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Digital Twin in Facility Management: a Survey to Determine the Market Perception in Adopting Digital Technologies

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Abstract
In recent years, the Digital Twin (DT) has become an extremely popular technology in the Architecture, Engineering, Construction, and Operation industry (AECO). Its application benefits not only the design and construction phase of the building life cycle but also the operation and maintenance (O&M), supporting a more efficient facility management (FM).

The DT most widespread applications are real-time monitoring, simulation, diagnosis, and performance prediction. DT allows to detect anomalies before they occur and make diagnosis, helping the decision-making process, and thanks to the presence of IoT, to control the conditions of the building, capturing current conditions such as temperature, humidity, noise, and occupancy. Supporting the sustainable transition of the built environment, the main outputs of DT implementation are the improvement of asset performance and building management. However, its application in FM is progressing slowly, largely due to the complexity of buildings, which involve various components.

Given the projected scenario, the paper investigates the literature on the digital transformation in FM, identifying the advantages and disadvantages of digital technologies adoption and DT implementations. To outline the most common barriers that slow down this digital transformation in the FM market, the research develops a set of questions to collect opinions from a survey to FM operators. The study represents a preparatory investigation to compare academia and industry experiences on the introduction of digital technologies in the built environment during O&M.

Keywords: Digital Twin, Facility Management, Digital transformation

1 Introduction

Architecture, Engineering, Construction, and Operation industry (AECO) is well known as slow-moving, with significant low investments compared to others (Agarwal et al., 2016; Chen et al., 2021). Several factors characterized the slow adoption, such as the uniqueness of the products, its fragmentation, and the temporary nature of its supply chain (Brozovsky et al., 2024; Agarwal et al., 2016; Chen et al., 2021). Although this transformation is challenging, an increased research interest in digital technologies and novel conceptualizations of the phenomenon emerge (Brozovsky et al., 2024). Digitalization and its tools are a big change in AECO, bringing numerous benefits to the operation and maintenance phase (O&M) by optimizing the processes of management, use and maintenance of resources, and addressing sustainable development. Digital transformation is not only a mere technological change, but it involves also the strategic management of the built environment (Pomè et al., 2023).

Among other fields, Facility Management (FM) is highly impacted by the AECO digital transformation, which improves traditional processes by supporting data-driven decision-making. Thus, FM clients focus on strategies to prevent issues (e.g., equipment failures), rather

than proceed with a corrective maintenance intervention when the problem occurs (Deng et al., 2021).

Different technologies, such as Building Information Modelling (BIM), Internet of Things (IoT) devices, and Digital Twin (DT) can be integrated by platforms, that enable facility managers to generate new strategies. For instance, through dynamic dashboards, it is possible to control and monitor the performance of buildings and make future predictions. Different systems connected by IoT networks can be used to audit buildings, plan maintenance, manage the helpdesk, track the equipment, or organize the cleaning (Atta & Talamo, 2020).

The integration of several digital technologies makes the AECO digital transformation a generator of data and information. Based on the flow of information coming from different contexts and disciplines, DT may foster digital transformation in the industry. While technologies like DT can optimize FM processes, they also introduce various complexities, particularly in older buildings that lack a foundational technological infrastructure and systematic data collection. The added level of complexity that requires a data management approach, especially during O&M, introduces one of the biggest challenges in FM: interoperability and exchange of information (Shaw et al., 2021). The slow FM digital transformation is influenced not only by internal factors within the industry, such as the high complexity of buildings but also by external factors, such as the low willingness of stakeholders to embrace change (Brozovsky et al., 2024).

Therefore, it is essential to analyze the phenomenon from various perspectives, including the market's viewpoint. This study aims to discuss the potential benefits and barriers of DT integration in FM to highlight the digital transformation process of the field. After discussing the results of the research background, the study distributes a survey to FM operators working in the Italian market to gather the market overview.

2 Research methodology

To compare the discussions of the literature with the market's viewpoint, the study is structured in four steps (Figure 1). First, the topic of digital transformation and the adoption of digital technologies in FM, especially DT, are investigated in a research background. The analysis of the literature helps identify the main pillars of digital transformation in FM and the development of DT through case studies. Second, to understand the drivers and barriers of the FM digital transformation, a set of information is collected by a survey process. As outlined by other similar studies (such as the IT barometer ones), a smaller market is selected for this preliminary study to assess the response capability of respondents (Davies Kathryn, 2010; Howard et al., 1998). Thus, due to the geographical area of the authors' activities, the Italian market is selected. Italian FM operators are asked to (i) discuss the adoption of technologies to digitalize FM processes, and (ii) highlight the implementation level, potential benefits, and challenges of DT. Third, to confirm the drivers and barriers, survey results are discussed and compared to the outcomes of the research background study. Finally, conclusions outline future developments of the research, which aim to be a preparatory investigation for the comparison of academic and market outcomes in adopting digital technologies in FM.

After reviewing different studies that conducted surveys to understand the adoption of digital technologies in AECO (Chen et al., 2021; Khosrowshahi & Arayici, 2012), this study implements the FM survey as described in Figure 2. According to this process, the initial steps require to understand the background and to identify the objective of the research (Boparai et al., 2018). In this study, the survey needs to confirm the outcomes of the research background, concerning the FM digital transformation and the market adoption of DT. Although an already validated survey framework (such as the IT barometer of Howard et al., 1998) is preferred to carry out this kind of research, the absence of studies outlining the digital transformation of the field requires to this research to design a new survey framework. According to the significant changes in the AECO digital transformation, the discussion of technologies adoption in previous studies would prevent highlighting the market's opinion on digital transformation. Thus, by defining the target audience (i.e., FM operators), and the online platform (Brace, 2008), the survey is published to collect results. On the one hand, the collected answers are used to present the response rate and

respondents' profiles. On the other, opinions and scenarios provided by the Italian FM operators are used to present drivers and barriers of the FM digital transformation.

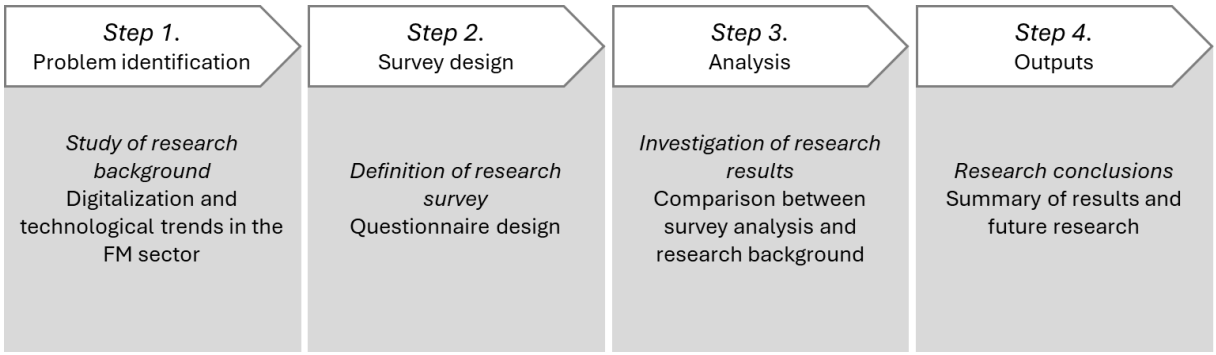

Figure 1. Research methodology steps

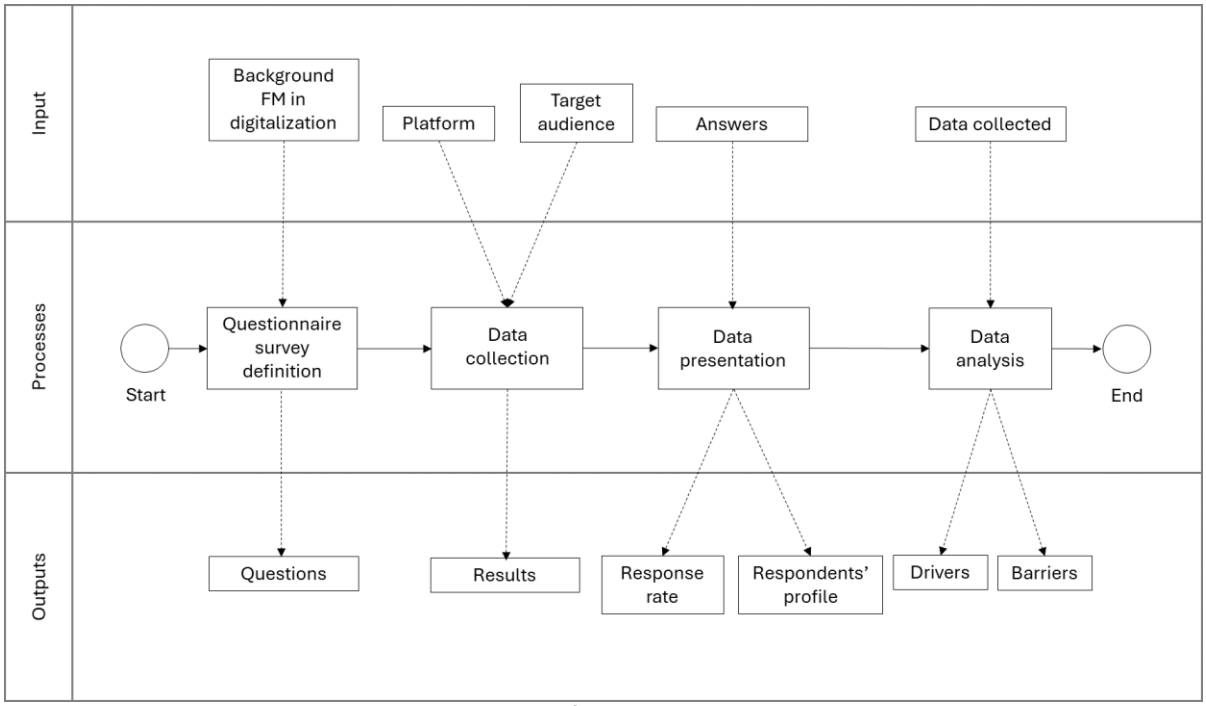

Figure 2. Main phases for the survey implementation

3 Research background

Over the years the focus of FM has changed from cost reduction to value creation (Kaplan & Norton, 2000). FM is especially affected by two disruptive phenomena that are emerging in AECO, namely sustainable development and digitalization. This twin transition, as defined by the European Union, asks the built environment to become "smart" and "sustainable". In this context, FM becomes strategic due to its connection with the value creation of businesses, and its ability to create new values for organizations. Moreover, by addressing the need to reduce the environmental pressure of O&M, FM is improving the management of the built environment and optimizing the well-being of occupants.

The role of FM in organizations is highly strategic for the development of businesses. Jensen identified two levels through which FM brings value to organizations (Jensen, 2019). First, FM outcomes are included in the development of organizational processes at the top level. Second, FM resources (both, facilities – real estate assets and technologies – and activities – human power and knowhow) affect the core business with 6 impacts (i.e., satisfaction, cost, productivity, reliability, adaptation, and culture), and the surrounding of organizational activities with 4 (i.e., economic, social, spatial, and environmental). By impacting society, customers, staff, and owners, the high complexity of FM operations makes the organizational value chain strongly dependent

on the success of FM (Scupola, 2019). To improve FM efficiency and optimize FM impacts on organizational businesses, FM needs to translate toward emerging features, meaning sustainable development and digital transformation (Jensen, 2019).

The critical role of buildings in minimizing the pressure of worldwide economies on the environment highlights the urgency of AECO to become more effective, efficient, and productive. The opportunity to improve operations and processes for achieving maximized performance, optimized productivity, and increased communication is given by digital technologies (Aliu & Oke, 2023). Moreover, among building life cycle phases, O&M is the longest and the most expensive, both economically and environmentally (Shvets & Hanák, 2023). In this regard, FM becomes strategic to optimize the overall industry.

The adoption of digital technologies results in significant improvements in FM operational efficiency and sustainability performance (Lok et al., 2023). Several studies discussed the improvements of digital technologies in O&M. For example, dynamically adaptive systems for self-maintenance and machine monitoring (Mourtzis et al., 2017) or IoT sensors for data collection (Lok et al., 2023) allow to make informed decisions about O&M activities. Or, intelligent algorithms, wireless technologies, and networking infrastructures make FM a smart management approach for buildings (Kumar et al., 2022). Finally, the use of smart management reduces the environmental impact of buildings by saving energy for lighting and HVCA systems or reducing operational costs (Choi, 2019). These examples confirm that digital technologies maximize FM operations in different ways: lower downtime, better sustainability, and more energy savings (as described by, Atta & Talamo, 2020; Zhan et al., 2023). However, the implementation in the market of these technologies is not smooth due to several barriers related to resisting in change, lack of investment, and complexity of buildings (Brozovsky et al., 2024).

3.1 Review of digital technologies adopted in FM

The digital transformation of AECO is coming from Industry 4.0 (Brozovsky et al., 2024), which is defined as the shift of the manufacturing process towards a self-regulating approach for value creation, an increase of decentralism, and integration of technologies (Hofmann & Rüsch, 2017). These processes represent a substantial opportunity for AECO to enhance productivity and efficiency (IPCC, 2023). According to Modery et al., four are the keys of digital transformation: digital data, automation, connectivity, and digital access (Modery & Valderrama, 2021). Thus, to support the value creation of organizations, FM needs to bring these keys and start using digital technologies.

Brozovsky et al. identified 38 categories of digital technologies that are affecting Construction 4.0 (another name for digital innovation in AECO). Investigating the major digital trends in FM, BIM, and DT are two of the most searched keywords (Siccardi & Villa, 2023). Along with them, IoT, Blockchain, Artificial Intelligence (AI), and Immersive Reality define the potential application for a digital FM. Even if the comparative study of Chen et al. recognizes the use of BIM and cloud technologies in AECO operators, the integration of this technology in O&M is rare and IoT is generally exploited for monitoring assets (Chen et al., 2021; Siccardi & Villa, 2023). Analysis of data from IoT systems allows to use the connected digital models to improve future design and building performance, reduce waste, prevent accidents, and optimize inventory management. IoT networks can help information-sharing and communication, providing a quicker decision-making process (Naji et al., 2024). BIM, even if it is not so widespread in the FM, can be considered as an interface to implement IoT and real-time data (Mannino et al., 2021). The combination of BIM and IoT results in DT, which aims to provide a virtual replica of the physical asset for real-time monitoring and data analysis (Naji et al., 2024; Siccardi & Villa, 2023). DT technology is implemented mainly to enhance FM in O&M performance.

Although technologies have the potential to improve interoperability and optimize information exchange within the industry, the fragmented nature of AECO and the lack of standards are factors that slow the digital transformation (Mannino et al., 2021; Siccardi & Villa, 2023; Zhan et al., 2023). In particular, given FM multidisciplinary nature, various activities, interactions across several domains, and hence the generation and sharing of various types of information. This presents challenges related to supporting author-authored file formats,

integrating software solutions, and accessing building data. Indeed, the interoperability between construction applications is crucial for the advancement in the use of digital technologies (Khosrowshahi & Arayici, 2012). Since data originate from many sources, interoperability remains one of the most frequently cited issues in digital FM (Shaw et al., 2021). Furthermore, besides producing vast and varied amounts of data, there is often no bidirectional exchange between different technologies, because they frequently "speak different languages", making the exchange of information difficult and inadequate. In this regard, Semantic Web (SW) technologies could support data integration. With the advent of SW, ontology represents a fundamental notion, that can be used to address the need for semantic interoperability by providing a shared understanding of common domains and by exchanging data and metadata in standard format. A great amount of data resulting from the O&M and the use of IoT devices necessitate data management based on the use of SW technologies (Shaw et al., 2021).

By defining terms and background, guiding the research, helping in developing new approaches, and encouraging collaboration between research and standardization bodies (Klungseth et al., 2023), standards in the digitalization process facilitate the integration of FM and digitalization management (Lok et al., 2023). For example, buildingSMART has brought improvements by developing the standard IFC to ensure the sustainability and transparency of the built environment information by guaranteeing delivery in a non-proprietary, commercially neutral format (Shaw et al., 2021).

Finally, technological maturity is still low in the FM sector even if the digital trends are significant. There is a need to integrate facility and sensor information to develop and use an intelligent management system and understand better the correlation among various facilities. In this way, it is possible to incorporate real-time monitoring of facility status and have a context awareness to identify the event and response. In addition, the use of AI for its skill to make predictions and capture risk level values in real-time is another step that could be taken (Pedral Sampaio et al., 2023). Then, there is the need to increase data interoperability and enhance IFC open standards and data specifications. Future studies are needed to find a standardized solution to integrate and manage different data and to develop other digital solutions such as Augmented and Virtual Reality and their application with BIM in the AECO (Mannino et al., 2021). Future research needs to focus on data management and analysis considering different sources of data. Consistent standards and interoperability guidelines to facilitate digital technologies integration are fundamental (Naji et al., 2024).

3.2 Digital Twin in FM

The birth and rising affirmation of DT have become increasingly essential in AECO (Boje et al., 2020). The authors have previously studied its impact within the FM area in a paper to which reference is made for further details by investigating case studies from the Italian market that use DT in the management of the O&M (Pomè & Signorini, 2023). Given the literature review and the previous study, some key points can be drawn, highlighting benefits and issues in DT adoption.

It is typically represented as being made up of several technologies, as the literature indicates, that allow for the fulfillment of particular needs. Thanks to the DT concept, it is possible to make data-driven decisions in operations, engineering, construction, and architecture, making DT a crucial enabling technology. The analysis of this technology reveals that DT enables early anomaly detection and diagnosis, supporting the decision-making process. Additionally, the IoT supports control over the building's conditions, capturing real-time data on temperature, humidity, noise level, and occupancy. Thus, the potential for O&M optimization through the use of DT in FM is growing. Among the benefits, it is an instrument to monitor building conditions, check energy consumption, manage maintenance, make predictions, mitigate the ecological footprint, optimize running expenses, and incorporate users' preferences (Lu et al., 2020; Peng et al., 2020; Pomè & Signorini, 2023). Building maintenance could benefit from DT through the use of platforms accessing real-time data and checking maintainability (Hosamo et al., 2022). Therefore, predictive maintenance, space use optimization, building safety, energy management, user comfort, and productivity improvement are other DT uses typical in FM sector (Meschini et al., 2023; Naji et al., 2024). Moreover, building management issues could be resolved by integrating

other digital technologies within the DT. For instance, DT could be used in conjunction with VR and AR technologies to enhance the experience of the building operation (Dawkins et al., 2018).

However, DT creation is complex and resource intensive, requiring time and high costs because of investments in hardware, software, and professional training are necessary (Meschini et al., 2023; Pomè & Signorini, 2023). In addition, DT implementation is affected by issues such as interoperability, inefficient integration, inappropriate management of information, data collection given the complexity of buildings, limitations in data sharing, lack of data in FM, barriers in the use and management of knowledge through the life cycle of a project (Hosamo et al., 2022; Ozturk, 2021).

4 Survey design

To confirm the results of the research background, a survey, divided into three sections, has been conducted on FM operators of the Italian market. The study adopts an explanatory survey approach to collect information on the digitalization status among FM operators (Boparai et al., 2018).

After profiling the respondents (Section 1), the survey explores the presence of digital technologies in FM, identifies which technologies offer significant opportunities for optimizing FM, examines the aspects of FM most impacted by these technologies, and highlights the main challenges in their adoption (Section 2). Section 3 is entirely dedicated to DT as a supporting technology for FM. Respondents are asked to assess how well this technology supports FM practices and to evaluate the barriers to its adoption. Finally, the survey inquiries about the level of DT adoption.

All questions are in closed format, with multiple-choice or rating questions set on a 5-point Likert scale, where 1 represents "Very insignificant" and 5 represents "Very significant". The survey was carried out through Qualtrics as a platform that allows easy accessibility and sufficient flexibility. The link to the survey was distributed through LinkedIn between April 2 and May 5 2024. A total of 50 respondents started answering, however just 28 completed the survey. Although the survey was distributed to a potentially large pool, the responses collected were sufficient for an initial analysis of the phenomenon. Especially because the respondents are well-distributed across the relevant categories, provide a representative perspective of the context. Specifically, 27% of the respondents are facility managers, 9% work in the FM department, 27% provide FM services, and 37% provide FM technology services. Additionally, only 9% have been working in FM for less than a year, while 68% have been in the field for at least six years, indicating a strong knowledge of FM practices.

5 Results and discussion

Based on the profiling of the respondents, the primary activities performed in their FM roles include maintenance management (82% of respondents), energy management, and space management (respectively, 32% of respondents). Conversely, only 9% indicated involvement in food services management and other services, such as control management. In executing these activities, 45% of respondents use digital systems, such as project management software for data exchange, while 50% utilize digital and automatized systems, such as ERP software. This indicates a significant level of knowledge and willingness to adopt new technologies.

However, the use of technologies in FM does not fully reflect the adoption of digital technologies in FM operations. Among the digital technologies categorized by Brozovsky et al. (2024), only “Website and Smartphone apps” are the most commonly used, rated 3,1 on a scale from 1 to 5. This is followed by “Computer Edge and Cloud” (rated 2,8), and “Management systems, such as AMI, BAS, BMS, and CAFM” (rated 2,6). Technologies, such as BIM, DT, AI, and ML have lower adoption rates, with an average rating of 2,0. Behind these, there are only Extended Reality (including, Virtual and Augmented Reality – evaluated 1,8), AI Chatbot, and Blockchain (rated 1,7). This comparison highlights that the digitalization process in FM starts with basic digital tools and progresses through monitoring and control systems, with the potential to evolve into more advanced AI and ML-based systems. Encouraging the development of open platforms and strengthening collaboration among FM team members is crucial for digital

transformation. This confirms the study of Chen et al. (…) that demonstrated the importance of targeted efforts to improve digital competence and support the emerging technologies in the industry.

Although FM is gradually embracing digital transformation (Mourtzis et al., 2017), the potential benefits of adopting digital technologies are substantial. Investigating which digital technologies offer the most opportunities for FM, "Big Data Analytics, Data Science, and Data sharing", and "IoT" (selected by 70% of respondents) emerge as the most significant, followed by "BIM" (55%), "AI and ML" and "DT" (45%). Only technologies such as "5G network," "Robotic systems and automation," "Human-machine interface," and "Blockchain" remain at the bottom of the list of technologies that could contribute to digitalizing FM. This is also confirmed by investigating which three main digital technologies will have the greatest impact on FM. Ranking the technologies by impact, respondents indicated "DT", "BIM", and "IoT network and sensors" as the top three (Figure 3). The survey results confirm the findings of the research background: DT is interpreted as a potential major innovator in FM practices.

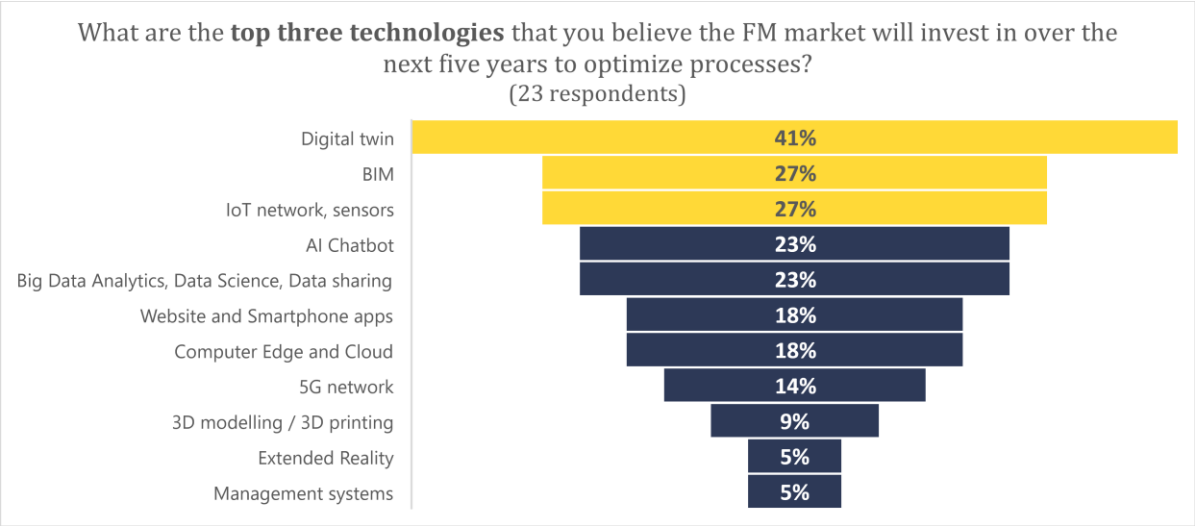

Figure 3. Representation of the main digital technologies that will impact the FM market in the next 5 years – elaboration by the authors from the survey's results

Several studies (including, Hosamo et al., 2022; Meschini et al., 2023; Naji et al., 2024; Siccardi & Villa, 2023) suggest that digital technologies benefit FM service performances by (i) improving identification, visualization, and diagnosis of problems; (ii) introducing interoperability, flexibility, users-friendliness for FM operators; and, (iii) encouraging collaboration and flow of information optimization among departments. This is also confirmed by the survey, as the potential impact of digital technologies in FM activities is ranked very high (Figure 4-a). In particular, respondents believe that over the next five years, technologies will primarily impact building energy efficiency, decision-making processes, maintenance, and the productivity of FM processes. This aligns with the literature, which highlights a close connection between sustainable development and the digitalization process (Pomè et al., 2023; Pomè & Signorini, 2023). However, several challenges will continue to hinder the digital transformation process. Respondents highlighted the high cost of technological investments as particularly significant (ranked 4.4), followed by the lack of effective data processing methodologies (ranked 4.0) (Figure 4-b).

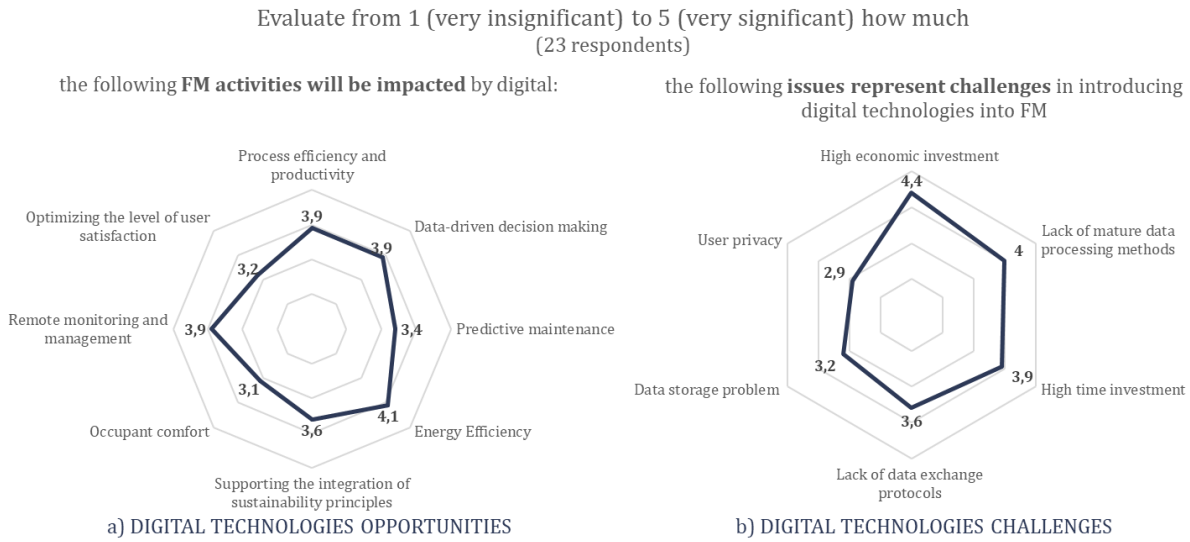

Figure 4. Representation of the (a) opportunities and (b) challenges of introducing digital technologies in FM - elaboration by the authors from the survey's results

The same studies (Hosamo et al., 2022; Meschini et al., 2023; Naji et al., 2024; Siccardi & Villa, 2023) outline that DT represents a significant opportunity to innovate FM activities, especially due to the ability to integrate the predictability into operations and make decisions based on comparisons between various simulations. From the survey analysis (Figure 5-a), it emerges that the DT represents a great opportunity for integrating various FM processes to optimize the management of operations (ranked 4.2). Although DT is considered the best technology to enhance interoperability in FM (ranked 3.2), respondents agree that its implementation in FM practices will be limited over the next 5 years. This is due to several significant challenges (Figure 5-b). Respondents rate the impact of costs and the need to train new workforce for introducing DT in FM very highly (both ranked 4.4). These issues are followed by concerns about the management costs of DT control software. Surprisingly, the data audit received a lower rating of 3.2. This demonstrates the operators' willingness to introduce digital practices to improve FM operability. However, only 13% of respondents declare to have implemented DT in their FM practices.

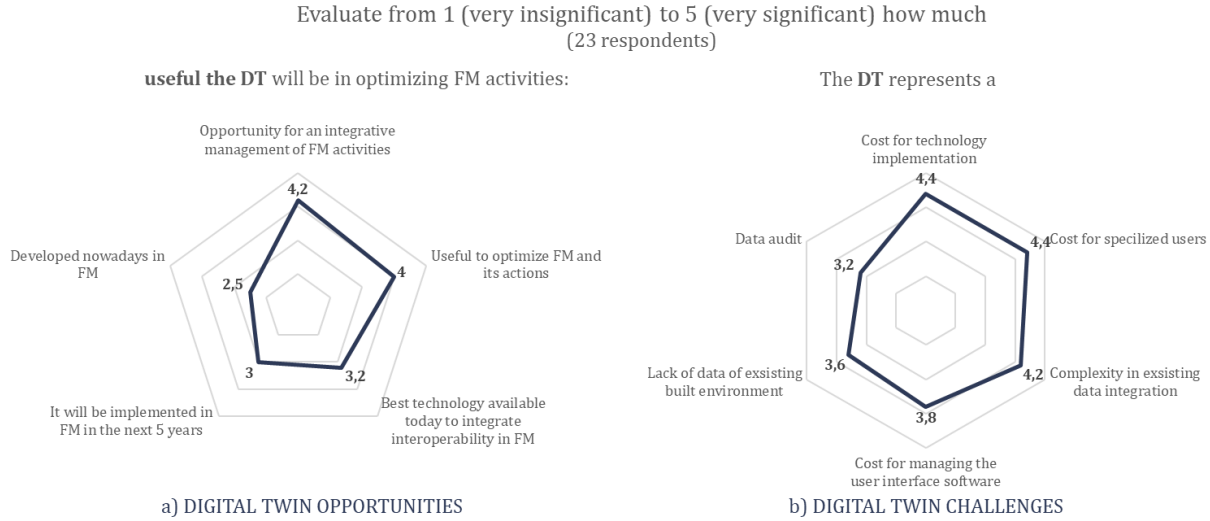

Figure 5. Representation of the (a) opportunities and (b) challenges of introducing the DT in FM - elaboration by the authors from the survey's results

6 Conclusions

The digital transformation of FM represents a great opportunity to boost the AECO digital innovation, which also supports the transition towards sustainable development principles. Moreover, among various digital technologies, DT emerges as a key technology for innovating FM.

Confirming the background research study, the survey reports that DT has not yet been fully implemented in the market, even if respondents identify its potential as a major innovator. Indeed, in the Italian market the digital transformation diffuses through the adoption of other digital technologies, such as AI, ML, and IoT networks. The survey also corroborates the slow digital transformation of FM due to the high cost of implementation, the need for training operators, and the difficulties in adapting systems and processes to new technologies (meaning, interoperability). Finally, respondents discuss the relevance of humans in the digitalization process, due to their extensive knowledge about the building and users' behaviors. Although the research is limited as it only explores the Italian market, it confirms that digital transformation, which is recognized as essential for improving the field, can occur just according to the willingness of operators to change.

Future studies will expand the sample of respondents by integrating a qualitative approach (such as interviews and workshops) to gain deeper insights from target operators. Finally, efforts will be made to extend the study to markets of other countries for comparing the adoption of digital technologies and especially the implementation of DT in FM.

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