example, real-time monitoring of the construction process and the state of the building's internal environment can be helped by proper integration of BIM and IoT technologies. [31-34] The Digital Twin emerged as a result of the integration of BIM and IoT [35-37].

It is clear that BIM helps to manage the physical and functional characteristics of a building during its design, construction and operation. Consequently, users need to understand that DT goes beyond BIM. Its purpose is to create a digital replica of a physical asset, such as a building or infrastructure, using real-time data and analysis to provide information on its performance, maintenance needs and problems that may arise. In other words, DT is a model that continuously changes and interacts with the physical asset.

The DT definition is often confused as an essential geometric digital representation of an asset. This overlaps with CAD and BIM, computer-aided design. The only thing that distinguishes a physical asset from any other digital model or replica is how it is connected to its digital counterpart. Dynamic information such as forces and loads, temperature variations and velocity-dependent phenomena are gathered through this connection. [38] Therefore, while CAD models are static representations of shapes, a DT should primarily be seen as a computational model capable of analysing and predicting the behaviour of physical resources in variable situations rather than as simple geometric representations. [39] A DT should be considered a paradigm rather than a technology. A DT is the idea of managing and interpreting large amounts of data to exploit the knowledge of an asset. [40]

The difficulties with the use of DTs in the management of heritage facilities focus on maintenance, operation, facility management and resource management. First of all, the development of a DT requires the creation of a significant amount of data, which is one of the main technical challenges for database development. Firstly, a huge volume of digital data includes historical information, building structure, system functions, building perspectives and data from multiple timelines; secondly, the development of structured and semantic databases is necessary due to the inherent differences in datasets in terms of semantics, geometry and development levels; third, the adoption of enabling technologies such as BIM, building simulation, virtual reality, machine learning, IoT to create a building replica is required; fourth, data management processes, such as defining the nature and content of data and translating professional practice into data input and output, require significant input [35,36]. Existing literature shows that researchers have engaged in the creation of process management mechanisms to map the decision-making process. Consequently, HBIM should be integrated during the development of DTs.

5 Conclusion

Management of the entire lifecycle of an asset cannot be provided by a digital model alone, particularly during operation and maintenance.

Information-based systems, such as BIM, which seamlessly integrate information, will enable advances in AEC-FM operations and improve project efficiency and effectiveness throughout the project duration. However, BIM will not meet the automation needs in the AEC-FM sector, nor will it address the smart data revolution and interoperability issues. In the AEC-FM sector, where there is minimal research, BIM needs to be combined with emerging technologies to improve building management and design.

Although there are problems with the integration of BIM and IoT and the processing of accumulated data, BIM has the advantages of already being implemented for many resources. The advantage of the Digital Twin is that it has a solid basis for data processing and integration with BIM.

Digital twin assets can enhance AEC-FM operations by improving data management and processing using data, information, knowledge integration and large-scale synchronization. This is possible by dynamically integrating data and information throughout the life of an asset.

In the AEC-FM sector, Digital Twin technology is still being developed and implemented. AEC-FM's Digital Twin research saw a significant increase in 2019. The implementation and adoption of Digital is expected to increase despite being associated with a number of problems, such as limited data sharing, project inefficiency and the absence of a collaborative lifecycle approach. The article sought to provide an overview of the evolution of AEC-FM operations by highlighting the potentials and difficulties developed in the course of their modernization. It will be a challenge to try to overcome the obstacles in this regard and move towards an increasingly efficient management of assets, be they historical or simply "dated".

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