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Real time facility management: assessing the effectiveness of Digital Twin in the Operation and Maintenance phase of building life cycle

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Real time facility management: assessing the effectiveness of Digital Twin in the Operation and Maintenance phase of building life cycle

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Abstract. The current scenario of the Architecture, Engineering, Construction and Operation (AECO) industry outlines an accelerating approach to digitalisation which is defined PropTech (abbreviation for Property Technologies). Among all the digital innovation brought to AECO, PropTech companies are introducing digital technologies in the Operation and Maintenance (O&M) phase of the building lifecycle to improve operational efficiency, performance of an asset, and effectiveness of provided services and supplies. Analysing the literature scenario of O&M phase, Building Information Modelling (BIM) and Digital Twin (DT) have resulted in a methodological innovation for the entire industry. Thanks to Internet of Things (IoT), the advent of DT makes its way into the building sector allowing among all to monitor the as-is conditions, detect anomalies before they occur, make diagnosis, and give an added value with respect to the BIM. Although DT is in its early stages, in the real estate market, some PropTech companies have embraced the challenge and applied the digital technology for building management. Therefore, the paper aims to analyse the numerous advantages of DT in the management of buildings. For this objective, the authors referred to two case studies, taken from the Italian PropTech Network ecosystem, that implement DT in management of O&M phase. On one hand the authors present the benefits of facility management digitalisation introduced by DT; on the other, they underline the issues faced by the two companies and the future implementations of DT in the O&M field.

1. Introduction

The widespread adoption of Building Information Modelling (BIM), Internet of Things (IoT), and Artificial Intelligence (AI) offers several new insights and decision-making capabilities for the optimisation of all phases of building life cycle [1]. This has brought to the new concept of Digital Twin (DT), which aims to control the physical asset simultaneously with the virtual asset in order to seamless manage and control of the building life cycle. However, DT in the built environment is still a new narrative, especially while managing the Operation and Maintenance (O&M) phase. Therefore, the present study conducted a review on real applications in order to access the advantages of using DT in the building management. This study has the potential to demonstrate to the lecture benefits and issues faced by real DT application, which contribute to enlarge the discussion on the adoption of digital technologies in O&M.

1.1. Technological innovation: PropTech

The technological innovation of sectors has been called Industry 4.0 [2]. This digitalisation is the most impactful drivers in economic for accelerating economic growth and productivity [3]. Existing companies may get several benefits from the digital transformation, such as process improvements, operational efficiency, or competitive advantage [4]. Even if digital transformation is affecting all the sectors, the knowledge-intense ones (like Media, IT or Professional Services) have been the digital frontiers, while agriculture, hospitality, and construction have been lagging [5]. Nevertheless, the digital innovation is gradually impacted the Architecture, Engineering, Construction, and Operational (AECO) industry. This technological innovation has been defined both by academia and professionals as PropTech (abbreviation for Property and Technology) [6]. Gianluca Mattarocci [7] pointed out that there are two ways to explain the meaning of PropTech. First, PropTech is seen as a support tool to improve efficiency and effectiveness of the construction process. Second, PropTech is technique, a method or a device that can change the development process of construction products, services, and management.

AECO industry is benefiting from PropTech for reducing delay in operations [8], increasing transparency [9], efficiently managing inspections [10] and visiting sites [11], or controlling processes (Saull et al., 2019). PropTech represents the massive implementation of emerging technologies to allow construction and real estate companies staying smart, sustainable, and inclusive in today's global business [12]. The concept of PropTech, firstly developed in 2017 by Oxford University School of Business[13], became the concept for radically introduce new approaches in the industry [14]. Even if the concept started to describe the digitalisation waves of the real estate sector, nowadays digital applications for the general construction sectors (such as, drones for site management) are listed in the PropTech maps of several networks. PropTech is still a new phenomenon, that is growing up over time and deeply itemising the different clusters, such as ConTech (Construction Technology) for smart cities and building applications, and FinTech (Financial Technology) for financial operations of the AECO industry [14].

There are both opportunities and risk in using technologies in the AECO industry [15]. Digital technologies attract more investors, increase the participation of stakeholders in design and property development processes, and optimise the use of buildings. On the other hand, there is the high risk of failures if the innovation is not supported by performance increase. Therefore, even if Breasemann and Baum [6] determined that the core business of the construction and real estate sectors remains to be material and space-based, PropTech applications prove that all information on using, managing, and owning buildings and buildings' operations can be digitalised.

Digital technology brought to the AECO industry three main emerging themes: (i) glocalisation of the sectors, (ii) pivotal role of data, and (iii) "platformisation" [6]. Instead of just improving processes, PropTech solutions make AECO data centric by supporting the information management process, which includes collecting, structuring, storing, analysing, and updating data [16].

1.2. Technology: from BIM to DT

Eddie Holmes, co-founder of Unissu[1] pointed out that PropTech business is firstly a company that supplies technology for the underlying property asset lifecycle (from build to demolish and all what is in between) [17]. The scientific literature focuses on several applications of specific technologies for building management, such as satellites and drones for property inspections [10], automated valuation models for operations [18], virtual and augmented reality (VR and AR) for site visits [19], and blockchain for land registration process [11]. According to the Joint Research Centre (JRC) of the European Commission on Digital Transformation in Transport, Construction, Energy, Government and Public Administration[2] , digital technologies in AECO can be identified as sensors, IoT, mobile internet, additive manufacturing, automation, 3D scanning, drones, BIM, VR, AR, and AI. These technologies are defined disruptive because they can introduce new business models and provide considerable advantages in terms of productivity, cost savings, improved quality, and innovated services [20]. The centre of digitalisation in the AECO industry is characterised by the effective use and elaboration of data. BIM, VR, AR, AI and IoT are some examples of interconnected technologies where the processing

[1] The largest network of PropTech worldwide – Accessible on: https://www.unissu.com/

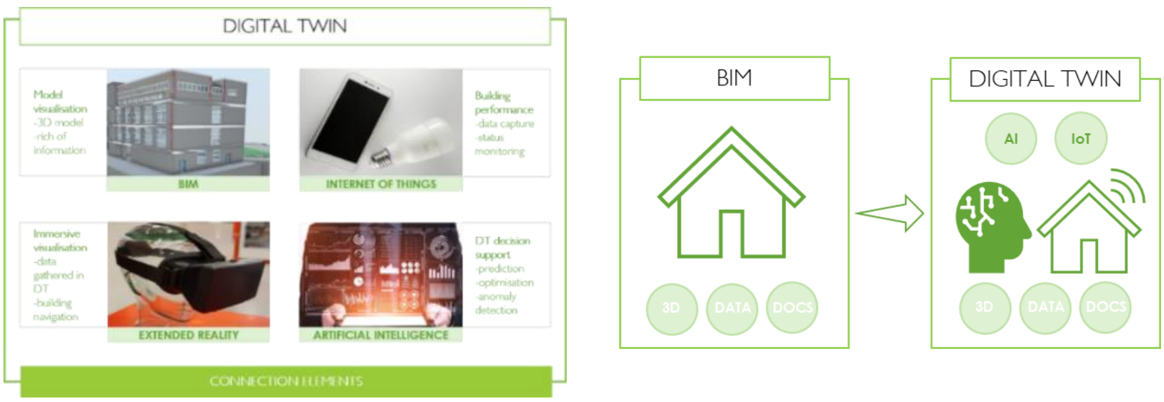
[2] Accessible from:
hhttps://publications.jrc.ec.europa.eu/repository/bitstream/JRC116179/jrc_digital_transformation_final_on_line_en_baja_resoluci%c3%b3n_online.pdf

of data enables improvements and transformations. The integration of these technologies is changing the way buildings are managing by introducing a new concept, namely Digital Twin.

When dealing with digitalisation in the AECO, BIM is one of the most used terms. The term BIM can refer to "the use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions" [21]. It describes an activity, a technology, or a process and not directly an object. Instead, BIM model is used to indicate the output of the modelling activity. Since many definitions of BIM exist, it is necessary to specify what BIM is not, namely models that contain 3D data without (or with a few) object attributes, models without any supports for parametric behaviour, models consisting of multiple 2D Computer Aided Design (CAD) reference files, which must be combined to define the building, models that allow dimensional variations in a view without reporting them automatically in other views. Thanks to BIM, collaboration among several stakeholders and stages of the building process is possible and the information related to the asset can be integrated within the 3D model. Therefore, there is a transformation from a paper-based process and graphic representations by CAD to an interoperable workflow where different tasks are integrated all together resulting in a coordinated and collaborative process that exploit computing capabilities, web communication, and data aggregation [22].

According to the need to monitor and control buildings, the AECO start to integrate other technologies (such as, IoT and AI), which brought to the diffusion of DT [23]. As for BIM, there is not a univocal definition of DT [24]. It can be defined as "a realistic digital representation of assets, processes or systems in the built or natural environment" [25]. Real space, virtual space and the data flow between the previous two are the necessary elements for the DT development [26]. DT is not intended as just a 3D visualisation of the asset, but thanks to the IoT devices integration within it and AI presence, as well as with the possible exploitation of extended reality, it is a realistic representation of the asset with its performances in real-time (see **Figure 1-A**). The most used DT applications are real-time monitoring, diagnosis, performance simulation, and prediction [27–32].

The strengths of adopting BIM during the design and construction phases felt in the O&M. As building performance monitoring is a crucial activity during O&M phase, the access to real-time data is essentials. This is generally not taken into consideration into a BIM context [33]. Thus, the frequency of collecting data and updating the model is the main different between DT and BIM. Even if some common elements may suggest that BIM and DT are synonymous, many studies consider the BIM model as the starting point for the DT creation. BIM can act as the viewed 3D model [23,34], which can be integrated with IoT devices to have a whole vision on building performances and access the real-time dimension [35] (see **Figure 1-B**).



A B

Figure 1. A) Digital Twin and most relevant technologies; B) From Building Information Modelling to Digital Twin.

Thus, monitoring is one of the main purposes of DT, which support facility management (see Table 1). The IoT devices allow to control the conditions of the building, capturing current conditions such as temperature, humidity, noise and occupancy. Checking the building performance is useful for the energy management and then for the sustainability assessment [36–38]. In addition, case studies exist in literature where DT is used for motion monitoring for a safety purpose [39], and it is applied for the management of the indoor safety checking the safety status. In addition, the monitoring of building conditions over time makes possible to carry out predictive analysis. This allows a predictive maintenance operations, which improve the efficiency of facility managers' decisions thanks to data support as well as equipment failure prediction [30,40–42]. Therefore, based on data analysis, which involves statistical theory, AI, and ML, the DT can be exploited for prediction use case. DT and IoT devices may also help facility managers in investigating users' behaviours in the buildings, and integrating in the management human comfort and preferences [43]. Finally, designers and civil engineers can use DT when designing a facility to simulate different scenarios. A lot of factors can be simulated, either directly in the twin or through connected simulation applications, such as structure, mechanics, energy, or natural VS. artificial lighting, or to estimate the effects of workers' actions on construction activities [44]. Therefore, the analysis of the literature, presented in Table 1, shows that the application of DT in the AECO, especially for optimise O&M phase, brings several advantages. Optimisation and prediction seem to be obtained thanks to the machine-man interface, which is more and more representative of reality. This allows an analysis of the status of the building like never before. The fields of application within the construction industry are different, with a prevalent growth in the O&M phase with the aim to improve facility management applications: from the monitoring to the prediction and simulation of conditions, from a simple system like a pump to the entire city.

Table 1. Application of Digital Twin. Example from literature analysis.

Author, year	**Objective**	**FM Application**			**Literature analysis**		**Selec -ted**
		Monitor -ing	Predict-ion	Simulat-ion	Case study	State of the Art	
[30] Errandonea 2020	Overview of DT in maintenance field	x	x		/	x	
[36] Tagliabue, 2021	DT framework for sustainability assessment through rating systems	x	x		eLUX lab cognitive building, Brescia (IT)		
[37] Zaballos, 2020	Smart campus based-DT concept for environmental monitoring and emotion detection	x			La Salle-University Ramon Llull, Barcelona (ES)		
[38] Francisco, 2020	DT–enabled energy management system	x	x		Georgia Institute of Technology, Atlanta. University campus		
[39] Hou, 2021	DT in Construction Workforce Safety	x			/	x	
[40] Khajavi, 2020	DT framework for enhancing sauna conditions	x	x		Sauna test bed		
[41] Lu, 2020	DT framework to detect anomalies	x	x		Cambridge IfM buiding (UK)		x
[44] Turner, 2021	Overview of DT capabilities	x	x	x	/	x	
[43] Dawkins, 2018	DT development for university campus	x	x		UCL campus (UK)		x
[42] Peng, 2020	DT development for China hospital	x	x		Shanghahospital, China		x

2. Methodology

Despite the various benefits and results achieved, the ongoing application of DT still requires study, collaboration between universities and companies, and efforts from the standardization point of view to standardise concepts, processes and information flows. Thus, with the aim to understand the real level of DT adoption in the real estate market, the authors analysed case studies from the literature and from the market. The literature case studies are selected among the ones presented in Table 1, while the market case studies have been selected among the Italian sample of PropTech solutions, defined by the unique

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Italian association of PropTech, namely Italian PropTech Network, that monitors the PropTech ecosystem since 2018. Italy has been chosen for two main reasons. (i) Italy is a moderate innovator, occupying a middle position in the European Innovation Scoreboard for 2022[3]. Thus, the Italian PropTech ecosystem may represent on average the European sample. (ii) Both the authors are Italian and operate in the Italian real estate market.

The methodology of this study is characterised by different steps, described as follows:

- Literature case studies: given the State of the Art analysis the most relevant and significant case studies about Digital Twin found in literature are investigated, analysing main common elements, advantages, and disadvantages.
- Market case studies: to confirm what founded in the literature, two market case studies are examined. The companies have been selected from the sample of the Italian PropTech Network for their special focus on DT and BIM. After a desktop analysis, the authors have interviewed the CEOs of these companies.
- Comparison among case studies: a comparison is performed to highlight benefits, issues, and gaps (to be implemented in the future) of DT applications in facility management.

The next sub-chapters analyse the different steps of the methodology that brought to outline the principal advantages as well as issues in DT development context.

2.1. Literature case studies: review process

Given the projected scenario, a literature review was performed as first step in order to have a clear overview of the research landscape around the target area. Common used keywords are digital technologies such as “Digital Twin”, “IoT”, “BIM”, “Extended Reality”, “AECO”. The literature search was done using the scientific database Scopus, with the following selection criteria:

- Articles should focus on the targeted areas: they should involve DT concept, digital technologies such as BIM, extended reality, and IoT in the AECO industry.
- Although journal articles are generally peer reviewed and could be considered more complete, in this literature review also reports and conference papers have been examined.
- Language filter has been applied to select only English or Italian documents.
- To allow free and unrestricted access to the content Open Access papers have been selected.

In particular, papers that contained the description of a developed or under development DT were analysed. Papers and reports about DT literature review were examined to determine and describe the research background, but they were not be considered as case studies.

2.2. Market case studies: selection process

Two Italian companies have been selected as “market” case study from the list of the Italian PropTech Network (IPN)[4], the only Italian association that collects PropTech companies in Italy. IPN is based in Politecnico di Milano and lists 273 PropTech companies divided into four clusters, Smart Real Estate, Professional Services, Real Estate Fintech, Sharing Economy, and ConTech. Among the ConTech cluster, the one more related to the construction and management field of real estate asset, just two companies (Ekore[5] and StrategicBIM[6]) integrate the Digital Twin to optimize the O&M phase.

After a desktop analysis on the respective websites, the call on Microsoft Teams were organized on 10/11/2022 with Ekore (Andrea Agostini, CIO and co-founder and Luigi Cesca, CEO and co-founder), and on 14/11/2022 with StrategicBIM (Roberto Demarchi, CEO and founder). The authors proposed the same questions to the two companies with the purpose to investigate: (i) the implemented digital platform and software; (ii) the type of data collected; (iii) the integration of the BIM model; and, (iv) the estimation of the return of the investment and some key performance indicators.

[3] EIS 2022 is one of the European indices that expresses the level of innovation of a country. Accessible from: hhttps://ec.europa.eu/research-and-innovation/en/statistics/performance-indicators/European-innovation-scoreboard/eis

[4] Accessible online: https://www.italianproptechnetwork.com/

[5] Accessible online: https://www.ekore.it/

[6] Accessible online: https://www.strategicbim.it/

Finally, the advantages and disadvantages of the DT applications have been confirmed also by one client company of StrategicBIM, Svicom. The authors had the opportunity to interview the head of Technical Department of Svicom, Chiara Mattei, on 14/11/2022. This third interview was important to add the point of view of a client company in the implementation of the DT.

3. Case studies analysis

3.1. Literature case studies

During the last years the concept of DT is growing in AECO industry, accompanying and partially replacing the concept of BIM, following the advancements of IoT and AI. Many studies try to embrace this new idea focusing the potentialities of DT on the O&M phase. The exploitation of DT wants to manage better the building and its facilities, reduce the energy consumption and improve the indoor conditions for users' advantages. The following sub-chapters describes three case studies of developed DT focusing on exploiting DT capabilities during O&M phase: a DT creation of two university campus (West Cambridge site and University College London campus), and a DT of an hospital (Shanghai East Hospital).

3.1.1 West Cambridge site. The University of Cambridge is responsible for one of the first DT developed in the AECO industry. The study is structured on the analysis of different levels, starting from the system, through the building and the whole campus. As a result, the digital model has a different level of detail – system level, building level, city level – depending on the specific area considered, from the whole campus to the Institute for Manufacturing (IfM).

The research group implemented the West Cambridge site with the purpose of: monitoring the asset conditions, increasing the maintenance in the IfM building (e.g., HVAC systems and lab equipment) by predictive data analytics and detecting anomalies exploiting Augmented reality [41,45].

For collecting geometric data about the campus and its buildings and external spaces, fixed wing drone scanning and vehicle-based scanning were used, while for developing a more detailed model of the internal areas of the building laser scanners and digital cameras were adopted with the collaboration of Bentley[7], GeoSLAM[8], and Topcon[9].

In addition, a series of sensors were installed on the campus and its buildings in order to monitor in real-time the general status and some specific conditions, such as energy consumption, occupancy, and air quality. Sensors and gateways communicate via radio frequencies, which act as transmitters and receivers within the sensor.

The DT integrates an as-is IFC BIModel, Building Management System (BMS) data, space management data, real-time data from IoT-based sensors and activity register data. Consequently, given different data sources, a platform and an information management system were created by Centre for Digital Built Britain (CDBB) researchers and Bentley to collect and manage all the different types of data in an efficient way. For the DT research platform, Autodesk Revit (version 19.0.1.1) was used to develop the .rvt model and then export it to .ifc (Industry Foundation Classes) files. It was developed based on AWS DynamoDB, Autodesk Forge (version 6.0) API, and web-based program design (i.e., .Net) using C# and Java script. While the commercial platform was developed with the cooperation of Bentley Systems.

The significant work of this DT is related to the provided guidelines and framework for replicability.

3.1.2 University College London campus. Another case study focusing on campus-scale and not only on building-scale is the DT of the University College London (UCL) campus at Here East located in Queen Elizabeth Olympic Park in East London implemented by the Bartlett Centre for Advanced Spatial Analysis (CASA) [43]. The 3D model is created using BIM and Lidar data acquired by Barlett scan group (Bscan).

[7] Accessible online: https://www.bentley.com/
[8] Accessible online: https://geoslam.com/
[9] Accessible online: http://www.topcon.it/

20 environmental sensors boxes have been installed to monitor temperature, humidity, air pressure and lighting level. Sensors measurements are updated every minute and they are collected in a cloud platform. They are visible in real time within the 3D model that can be investigated by the user in a platform built on Unity game engine. The 3D model navigation allows to monitor building's daily performance and the real-time detection of any anomalies by the changes in the DT. Additionally, the 3D model enables visualising and analysing the various sensors attached to the work locations, as well as measurements.

This case study reserves attention also to the relationship between the building and the physical and social environment, then an integration with the model of the Olympic Park of ViLo (Virtual London Platform) has been planned. The staff and the students can interact with the DT daily and as a result the definition of the impact of this on human behaviour could be retrieved.

3.1.3 Shanghai East Hospital. [42] developed a DT for the Shanghai East Hospital, considering the "continuous lifecycle integration". The authors propose a framework consisting in the modelling, mainly conducted with CAD drawings and 3D point cloud method, which generated a first static BIM model and then by monitoring processes through IoT sensor devices, a dynamic BIM or digital shadow emerged [46]. Among IoT devices, 1900 intelligent sensors were installed aiming to monitor air supply temperature and humidity, and CO2/CO concentration.

Raw data from the physical and digital shadow were processed through Apache Kafka engine as high-density stream data. Apache Flink engine and scheduled Extract-Transform- were used to transform analysis data of building status into a predefined data Warehouse; by the AI exploitation a diagnosis engine and diagnosis data are received. The problem detected is prompt back to visual management interfaces. Information and data from design to O&M are integrated into a DT system and the real-time status of the hospital building is displayed in a control centre room. Abnormal electrical usage detection, air-handling unit fault prediction and frequent repair pattern recognition are some of the DT applications for the O&M exploited by the authors.

The three case studies conclude that the DT application would optimise the facility management of buildings, but some general issues have been highlighted. First, the West Cambridge Site case study alert the huge work of data collection that is need before the implementation of DT. Second, the University College London case study concluded with the need to add more VR and AR in the DT in order to make it a more collective experience. Third, the Shanghai Hospital case study emphasized the financial risk in implementing a DT. Finally, all the case studies showed a possible private issue to take into consideration when collecting real-time data.

3.2. Market case studies

In order to define the real application of DT in the AECO industry, the analysis of two companies is fundamental to confirm what the previous studies have highlighted. DT has a huge potential in optimizing the facility management of buildings by reducing operational costs and minimizing energy consumptions; however, its implementation is still complex and needs a huge use of resources, both in time and in costs. This has been confirmed by all the interviewed companies.

3.2.1 Ekore. Ekore was founded in the summer of 2022, and it is the result of the competences of two Italian companies, Adhox srl, a consultancy company in the topic of BIM, and BeanTech, an Information and Communication Technologies (ICT) and IoT for the built environment company. Ekore is a platform for optimizing the Facility and Energy Management processes of the built environment by integrating several technologies together, such as BIM, IoT, and AI. The Ekore platform aims to solve the critical issues of the building management, including the Energy consumption, the difficulties in data collection, the use of several sensors without implementing a management network, and the scarce digital support of managing the building. Thus, Ekore proposes to its clients to build an "on-demand" technological structure for building management starting from the available data (such as, Excel files, energy and water bills, paper drawings, .dwg, BIM models, or BMS). Aiming to work as a Common Data Environment for its clients, the Ekore platform is based on two layers. First, Microsoft IoT HUB layer collects all the data coming from BMS structure and sensors and allows to visualize the BIM model (if present) through Autodesk Platform Services (formerly, Forge). Second, Microsoft Power BI analyses the collected data and generates reports. On this second layer, an AI algorithm is added in order to create an automatic structure for managing the building. This AI implementation allows the Digital Twin system to control the built environment, such as looking at the weather forecast to automatically act on the indoor environmental parameters, temperature, lights, and humidity.

Several types of data are collected by the Digital Twins implemented by Ekore for different clients. Indeed, the open structure proposed by Ekore allows to manage different parameters according to the needs of the facility managers. Since now, Ekore implemented 10 different Digital Twin platforms, collecting data related to the energy expenditures (electricity, fuel, and water consumptions), indoor environmental quality (temperature, humidity, noise, lights, and level of CO2), space occupation (specially, for office buildings), and stability of the building structure. The data collection starts with a detailed survey on all the documents available of the building. Some questions are related to generic data, such as the availability of .dwg drawings or BIM model; others asked the typology of installed plants, and the presence of a BMS network; and others investigate the maintenance and energy management with the collections of bills and maintenance programs.

The collected data are analysed in the digital platform and the user can see reports about savings (such as, operational savings, energy saved in MWh, and CO2 saved in tons), performance of maintenance activities (such as, number of tickets open, and time to close tickets), and performance of technical plants (such as, the operation of the electrical system). However, due to the novelty of these applications, Ekore is still not able to define the return on the investment of the Digital Twin implementations, but it was only able to estimate some savings of the 10 case study pilots: 40% of energy costs saved, 15% of facility management costs saved, and 30% of operational costs saved (mostly, due to cleaning activities).

3.2.2 StrategicBIM. StrategicBIM was founded in 2020 with the objective to make asset management simpler, connected, and digital. StrategicBIM has developed an own platform, called UTwin, to collect and manage building data throughout the Digital Twin. After the creation of the BIM model of the building, all the data coming from the different setpoints presented in the real building are collected into the digital platform and analysed to create reports about building management performance.

StrategicBIM and Svicom

Together with StrategicBIM, the authors had the chance to talk with Svicom, a client of StrategicBIM. Svicom is a property consultancy company, boasting a portfolio of 130 assets which include shopping malls, food halls, logistics and office buildings. StrategicBIM works for implementing a Digital Twin for a shopping mall managed by Svicom. This further discussion allowed the authors to understand the purpose of a client in implementing a DT and also the issues faced in the process. The objectives of the Svicom Digital Twin were illustrated by Chiara Mattei, head of Technical Department. First, Svicom had the need to centralise the maintenance management of the shopping mall. To do this, StrategicBIM implemented a integrated platform to collect all the maintenance information, manage the activities, and report the performance. Second, Svicom aimed to manage the spaces of the shopping mall dynamically. To do this, StrategicBIM offered a real time visualisation of the performance of the spaces, including the level of occupation of users. Third, Svicom addressed the need to visualize the location of the plants. To do this, StrategicBIM developed the BIM model of the shopping mall.

4. Results

From the analysis of literature and market case studies, a strong exploitation of DT during the O&M phase of the building asset emerges. Generally, what emerges both from the analysis of the literature case study and the discussion with the market case studies is the importance of understanding the purpose that the client has in implementing a DT.

From one side, the three literature case studies underline the main advantage of DT as its ability of monitoring not only the building structure, but all the building sub-systems and integrating users' behaviours. The primary objective is to improve the efficiency of the asset focusing on its environmental performances. Therefore, monitoring the indoor conditions is essential to assess the comfort of users and improve it. For this reason, different types of IoT devices are installed to collect and gather in a

BMS building-related information. Another interest concerns the maintenance topic as it is evident in West Cambridge campus and Shanghai hospital. In these studies DT is used to monitor the status of the building and its components (such as pumps) in order to verify potential damages and anomalies and promptly solve them. In addition, it makes use of AI to predict the behaviour and failures of the system before they occur by analysing available data.

From the other, the two market case studies show two different approaches of implementing DT. On one hand, Ekore proposes a data-driven method to implement the DT, which is not thought as a 3D visualization of the building, but it is the place to collect, manage and integrate data. Ekore proposes to build an ad hoc technological structure for the building under analysis, starting from the available data (e.g., .xls files, bills, paper drawings, .dwg, BIM models, BMS, etc.), creating an IoT network of monitoring and control of the real model, and implementing an analysis tool (based on AI). Over time, by collecting data from the real model, the analysis tool sends automatic adaptation impulses to the real building system, developing a Blockchain-based control and verification system for procedures/activities. On the other, StrategicBIM starts from the implementation of the 3D model to visualise the data throughout a digital environment. After the discussion with the client, StrategicBIM connect the data coming from the IoT with the digital environment represented by the BIM model.

Table 2. Literature and Market case studies comparison – elaboration of the authors.

	Company	Technological solution	Types of collected data	Calculated return of the investment	BIM model integration
LITERATURE CASE STUDIES	**West Cambrid-ge site**	AWS DynamoDB, Autodesk Forge API, web-based program design using #C and Java Script Platform developed via cooperation with Bentley System	Temperature Humidity Lighting, Energy consumption, Occupancy, Quality air	NA	Autodesk Revit used to develop the RVT model and then export it to IFC files
	Shangai East Hospital	Raw data processed through Apache Kafka , Apache Flink engine and scheduled Extract-Transform- used to transform analysis data of building status into a predefined data Warehouse	Filter status, air supply temperature and humidity, and CO_2/CO concentration	NA	CAD drawings and 3D point cloud
	UCL campus	Platform built on Unity game engine	Temperature. Humidity, air pressure, lighting	NA	BIM and Lidar data captured
MARKET CASE STUDIES	**Ekore**	Microsoft Azure Iot HUB Microsoft Power BI own AI algorithm (Machine Learning) Autodek Plaftorm Services (formerly Forge)	- Energy expenditures - Indoor environmental quality - Space occupation - Maintenance and Energy management - Building structure	- Not the total return of the investment for the digital twin implementation - Some savings: 40% energy costs; 15% of facility management costs; and 30% of operational costs	The BIM model is not considered essential for the development of the digital twin, which is implemented to manage the building by integrating data coming from several documents.
	Strategic BIM	UTwin	- Energy expenditures - Indoor environmental quality - Space occupation - Maintenance and Energy management	NA	The BIM model is seen as the first step to be implemented for developing the Digital Twin.

A comparison among the five case studies (Table 2) confirms the potential of implementing DT in facility management for optimizing O&M phase. DT is a complex monitoring and controlling system that needs the integration of several technologies (such as, digital model, IoT sensors, AI, and machine learning). However, two technologies result fundamental in the applications: digital model and IoT sensors. The first to visualize data and the second to collect data. In each case study the modelling is an important phase that works as the foundation on which to build the DT. In fact, the creation of the BIM model is essential to visualise the building in 3D and navigate it. In the DT development IoT plays a large role. According to the objectives, different types and number of sensors are applied in the building to monitor its performances and collect information about its status.

Even if the technological network built for integrating data from different sensors and return commands to building's systems is different, all the case studies collect the same typology of data. Especially, the main purpose of a DT is to optimize energy management and maintenance management. Therefore, data related to humidity, temperature, and indoor air quality are the most collected.

Finally, only one case, Ekore, has looked at the economic aspect of the DT implementation. A comparison and a general comment is not possible to be performed of this aspect, which is essential to understand the future development of such digital technology.

5. Conclusions

This paper has identified three case studies from the academia context and two market case study from PropTech to analyse the concept of DT and underline its main features in the O&M phase. The comparison reported by this study shows that the DT implementation is homogenous both in the academia and in the market. Generally, the study highlights the steps still needed to completely integrated DT in the facility management. All the analysed case studies agreed that a well-designed IoT network is fundamental to implement a working DT. On the other hand, the case studies do not concentrate on the return of the investment. This must be analysed in future improvements of this study.

The AECO industry is subjected to the increasingly use of DT given the potentialities of this technological solution. It is not a mere digital representation of the asset and for this reason it should not be confused with BIM. In fact, DT combines the virtual representation of a physical element and data of different nature coming IoT devices and AI analysis to not only monitor, but also control the physical asset. DT has the potential to make facility management predictive by learning, from input data (such as, weather forecast and users' behaviours), how to control the building's systems (HVAC, electricity plant, etc.). This makes DT fundamental in O&M phase for monitoring the conditions, checking the energy consumption, managing maintenance and eventual failures of building systems, improving the effectiveness of the building by solving promptly the issues and predict behaviour to manage better the maintenance. This huge potential defined by the literature case studies and remarked by the market ones goes together with the only problem of DT, its implementation complexity. Since buildings are complex environments, the data collection needed to implement the DT is hard. Adding to this the fact that DT is at its early stages, its implementation needs time and high costs. This complexity is more evident when talking with clients of DT applications, such as Svicom, which highlighted the hardness in collecting data, and the retention of facility managers and maintenance workers in using the DT. To answer this issue, both the interviewed companies highlighted the importance of firstly defining the scope of DT (such as, minimization of energy consumptions or optimization of maintenance activities), and secondly collecting all the available data (such as, CAD drawings, energy/water/fuel bills, and maintenance programs).

Although these difficulties, both the literature case studies and the market case studies saw a future in the implementation of DT for the managing of O&M phase of buildings. This seems the only way to make predictions, reduce the environmental impact, optimise the operational cost, and integrate users' preferences. In future, the possibility to add several technologies into the DT network will have the potential to solve other issues of the building management. For example, DT can be integrated also with Blockchain, as suggested by Ekore, in order to collect in only one chain all the information of a building. Or, as concluded by the University College London case study DT may be implement with VR and AR technologies to make the operations more a collective experience. Probably, this will bring to connect the Digital Twin with Metaverso, which is an emerging technology in real estate. In order to answer these questions, further studies need to be conducted. In particular, the authors need to go further the limitations of the present research that just compared two market case studies. The analysis of more case studies would improve the understandings of the benefits and of the issues in implementing DT for

O&M operation. In future studies, the authors will conduct an analysis on different PropTech ecosystems in order to compare different level of innovation market. Finally, a question that still needs to be answered is about the return of the investment of DT. Only Ekore case study started to compare operational costs, however due to the novelty in applying DT for O&M management is still complex the evaluation of savings. Therefore, future studies would also compare the “traditional” management with the “digital” management implemented by DT.

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