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Digital transformation in facility management: An analysis of the challenges and benefits of implementing digital twins in the use phase of a building

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Digital transformation in facility management: An analysis of the challenges and benefits of implementing digital twins in the use phase of a building

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Abstract. Digital transformation and the adoption of technologies in the AEC-sector can lead to efficiency gains in facility management (FM). Digital twins, that is a living representative of the physical asset building, can facilitate real-time data gathering, data monitoring, data-based decision making and support predictive management. The purpose of this study is to analyse the gap between theory and practice regarding the application of digital twins for FM and to understand the benefits and challenges connected with its implementation during the use phase of a building. Despite the growing interest in this topic in academia, the concept of digital twins in connection with FM is rarely employed in practice in the AEC-industry. The findings obtained through a literature review and a set of semi-structured interviews with experts in the field, show that the main challenges for digital twins in FM relate to the organisational culture and that a robust framework for information management is a benefit for digital twins' implementation. The adoption of digital twins in the built environment needs to be considered in the context of digital transformation. The study supports practitioners with the adoption of digital technologies for the built asset and suggests that future research should examine in further depth the challenges of implementing digital twins.

1. Introduction

The way the building industry manages its projects has dramatically changed during the last decades due to technological advancements in software, applications, and technologies [1,2], moving towards digital transformation on different levels and introducing several potential advantages through the asset lifecycle. Based on the definition provided by Savić [3], digital transformation involves strategic and cultural change within organisations, using modern information technology [3]. Despite the different definitions that can be found in the literature [4], experts agree that digital technologies support the digital transformation process [3].

Digital transformation can have positive effects on facility management (FM). By applying digital technologies FM can obtain major efficiency gains and cost savings. For example, the annual operation cost (including energy, cleaning, security and operations) for an office building in Norway represents approximately 66% of the total annual cost for the use phase (operation, administration, and maintenance) [5]. A more efficient process would provide significant cost savings [5].

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Many technologies can assist organisations going through digital transformation; however, this paper focuses on digital twins. Digital twins can be implemented for the use phase of an asset and can help bring tangible benefits within the context of sustainable production and maintenance [6]. However, regardless of the potential advantages that could be achieved with digital twins, Errandonea et al. [7] underlined how the practical application of this technology within the built environment is advancing slowly, while research and literature studies about digital twins in connection with FM have significantly increased over the last few years.

This study contributes to closing the gap between theory and practice, by offering an analysis of the benefits and the challenges of bringing digital twins into practice during the use phase of a building and in connection with FM practices. The research question formulated for this study is as follows: *What are the benefits and challenges of implementing digital twins in facility management (FM) practice?*

The main challenges for digital twins in FM seem to relate to people and organisational culture. To achieve higher value and bring innovation within the architecture, engineering, and construction (AEC) sector, the adoption of digital twins needs to be considered in the context of digital transformation. The findings of this study were obtained through an analysis of the literature and a set of semi-structured interviews with experts in the field. The following section describes the theoretical background for the study and presents the concepts of FM, digital transformation and digital twins. Section 3 explains the research method and section 4 describes the findings. The conclusions provide a series of recommendations for practitioners and researchers who wish to explore the topic further.

This study is developed in connection with the research project Bridging the Gap. This research project is in collaboration between NTNU and the industry partners – the building owner and FM service provider KLP Real Estate Trondheim, the entrepreneur NCC Buildings Nordics and the architect Pir 2. The aim of the research project is to examine the development of digital twins from the perspective of FM. The project Bridging the Gap starts from the assumption that the adoption of digital twins in the use phase of a building differs from the design and construction phase. This gave inspiration for this paper to contribute to understand the application of digital twins in the use phase of a building.

2. Theoretical background

FM is defined by the International Organisation for Standardization (ISO) as an ‘organisational function which integrates people, place, and process, within the built environment, with the purpose of improving the quality of life of people and the productivity of the core business’ [8].

A mature and effective FM approach can enable organisations to achieve a competitive advantage, but a robust infrastructure for information management and automated processes is needed [9]. As stated by Atkin and Brooks [10] ‘information is (the) lifeblood of FM; without it, the organisation is not in control of its facility assets and it unlikely to be able to account for them reliably’. Many technologies can support FM in their efforts to deliver efficient services to organisations such as: Building Information Modelling (BIM), Computerized Maintenance Management System (CMMS), Virtual Reality (VR), Augmented Reality (AR), Internet of Things (IoT) and digital twins. Dzulkifli et al. [11] provided an overview of how these technologies can assist FM. In short, CMMS can help to modernising maintenance methods and simplify the work orders and technical support; BIM can improve accuracy and accessibility of data and information; VR/AR can contribute to understanding information and minimising commuting times; and IoT can support predictive and preventive maintenance based on real-time data [11].

To enable the FM process, these technologies require well-structured data and information management about the building, elements and components [12, 13]. Patacas et al. [14] mentioned that information management can be a challenge in FM. In their study, they analysed different available data standards to develop a structured framework for information management in FM [14]. Similarly, Ghorbani et al. [15] studied information management for FM from the workers’ perspective. An essential requirement is interoperability. The concept of interoperability implies that the data generated by one system can be properly interpreted by all other systems [16]. Traditional as-built information, as well as dynamic real-time models, can be connected and transformed into a digital version that can be more readily updated using BIM. According to Mêda et al. [17], the connection between existing data and information and the sensored built environment is a relevant key issue, but it has not yet been at the centre of academic discussions. In addition, the implementation of these technologies should be embedded across organisations, businesses and projects to push fundamental changes [18] and achieve digital transformation. The digital transformation process requires strategic changes in the organisations, supported by digital technologies and tools [3].

The adoption of BIM has been considered a game changer in the building industry and FM sector [9] and in connection with digital transformation. More recently, however, some authors have investigated the benefits of moving from BIM to digital twins. For the purpose of this study, a digital twin is defined as a digital living representative of the physical asset building, capable of being aligned with FM tools. Lu et al. [19] from Cambridge University investigate digital twins in O&M and FM. In their latest research, they highlighted that 'Digital twins is more suitable for complex and comprehensive data management considering the limitations of BIM… because digital twins are built on data and have the capacities of integrating various data resources' [19 p. 53]. Digital twins are increasingly becoming a project deliverable from the design and construction phase to the operation phase of a building, which is managed by FM. buildingSMART International [20] highlighted in their report *Enabling an Ecosystem of Digital Twins* that digital twins are a relevant part of the digital transformation strategy, allowing data interaction between the physical asset and the digital twin. Opoku et al. presented several definitions of digital twins across different fields of application [21]. Many of the definitions presented were quite similar, but table 1 presents some of the variations they found. Further definitions of digital twins exist, such as that by Scheper [22], who defined digital twins as digital models, that are developed to imitate a real-world object or environment. According to Labonnote et al. [23], digital twins are digital representations of physical and complex objects and typically combine knowledge-based representations of the objects with data collected from sensors and technical systems. According to Fjeld [24], digital twins offer capabilities such as simulation, decision assistance, automation and integration, which are necessary to move the AEC and FM sectors into Industry 4.0, which entails a continuous interaction between people and technology [25].

Table 1. A selection of digital twin definitions based on Opoku et al [21].

Year	Digital Twin definition	Application
2013	A coupled model of the real machine that operates in the cloud platform and simulates the health condition with an integrated knowledge [32].	Predictive manufacturing
2016	A digital representation of a real-world object with focus on the object itself [33].	Industrial lifecycle management
2017	A set of virtual information constructs that fully describes a potential or actual physical manufacturing product from the micro atomic level to the macro geometric level [34].	Product lifecycle management
2018	A specific engineering paradigm, where individual physical artifacts are paired with digital model that dynamically reflects the status of those artifacts [35].	Health care management
2019	Building information model (BIM) is a digital twin [36].	Lifecycle management of railway turnout systems
2019	A connected and synchronised digital replica of physical assets which represent both the elements and the dynamics of how systems and devices operate within their environment and live throughout their lifecycle [37].	Architecture for cyber physical systems
2021	Digital entity that reflects physical entity's behaviour rule and keeps updating through the whole lifecycle [38].	-

Ideally, digital twins can be used in all stages of the building lifecycle, but an increasing number of studies have examined the application of digital twins in FM and maintenance. For example, in a recent study, Yu et al. [26] analysed the use of digital twins to enhance the O&M phase of tunnels, and Sivalingam et al. [27] examined the use of digital twins in the maintenance of wind turbines. Zhao et al. [2] developed a framework for digital twins that can contribute to facilitating FM in the built-asset industry. The main advantages of using digital twins in FM are real-time data gathering and monitoring, a more effective decision-making process and improved predictive maintenance [2]. This maintenance method refers to an advancement on the so-called preventive maintenance [28]. Preventive maintenance entails planned periodical interventions on the asset, while predictive maintenance uses conditioning-monitoring systems, and the failures are predicted based on historical data [28].

Xie et al. [29] described the implementation of digital twins in an asset, showing how digital twins could be used to facilitate the detection of anomalies in connection with FM. While a lack of site inspections and specific measurements are challenges to the implementation of digital twins, Shi et al. [30] proposed a data-driven method to transform 2D pictures into 3D models. Broo et al. [31] highlighted the importance of infrastructure systems and used digital twins to turn passive infrastructure assets into dynamic and data-centric systems. These studies indicate that there is a growing interest in academic research on the concept of digital twins in connection with FM; however as underlined by Errandonea et al. [7], its application in practice within the built environment is advancing slowly.

The literature usually refers to two types of digital twins' classification. The first classification is based on the model presented by Errandonea et al [7], among others, and it is represented in figure 1. This classification distinguished between 'digital model', 'digital shadow' and 'digital twin', depending on how the data are exchanged between a physical and a digital object.

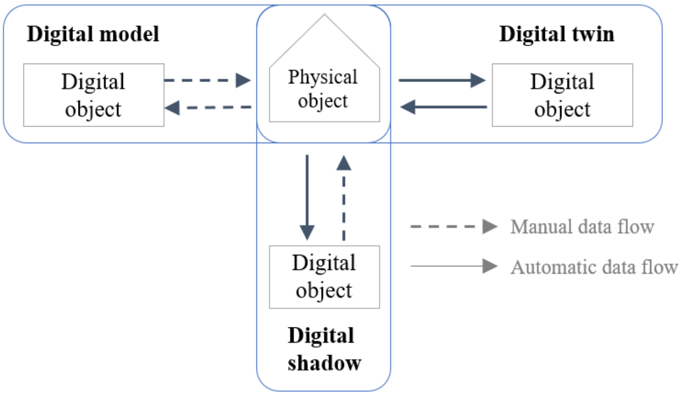

Figure 1. Digital twins' classification based on Errandonea et al. [7].

The second classification is based on the Digital Twin Maturity Index (DTMI) presented by Mêda et al. [17] and Fjeld [24], among others, as shown in figure 2. According to this classification, the static BIM model is enhanced with IoT to become an interactive and dynamic digital twin. At this level several different capabilities are achieved, for example real-time monitoring, better documentation and communication management, predictive and scheduled maintenance, data learning, enhanced decision-making processes, improved equipment utilisation and improved design in future projects [17]. The results of this research will be assessed based on the second classification, more suitable to assess digital twins' maturity during the use phase of a building.

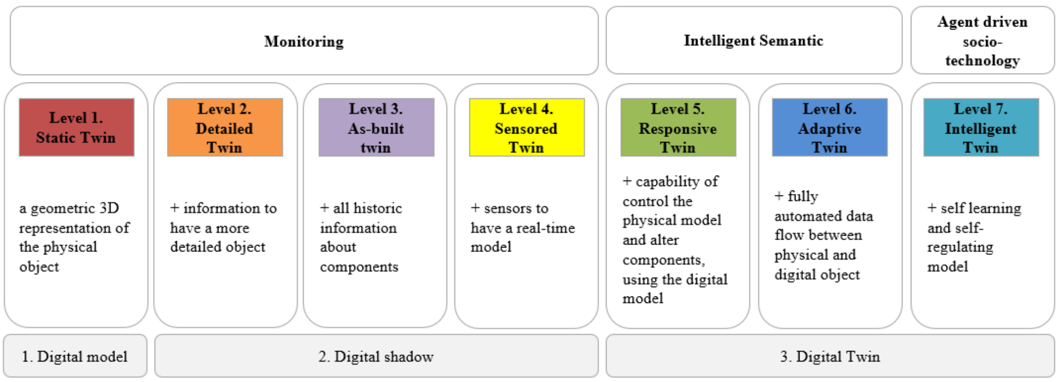

Figure 2. Digital twins' incremental maturity levels based on Mêda et al. [17] and Fjeld [24].

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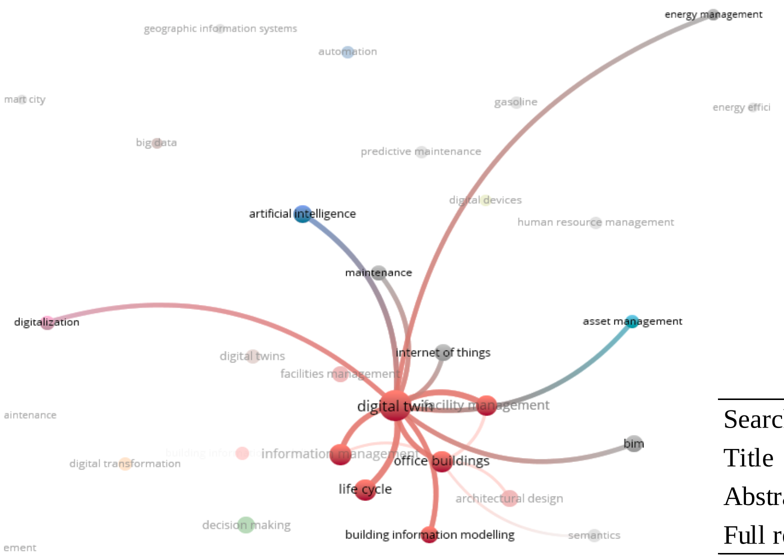
3. Research method

The purpose of the research is to examine the gap between theory and practice in the implementation of digital twins for FM and answer the following research question: ‘what are the benefits and challenges of implementing digital twins in facility management (FM) practice?’. A preliminary literature study and a series of semi-structured interviews were conducted to obtain the findings. The research methods are presented in more detail in the following sections, together with the measures taken to ensure the validity and reliability of the findings.

3.1. Literature review

During the last few years, there has been growing interest in the academic literature on the topic of digital twins in connection with FM and in the context of digital transformation [7]. A review of the literature was initially conducted to better understand the state-of-the-art research on this topic and to build a base for comparing and analysing the findings obtained from the interviews. Following Creswell’s recommendation [39], the review started with a large number of articles, which were reduced to a selection that was analysed in a qualitative manner.

The process of collecting relevant articles started with a broad search of the literature in the databases and search engines (Science Direct, Scopus, Google Scholar and Oria), using the key words: ‘digital twins’; ‘facility management’ and ‘operation & maintenance’, in different combinations (figure 3). The search resulted in around 1000 articles. These were extracted and the analysis of a bibliometric network was conducted, based on the keywords that were defined by the authors of the articles. The purpose was to identify the main themes connected with the topic of the research and to highlight the correlations among these. VOS Viewer software was used to help create and visualise the bibliometric network [38]. The *distance-based network* created with VOS Viewer (figure 3) shows the main themes; the distance between two nodes represents their correlation and the dimension of the nodes represents the number of citations for that theme [40]. Using the parameter *strength of links* equal to 2 in VOS Viewer, it emerged that the bibliographic themes that are most strongly related to the topics ‘digital twins’ and ‘facility management’ in the academic literature are: information management, office building, lifecycle, BIM, IoT, asset management, energy management, digitalization, maintenance and artificial intelligence (figure 3). From the first analysis of the literature, it is therefore possible to see that several themes are related to ‘digital twins’ and ‘facility management’, but there are not clear boundaries between these in terms of relevance.



	Digital twin &			
	Maint.	FM	O&M	Tot
Search	854	147	35	**1036**
Title	100	80	35	**215**
Abstract	28	24	18	**70**
Full read	6	6	3	**15**

Figure 3. Bibliometric network with VOS Viewer including process of literature selection.

The bibliographic review in VOS Viewer was useful for understanding the main key-themes connected with the research topic. Following this, the articles were filtered for 2017-2022 publication period (the last five years prior to this study). In the first screening, the titles and abstracts were reviewed. The articles were assessed by their relevance in connection with the topic of digital twins, FM, and the AEC-sector, resulting in 70 articles that were skimmed through. Finally, 15 articles, that had the most relevance to our topic, were selected and analysed in depth to answer the research question. Figure 3 shows the process of selecting the literature.

Table 2. The 15 articles selected for the literature review.

	Authors	Year	Topic	Sector
1	Lu et al. [19]	2020	Digital Twins and O&M	AEC/FM
2	Errandonea et al. [7]	2020	Digital Twin for Maintenance – review	AEC/FM
3	Opoku et al. [21]	2021	Digital Twin for Construction – review	AEC
4	Zhao et al. [2]	2022	Digital Twin and O&M	AEC/FM
5	Xie et al. [29]	2020	Digital Twin and FM	AEC/FM
6	Dzulkifli et al. [11]	2021	FM and Digital tools	AEC/FM
7	Fjeld [24]	2020	Digital Twins	AEC/FM
8	Parsanezhad [9]	2019	BIM and FM	AEC/FM
9	Patacas et al. [14]	2020	BIM and FM	AEC/FM
10	Ghorbani et al. [15]	2022	Facility Management	AEC/FM
11	Yu et al. [26]	2021	Digital Twin for O&M of tunnel	AEC/FM
12	Mêda et al. [17]	2021	Digital Twins and Construction	AEC
13	Broo et al. [31]	2022	Digital Twins and Smart infrastructure	AEC
14	Shi et al. [30]	2022	Geological Data-Driven model	AEC
15	Rojek et al. [6]	2021	Digital Twins and Maintenance	Manufacturing

3.2. Interview process

A series of semi-structured interviews was conducted to fully address the research question and to support the results obtained with the literature review. In line with Bell et al. [41], this method is suitable with the purpose of this research, that is to find out how the practitioners consider the implementation of digital twins in the use phase of a building. The interviews were conducted to obtain contextual information, and that contributed to a comprehensive understanding of the research areas and gaps.

Initially, it was difficult to find relevant interviewees who had competences and experience working with digital twins and FM in the AEC-sector in Norway because of the novelty of the issue. Finding relevant interviewees required the active involvement of the two co-authors and other network connections. Eventually, the interviewees were carefully chosen from both private and public organisations. Of the 15 experts initially contacted and invited to participate in the interview, 10 participated in the interviews. All of the respondents had a strong interest in digital technologies and were willing to help in this study and facilitate the adoption of digital twins in the industry. Some of the interviewees were directly related to the research project Bridging the Gap and some of them had strong expertise working with FM and maintenance. Specifically, three interviewees were responsible on a tactical level to develop digital solutions for FM, including BIM and digital twins. One interviewee was an advisor who helped organizations changing their business models, implementing digital solutions. Two interviewees were architects and engineers working with BIM. Three interviewees were experts for digital technologies and worked either in academia and/or with international standardization for BIM in FM. Finally, one interviewee had his own company helping organizations to scan their buildings for BIM implementation. Table 3 presents the interviewees' backgrounds and fields of expertise. The interviewees had many years of experience working in the industry; this was a relevant aspect that helped ensure the reliability of the results. While some of the respondents had experience in several project phases, only the phase that each interviewee discussed most during the interview is reported and check-marked in table 3. The category in table 3 refers to the latest position held by the respondents in their

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careers, and to which the discussion referred during the interview. The categories included operation & maintenance, design and construction and consultant.

Each interview lasted approximately 45 minutes and was conducted digitally, via video call. The Covid-19 pandemic situation in Norway caused a slowdown in the process and did not allow for in-person meetings with the interviewees. The same author conducted the interviews and coded the results, which helped to ensure a better understanding, coherence and validity of the findings. The coding process was done iteratively in parallel with the interviews, as recommended by Bell et al. [41]. The outcome of the interviews was the identification of the benefits and challenges of implementing digital twins for FM. Using a triangulation method, the findings from the interviews were compared and cross-referenced with the results from the literature to ensure validity. To guarantee data quality and give confidence in the results, the authors checked that the themes identified with the bibliometric network were present in the interview transcript. As the analysis was conducted, it became evident that the findings from the interviews and the insights from the literature seemed to converge, suggesting a higher degree of relevance to the findings.

Table 3. Interviewees and their backgrounds.

Interviewee	AEC	Project phase			Years of experience			Category
		Design	Construction	FM	5+	10+	20+	
1	√	√		√		√		O&M
2	√		√	√			√	Design and Construction
3	√		√	√		√		Consultant
4	√		√	√			√	Consultant
5	√	√	√		√			Design and Construction
6	√			√	√			O&M
7	√		√	√			√	Consultant
8	√		√	√			√	O&M
9	√	√	√		√			Design and Construction
10	√		√	√			√	O&M

4. Empirical Results

This section presents the results of the interviews. The purpose of the interviews was to investigate the state-of-the-art for adopting digital twins in the AEC industry and to underline the following:

(1) How does the AEC-sector define digital twins?
(2) What are the benefits of adopting digital twins for FM?
(3) What are the challenges of implementing digital twins in practice?

Together, these questions help us identify the benefits of and challenges to implementing digital twins for FM in practice.

4.1. How does the AEC-sector define digital twins?

The results from the interviews revealed that 5 out of the 10 interviewees could not provide a clear definition of digital twins. Among these, two interviewees directly affirmed that an accurate definition of digital twins in the AEC-sector is still missing. One respondent mentioned that the digital twins' concept is strictly related to BIM, defining it as 'some kind of advanced BIM'.

In the definitions provided by the interviewees, the words *dynamic* and *living representative* were often mentioned. Four respondents described digital twins as a dynamic 3D model that can be connected to IoT sensors and represent an updated digital version of the building. According to one interviewee, digital twins provide a platform on which to connect all the data from the building with the model. Similarly, two respondents underlined that the 3D model should be accurate and store the lifetime data of a building. One expert defined digital twins as hub that connect different software and sensors together into a living digital object. Table 4 summarises the definitions of digital twins collected from the interviews.

Table 4. Digital twins' definitions from the interviewees.

Respondent		**Definition of Digital Twin**
1	Direct quotation	'Correct, updated and complete digital representation of a building. It is not just a BIM; we need to use IoT sensors and integrate its data with BIM.'
2	Paraphrased message	There is no clear and precise definition of digital twins.
3	Paraphrased message	There is no clear and precise definition of digital twins, due to 'low maturity' level of the digital twins' concept. There should be distinct types of digital twins, for example in the AEC-sector and for construction purposes.
4	Paraphrased message	Digital twins it is *something* digitally connected to a 3D model, not specifically using IoT sensors. Digital twins can be defined as hubs; they enable the system to link different software and sensors together.
5	Direct quotation	'In our contracts, sometimes digital twin is mentioned but there is no real definition anywhere.'
6	Direct quotation	'An accurate 3D model that presents the current situation of a building.'
7	Paraphrased message	Digital representation of an object. It is not limited to one specific subject, such as energy or FM. Something with a holistic view that changes continuously. If it is a static snapshot, it is not a digital twin.
8	Paraphrased message	Digital twin is a result, where you put things together. Digital twins should include geometry data on a 3D model as well as a database of different data.
9	Paraphrased message	It could be something like BIM or enterprise BIM.
10	Paraphrased message	The digital twins' definition depends on the project's phase. You can call it the place to put all the documentations together.

4.2. What are the benefits of adopting digital twins for FM?

Table 5 presents the values and benefits of adopting digital twins for FM, that emerged from the interviews. Most of the interviewees agreed that the main benefit of implementing digital twins relates to information management, – that is, better knowledge and understanding of the building. As one interviewee mentioned, 'Information is the bloodline of FM, and digital twins help us to share and update information more easily'. One respondent added that connecting different types of information through digital twins can lead to improved learning and understanding of the building and the FM process.

Table 5. Benefits of digital twins according to the interviewees.

Value	Benefits	Interviewees
Information	Better knowledge and understanding of building	5
	Improved learning	1
Management	Increased collaboration	1
	Better decision making	1
	Continuously updated model	1
Technical	Energy and building efficiency	1
	Increased connection to external applications	1
	Safety and security purposes	1

Better accessibility and management of the information for the FM can consequently bring other benefits such as better collaboration (both internally to the organisation and externally); increased energy and building efficiency; better decision-making (thanks to a better understanding of the building and processes); increased connection to external software and applications (e.g. circular economy, GIS); a continuously updated model; and better safety and security of the building.

4.3. What are the challenges to implementing digital twins in practice?

The main challenges to implementing digital twins in practice within the AEC sector related to *change management* and *standardisation.* Table 6 presents a summary of the challenges. Five interviewees pointed out that *change management* is the main barrier to bringing digital twins into practice. Two respondents said that 'people and cultural alignment*'* represent a barrier to implementing digital twins in FM. One expert stated, 'One challenge is how to implement [digital twins] with regards to different types of organisations and businesses', and others underlined the complexity of this process. According to one interviewee, the successful adoption of digital twins is inevitably tied to digital transformation. However, the low level of innovation and the resistance to changes that are typical of the AEC sector do not facilitate the adoption of digital technologies and digital twins.

Three interviewees pointed out that *standardisation* is also a main challenge to implementing digital twins. The interviewees acknowledged that the Industry Foundation Class (IFC) format is the most common standard for BIM in the industry, but it can be difficult to maintain and update due to its complexity. One expert underlined that IFC is not directly developed to implement digital twins and the handover of information between the construction phase and O&M can be difficult.

Another barrier to the adoption of digital twins is that, while it might be relatively easy to implement digital twins initially, it is more complicated to maintain, because it comprises several data sources and components: 'It is quite challenging because many people have been involved in the project that has made that model, so it includes many components'. Maintenance of the digital twin therefore requires more resources and competences in the organisation. Two experts also highlighted the low maturity and limited understanding of the concept as challenges. Finally, cost is identified as a barrier for digital twins' practical adoption by one interviewee: 'Digital twins are expensive, and the AEC sector is a conservative sector with a low [profit] margin'. Even though only one interviewee explicitly mentioned cost as a direct challenge for implementing digital twins in construction, others pointed towards the lack of competences in what a digital twin is. Some interviewees mentioned that they refuse the adoption of digital twins in FM, because they believe the cost / benefits are generated in the construction phase.

Table 6. Challenges related to adopting and implementing digital in FM.

Challenges		Interviewees
Change management	People and cultural alignment	2
	Different organisations and businesses	2
	Low level of innovation and resistance to change	1
Standardization	Different data sources	1
	IFC is complex and not-well defined	1
	IFC format is one-way editable	1
Complexity		2
Low maturity and understanding		1
Handover process construction / O&M		1
Cost		1

5. Discussion

This study investigated the benefits and challenges of implementing digital twins in practice during the use phase of a building and in connection with FM practices. The findings were obtained through an analysis of the literature and a series of semi-structured interviews with experts from the AEC sector in predominantly in Norway.

An increasing number of researchers, such as Lu et al. [19], Mêda et al. [17], Zhao et al. [2] and Xie et al. [29], have examined the application of digital twins in FM and maintenance considering different contexts. In the academic literature, the concept of digital twins is assessed, and the potential applications and maturity levels are classified based on their integration with other technologies and digital solutions, such as machine learning and artificial intelligence (Figure 2). However, the empirical results revealed that practitioners in the AEC sector have yet to fully define digital twins and their practical application on the same level. This highlights the gap between practice and theory and confirms the statement by Errandonea, who claimed that despite a growing interest in academic research on the concept of digital twins in connection with FM, its application in practice within the AEC sector is advancing slowly [7].

Figure 4 is a representation of the concept of digital twins based on the maturity levels presented by Mêda et al. [17] and Fjeld [24], which we compared and assessed against the empirical findings from the interviews. It is possible to affirm that digital twins for FM is a digital representative that shows the current state of the physical asset powered by IoT sensors, the model is connected with maintenance-related documents and it interacts with FM software and CMMS systems. However, based on our interviews, this maturity level has not yet been achieved in practice; what the interviewees defined as digital twin corresponds to the maturity level *digital shadow* (figure 4), based on the model previously defined based on the literature. While new definitions and classifications emerge in the academic literature, it is not assured that adding new levels and distinctions will necessarily contribute to digital twins' implementation in practice. However, these classifications can help the practitioners in expressing their needs and expectations of digital tools with increased accuracy, both to the providers of such tools but also when exchanging experiences with other practitioners regarding opportunities, possibilities, and challenges.

One of the most important advantages of implementing digital twins in FM, according to the literature relates to improved preventive maintenance [2,19,29]. However, based on the findings from the interviews, this is not fully achieved in practice because it requires the integration with other technologies, such as artificial intelligence and machine learning. The benefits identified by the experts are more tangible. It is possible to achieve a competitive advantage through implementing digital twins and through more efficient information management. Accordingly, several authors have affirmed that a robust infrastructure for information management is needed for FM [9,10]. While some authors state that it can be a challenge to develop a structured standard-based framework for information management in FM due to its complexity and multiple data sources [12,13,14], practitioners view this more as an advantage that can lead to a better understanding of the building and increased collaboration.

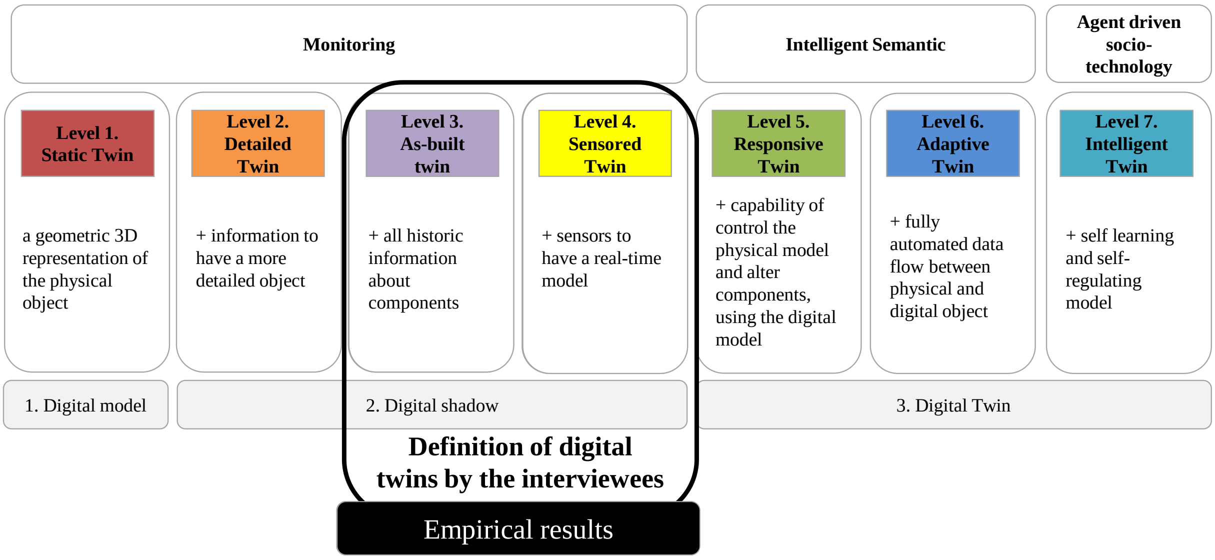

Figure 4. Practitioners' understanding of digital twins compare to figure 2.

From the interviews it emerged that the main challenge to bringing digital twins into practice for FM relates to people and change management. The low level of innovation and resistance to change that characterises the AEC-sector do not facilitate the adoption of digital twins for FM. A shift in the organisational culture is a success factor for digital transformation [3], which is inevitably tied to the implementation of digital twins. Digital twins and digital transformation have been studied separately in the AEC sector by several scholars, and to date, these two concepts remain to be studied together. This is visible from the analysis of the bibliometric network through VOS Viewer (figure 3), where it is possible to notice that the keyword 'digital transformation' is greyed out, meaning that it does not have a strong link with the keyword 'digital twins' in the selected literature.

Some interviewees considered standardisation to be a challenge to implementing digital twins in FM. For example, several data sources must be integrated to build a digital twin, and the most available standards are quite complex to implement and not specifically targeted for digital twins. However, the interviewees suggested that while these challenges related to standardisation and technologies can be resolved, cultural and organisational change might require more time, effort and resources.

This study aimed to identify the specific barriers for digital twins applied to the use phase of a building. However, some of the identified barriers are also valid for other lifecycle phases of an asset. Only a few interviewees noticed this and reflected upon it, which might indicate that the concept of digital twins is still only vaguely defined in the AEC industry, and specific analyses should be conducted to assess each challenge to implementing digital twins.

6. Conclusions

This study examined the adoption of digital twins during the use phase of a building and in connection with FM practices. The research attempted to answer the research question, 'What are the benefits and challenges to implementing digital twins for facility management (FM) practice?' through an analysis of the literature and interviews with 10 experts from the AEC sector predominantly in Norway.

To fully answer the research question, it was necessary to assess the maturity of digital twins in the AEC-sector. It emerged that there is divergence between how the literature defines and classifies digital twins and how practitioners have understood and adopted them. By comparing the findings from the interviews with the maturity levels presented in the literature, it is possible to see that classifications of mature digital twins by researchers such as Mêda et al. [17] and Fjeld [24] have not yet been achieved in practice, according to our sample of interviews (figure 4). This is still an emerging field, and much can change in the years to come. Practitioners' interest in the concept is recognised and increasing. Further analysis can investigate to what extent the classifications from the theory contribute to digital twins' practical implementation and how these may develop to enable practitioners to express their digital visions and needs more accurately.

The implementation of digital twins in FM requires a robust framework for information management. The practitioners considered this a benefit, because it can lead to a better understanding of the building, improved efficiency, and more effective collaboration between the stakeholders.

As shown in Table 6, which summarises the challenges for digital twins in FM and discusses them against the theory, the main barrier relates to people and culture. Resistance to change and a conservative organisational culture hinder the adoption of digital twins, and this is also valid for digital transformation. Therefore, the adoption of digital twins for FM in the built environment needs to be considered in the context of digital transformation since the change in the organisational culture requires an integrated approach. Other barriers related to standardisation and technologies are also relevant. The findings from the interviews partly converged with the literature, which seems to introduce a more advanced understanding of digital twins. However, it would be relevant to analyse these challenges in more detail and suggest measures to overcome them.

Finally, the AEC-industry has not yet been fully able to implement digital twins at its maximum potential during the use phase of a building. This makes it difficult to fully achieve the benefits of digital twins and connect their implementation with FM. By providing a clear and practical definition of the barriers to digital twins in FM, this study supports practitioners with the adoption of digital technologies for the built asset. Further research should contribute to improving the understanding of the topic in the industry, by ensuring that practitioners are able to grasp what digital twins are and help them overcome the challenges to see how they can harvest the benefits. Both practitioners, researchers, and standardisation bodies, are encouraged to continue investigating the relationship between digital twins and digital transformation concepts as a joint perspective can increase the benefits of implementing digital twins.

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