# The Digital Twin in the AEC/FM Industry: a literature review

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## Abstract

The Digital Twin (DT) is a digital representation of a real-world entity. It provides both elements and dynamics of how the represented system operates throughout its lifecycle. Conceptualized in manufacturing, it spread to other sectors aiming to ride digital transformation, e.g. robotics, automobile, healthcare, and logistics. Recently it starts to enter the Architecture, Engineering, and Construction (AEC) and Facility Management (FM) industry but the literature is still fragmented. To provide a comprehensive analysis of the Digital Twin in constructions, a systematic literature review was carried out. This methodology was intended to reach the following objectives: define the origin of the DT in AEC and its main features; show application fields and enabling technologies involved within the practice; analyse benefits getting from its adoption; highlight where the research has arrived up to now; and examine what are the feasible developments of this innovation and its relative gaps.

Keywords: Digital Twin, AEC/FM, Systematic literature review

## 1 Introduction

The DT is "a reengineering of structural life prediction and management" (Boje et al., 2020b). Two main characteristics are the connection between physical and corresponding virtual model, and the continuous generation of real-time data using sensors applied on the system analyzed. These procedures allow to simulate behaviours of that given system in digital form and to discover issues of the existing asset, implementing also solutions and future developments. Today, the use of this management approach in the AEC/FM sector is still little known, and the literature on the subject is rather fragmented. Hence the need to comprehensively review DT components, capabilities and applications in this industry, also identifying current gaps and directions for future research.

An early conceptualization of twinning originated in 60s under the Apollo Programme and was used for mirroring the conditions of the vehicle in space (Kan & Anumba, 2019). However, the original meaning is attributed to Michael Grieves that, in 2003, introduced this concept in manufacturing, in a lecture on Product Lifecycle Management (PLM). Only in 2010 the first official definition was provided by NASA in the aerospace industry (Shafto et al., 2010). In 2014, Grieves himself defined a three-dimensional DT paradigm considering a physical entity, a virtual entity and data connecting the latters (Grieves & Vickers, 2016). About connections, three levels of integration between physical and digital asset have been defined: Digital Model (DM), Digital Shadow (DS) and Digital Twin (DT) (Jazzar & Nassereddine, 2020) (Figure 1).

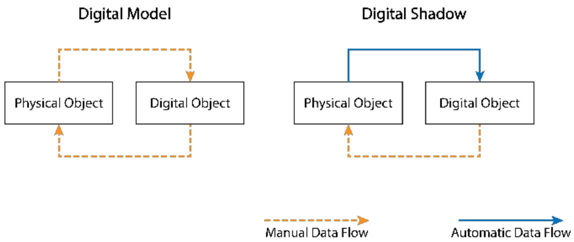



**Figure 1.** Digital Model, Shadow and Twin. Re-elaboration by the author. Source (Jazzar & Nassereddine, 2020) .

The potential of DT was better supported by Industry 4.0, whose main technologies employed it in many other industries. In 2018, the Centre for Digital Built Britain provided a new DT definition in AEC, conceiving it as an approach to information management in the built environment (Bolton, 2018). The path to reach this solution was gradual. The progression is related to the attempts of embodying the BIM approach, that corresponds to DM, within FM. For this reason, existing literature on DT in this industry is not easy to find: the term "Digital Twin" is not always explicitly mentioned in most papers and is occasionally referred as BIM-FM. In construction, the DT realization starts with the data told in the design phase using a BIM model and this data should be continuously updated and collected throughout the asset life cycle, by means of the sensors installed on its construction (Jazzar & Nassereddine, 2020).

Following these premises, this work intends to overcome the fragmentation of the existing literature by means of a systematic literature review, in order to propose an integrated analysis of origins, enabling technologies, capabilities and applications about DT implementation in the construction sector.

## 2 Systematic literature review

The research method applied is the systematic literature review, a defined protocol to identify, organize and synthesize relevant literature findings. This method allows reviewers to objectively select and appraise researches to answer a clearly formulated question (Hammond, 2021). The main feature is the use of keywords to carry out the search and highly referenced sources to identify and evaluate all evidence related to a specific topic. This research is structured by four phases (Figure 2):

Planning. The purpose of the research and the search strategy to adopt are defined. The strategy is created to limit the scope review. It is put into effect fixing inclusion parameters, recording keywords to search for topic and building search strings that will help find sources.

Searching. Only relevant databases to the topic, and sources too, are considered.

Collecting. Reviews are examined evaluating the quality of the studies and identifying gaps and weaknesses of the readings.

Reporting. The results are analysed identifying commonalities and divergences of the documents selected and combining facts extracted. Then, the writing of the stand-alone literature review is drafted.


**Figure 2.** Phases of Systematic Literature Review

After defining the purpose of the literature review, i.e. the Digital Twin approach in the AEC sector, the examination is carried on for three months, starting on the 10th September 2020, both with common search engines, i.e. Google (www.google.it), ScienceDirect (www.sciencedirect.com), ResearchGate (www.researchgate.net) and IEEE Xplore (ieeexplore.ieee.org), and with meaningful electronic scientific database, i.e. Scholar (Scholar.google.it) and Scopus (www.scopus.com). However, a remote connection to the university library SIBA (http://unisalento.summon.serialssolutions.com/#!/) is needed to access some documents found through the public search channels. The entire research has not had temporal restrictions, in order to collect all the available documents and to get an idea on how much work has been already done on this topic over time. Search criteria consist of the following words and combinations of words: “Digital Twin”; “Digital Twin Concept”; “Digital Twin” and “BIM”; “Digital Twin nelle costruzioni”; “Digital Twin nell’edilizia”; “Building Twin”; “Digital Twin in construction”; “Digital Twin in AEC”; “Digital Twin in construction industry”; “Semantic Web” and “BIM”; “Digital Building Twin”; “Digital Twin in architecture”; “Digital Twin” and “Sensors”. After searching and an initial reading of the documentation, the off-topic results were eliminated while the others were classified according to different criteria, i.e. source, search keywords, date and document type and main topics described, and a critical appraisal is made in order to evaluate information extracted. For the drafting of the stand-alone literature review, these papers were processed in four areas of detail: DT origins, application fields and functionalities, associated approaches and enabling technologies as shown in the following paragraphs.

## 3 Findings

### 3.1 Document classification

The search result consists of 79 documents. In Figure 3 findings are divided according to search engine typology. Specifically, documents identified through public search engines are 22, while the others are accessible through the specific scientific search channels and the remote connection of the university library. The latter approach produced the greatest results. These documents can also be distributed among the original sources (Figure 4(a)): the outcomes are mainly traced back to ProQuest, and so to the University Library, ResearchGate and Google. In contrast to the first two sources, the latter does not present scientific documentation. Moreover, most papers recovered on ResearchGate and Science Direct were found also on Scopus and ProQuest. According to the previous table, on the top are collected all papers found through Google and some documents recovered from Science Direct, ResearchGate and IEEE Xplore. The others were aggregated in the second one, together with all those retrieved from Google Scholar, ProQuest-University Library and Scopus database. A large part of the documentation falls under the cluster scientific research documentation, mostly identified through scientific search engines.


**Figure 3.** Papers division by search engine

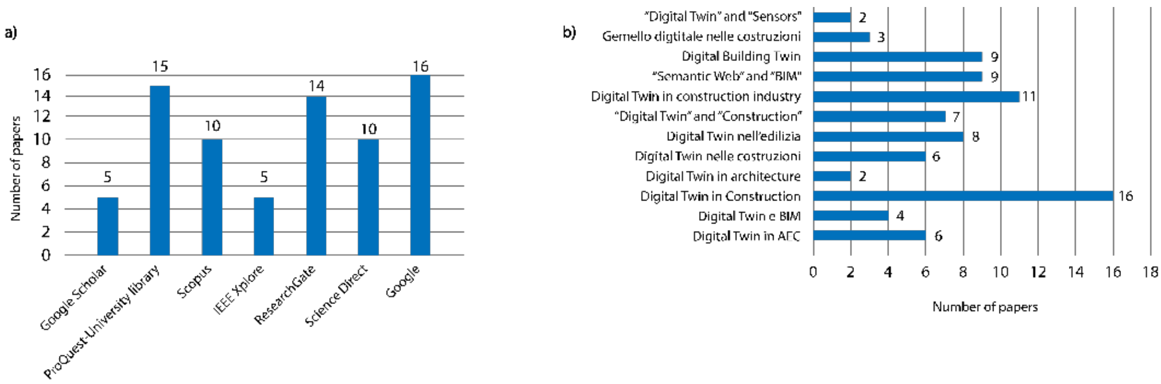



**Figure 4.** Findings classification: (a) Sources (b) Keywords search

Figure 4(b) shows the results of the search by keywords. The most effective were the ones that express exactly the subject of the search work. Some of the keywords used, i.e. "Digital Twin" AND "BIM", "Semantic web" AND "BIM", "Digital Building Twin" and "Digital Twin" AND "Sensors", are less immediate to be understood in their use because their choice is related to the first reading of some papers. Moreover, 19 results have been counted out from classifications in this work for several reasons described below: 7 of them refer to the general theme of Digital Twin, or weakly refer to the DT in the constructions (Autodesk, 2020; Dunn, 2020; Fink & Mata, 2020; From BIM To The Digital Twin, 2020; Grieves, 2019; Jung, 2017; Yokesh, 2020); 8 others are not relevant, dealing with other application fields (Barat, 2020; Bäßler et al., 2020; Erol et al., 2020; Eyre & Freeman, 2018; Kaewunruen & Xu, 2018; Mandolla et al., 2019; van der Valk et al., 2020; Wortmann & Tunçer, 2017); and 4 are not usable, making only the abstract accessible (Kaewunruena & Lianab, 2019; Küsel, 2020; Mateev, 2020; Rao, 2020).

The documents collected are quite recent (none before 2018) although the research is not filtered by setting time limits (Figure 5(a)). This analysis is interpreted considering DT has developed in recent time, even more considering that the AEC sector is the last field in which the DT was applied. These documents are also grouped according to the nature of the records. Figure 5(b) reveals that more than half of the outcomes is represented by scientific search documentation. Moreover, the second cluster by type is characterized by website documents.

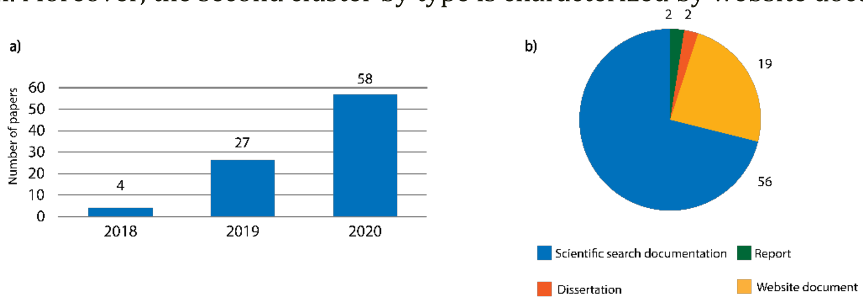



**Figure 5.** Findings classification: (a) Publication date (b) Document typologies

### 3.2 DT origin in construction

With the aim of identifying the reasons for the need for this approach in construction and not just the evolutionary steps as reported in Section 1, papers were classified according to the origins identified. Table 1 shows that the origin of this method is related both to the limitation of the current tools in managing constructions throughout their lifecycle and to the growth, sometimes mandatory, of policies required by the Industry 4.0. In particular, on the top are tabled all papers for which DT provides real-time analysis and intervention, tools that cannot be provided by the instrumentation in use to date. Instead, at the bottom are listed records that refer to a plan concerning incentives for innovation, both in terms of services and goods. Some government policies, e.g. Horizon 2020 (Alonso et al., 2019) and 2050 Swiss programme (Lydon et al., 2019), are also mentioned in these texts as research and innovation projects aimed at reaching national and international targets, thus facilitating the digital turning point. From this analysis, Industry 4.0 technologies and sustainable government policies promoting digitization emerge as the main reasons for the introduction of DT in this sector, which has fallen behind in digitization (IoT For All, 2020).

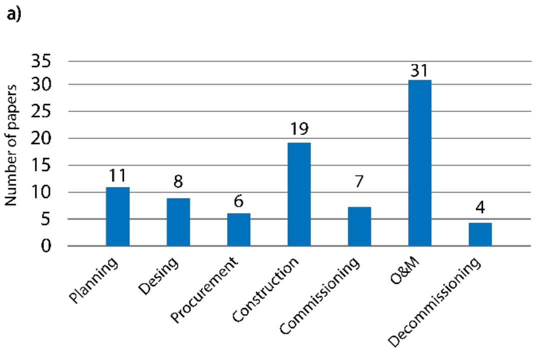
**Table 1.** Origins of Digital twin in AEC sector

| Origin | Findings |
|---|---|
| **Limitations of existing instruments** | (Boje et al., 2020b), (Khajavi et al., 2019), (Jazzar & Nassereddine, 2020), (Ito, 2019), (Caufield, 2019b), (Lu, Chen, Li, & Pitt, 2020), (Bentley, 2019b), (Lu, Parlikad, Woodall, Don Ranasinghe, et al., 2020), (Lu et al., 2020), (Huynh & Nguyen-Ky, 2020), (Al-Sehrawy & Kumar, 2020) |

| | |
|---|---|
| **Industry 4.0 and Government policies** | (Boje et al., 2020b), (Teng et al., 2020), (Jazzar & Nassereddine, 2020), (My Smart, 2019), (Ballocchi, 2019), (Fraunhofer Building Innovation Alliance, 2020), (Alonso et al., 2019), (Kan & Anuba, 2019), (Skimanski et al., 2019), (Turner et al.), (You & Feng, 2020), (Lim et al., 2020), (Tchana et al., 2019), (González et al., 2020), (Trancossi et al., 2020), (Bolton et al., 2018), ( Maskuriy et al., 2019), (Austin et al., 2020), (Chionelli, 2020), (Wagg et al., 2020), (Lydon et al., 2019), (Hamalainem, 2020) ( Kaewunruen et al., 2018), (Love & Matthews, 2019), (Construction Week Online, 2020), (Agostinelli et al., 2020) |

### 3.3 Application fields and functionalities

The DT makes reference to buildings, infrastructures (Shirowzhan et al., 2020a; Bentley, 2019a; Tchana et al., 2019; Tomar et al., 2020), and didactic in schools of engineering and architecture. Most of the papers concern the usage of DT at different phases of a building lifecycle or an infrastructure. Figure 6(a) shows that recurrent lifecycle phases are: planning, when defining construction project establishing building type or building area; design, architecture and structure; procurement, when raw materials and required manpower are defined; construction, the phase in which the structure is realized defining construction sequences, operation times and risks; commissioning; O&M, the stage at which the structure, or the infrastructure, is in use; and decommissioning, in terms of demolishing or recycle. O&M is the stage at which the DT is most applied. In the same way, another classification can be made on the records relating to the functionalities of DT (Figure 6(b)). The functionalities identified are: optimization of consumptions and services, simulation of usage condition for what-if analysis, prediction of future scenarios, sensing, monitoring & control (M&C) to check irregularities and decision making for current and future projects and improvements too. From these search outcomes, M&C, decision making and optimization are, respectively, the first, the second and the third main missions of DT.



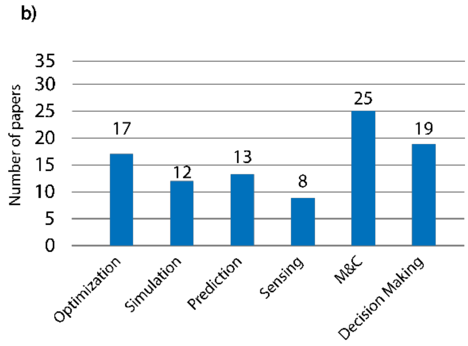




**Figure 6.** DT applications in constructions: (a) DT application fields (b) DT functionalities

Among papers, DT is related to Smart Building and Smart City (Table 2). They define, respectively, building and city equipped with tools and technologies that allow an overall optimization of their usage and their management.

**Table 2.** Recurrence of "Smart Building" and "Smart City" concepts

| Smart environment | Finding |
|---|---|
| **Building** | (Khajavi et al., 2019), (Ballocchi, 2019), (Roxin, 2019), (Cozzi, 2020), (O'Dwyer et al., 2020), (La Russa & Santagati, 2020), (Bolton et al., 2018), (Chevallier et al., 2020) |
| **City** | (Boje et al., 2020b), (Khajavi et al., 2019), (Cozzi, 2020), (Shirowzhan et al., 2020), [38], (Akbarieh et al., 2020), (Kirk, 2019), (O'Dwyer et al., 2020), (Lu et al., 2020), (Bolton et al., 2018), (Mohammadi & Taylor, 2017), (Austin et al., 2020), (Chionelli, 2020), (Petrova-Antonova & Ilieva, 2020) |

About others DT applications, (Chevallier et al., 2020), (Sepasgozar, 2020), (Wahbeh et al., 2020) consider twinning also as a didactical goal. Proposing the DT as an objective for a project-based learning approach in a didactical setting, these documents show its impact on the traditional frameworks in the educational domain of construction and its value as an opportunity to introduce interdisciplinary expertise to all students in these fields.

### 3.4 Association to BIM, GIS, PLM and CPS approaches

The DT is often associated to other approaches applied in the construction: more than half describes the relation between DT and BIM, GIS, PLM and CPS approaches (Table 3).

**Table 3.** Recurrence of "Smart Building" and "Smart City" concepts

| Approach | Finding |
|---|---|
| **BIM** | (Boje et al., 2020b), (Teng et al. 2020), (Jones et al., 2020), (Jazzar & Nassereddine, 2020), (Khajavi et al., 2019), (Dari, 2019), (Myers, 2019), (My Smart, 2019), (Ballocchi, 2019), (Intellectsoft, 2018), (Medium, 2020), (Ito, 2019), (Lu, Xie, Parlikad, Schooling, et al., 2020), (Roxin, 2019), (Caufield, 2019a), (Bentley, 2019c), (Akbarieh et al., 2020), (Turner et al.), (You & Feng, 2020), (Boje et al., 2020a), (Diakite & Zlatanova, 2020), (Lu et al., 2020), (Bolton et al., 2018), (Pasolini & Vianello, 2018), (Chionelli, 2020), (Tomar et al., 2020), (Chevallier et al., 2020), (Negri, 2019), (Bolshakov et al., 2020), (Maskuriy, 2019), (Robins, 2019) |
| **GIS** | (Dari, 2019), (Roxin, 2019), (Shirowzhan et al., 2020), (Diakite & Zlatanova, 2020), (Tomar et al., 2020) |
| **PLM** | (Wahbeh et al., 2020), (Lim et al., 2020) , (Tchana et al., 2019) |
| **CPS** | (Ito, 2019), (Jouan & Hallot, 2020), (Wahbeh et al., 2020), (Kan & Anuba, 2019), (Turner et al.), (You & Feng, 2020), (Song et al., 2019), (Jones et al., 2020) |

Among the previous documents listed, another sub-division can be made according to association typology: some papers mention the above systems with the intention of making a comparison with the DT approach; others try to explain why the DT is sometimes confused with them; several records show why the Digital Twin is used in a combined way with these other approaches; and others demonstrate that DT is the next-needed evolution of that current practices (Figure 7). In relation to BIM, the literature takes different positions of reflection, sometimes showing its confusion with DT. (Boje et al., 2020b) argues that the DT is nothing more than an evolution of the BIM method, because it does not lend itself to a real-time representation of data and a dynamic analysis of asset information. The two approaches are one the supplement of the other in relation to the object of reference: BIM focuses mainly on the design and construction of an artifact, while DT is a tool of analysis and modeling of interactions between people and the built environment. BIM is also a key data source for the development of a DT (Dari, 2019), and therefore a necessary starting point constituting the dataset from which to get data (Pasolini & Vianello, 2018). DT combines representations of constructions with 4D topographic surveys, producing a more realistic model of built environments (Shirowzhan et al., 2020b) and defining the impact of the building on the surrounding environment and vice versa. Providing an intuitive and immersive environment, the integration of GIS and DT allows supporting designers and engineers in the development of properties, services and public works (Bentley, 2019a). Also, the CPS is a concept to which the literature does not define univocally the DT. (Jouan & Hallot, 2020), (Love & Matthews, 2019) and (Ito, 2019) tends to identify the two concepts, while (Kan & Anumba, 2019), (Jones et al., 2020) and (You & Feng, 2020) consider the DT as a tool for the realization of a physical cyber system, constituting a bridge connecting the real world with the virtual one. Concerning PLM, (Lim et al., 2020) and (Tchana et al., 2019) refer to DT as a kind of complementary tool for managing the lifecycle of a structure or infrastructure, while (Wahbeh et al., 2020) gives an evolutive consideration.

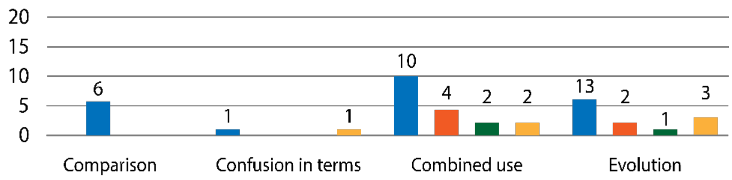



**Figure 7.** Association of Digital Twin to the other methods applied in AEC

### 3.5 Enabling technologies

Some findings refer to the enabling technologies that allow the application of the DT approach, ensuring its full efficiency and effectiveness. These technologies are grouped into three subsets according to their typology and specific goal (Figure 8): connectivity, digitalization and intelligence. Sensor, big data analysis, Internet of Things (IoT) and cloud are the first cluster. Digitalization encompasses simulation and data-driven model techniques and intelligence concerns artificial intelligence (AI), analytics and actuators. The joint use of these technologies allows DT to reach its goals of reflecting the actual condition of the asset which refers, best performing all the tasks for which it was adopted.

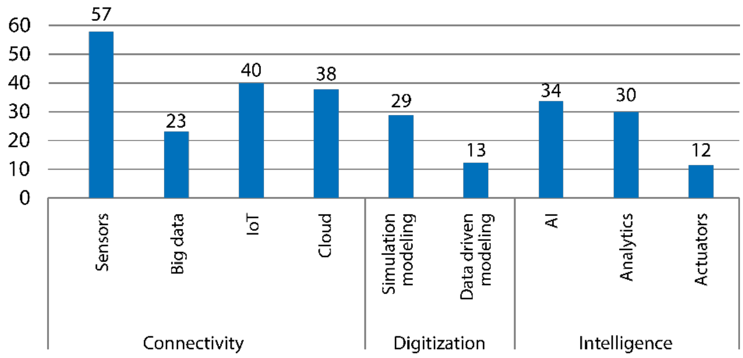



**Figure 8.** DT enabling technologies

### 3.6 Discussion

To overcome the fragmentation of the literature on the proposed topic, this study investigates the DT in the AEC/FM industry through a systematic literature review. This choice aims to provide a convincing and comprehensive analysis of the contents deriving from selected documents. The study takes into account not only scientific search engines but also common ones. Similarly, reference is made not only to scientific documentation but also to various documents from the web and dissertations. This method, in fact, gathers all the available papers on the subject, providing a broader view of how and why DT is a structural and infrastructural asset management system.

Whereas existing literature has concentrated on describing the need of evolutionary steps from BIM to DT in construction (Jazzar & Nassereddine, 2020), in this examination Industry 4.0 and sustainable government policies emerge as drivers for the implementation of this new approach in the AEC/FM industry. Moreover, while (Dari, 2019) defines BIM as a starting point for DT, this research work considers BIM as a necessary but not sufficient source. In fact, this study identifies also other approaches and technologies involved in a DT implementation. First of all BIM data have to be integrated and updated real-time both by those generated by the sensors on the asset to be managed and those relating to the GIS system. About GIS system integration, combining BIM and sensors with this approach, not only is a complete representation of the built environment achieved (Shirowzhan et al., 2020), but related data is also georeferenced. In addition, regarding other approaches, DT results from an evolution of the PLM concept in construction rather than a complementary tool (Tchana et al., 2019), while it is indeed an evolution of CPS as it goes beyond the simple connection between the real and virtual worlds (You & Feng, 2020).

Finally, this study brings together, reviews and analyses all the possible applications of DT in construction, demonstrating how this approach can be used throughout the entire life cycle of a structure or infrastructure (Bentley, 2020; Da Silva et al., 2020; Emery, 2020; Liang et al., 2020; Liu et al. 2020; Lu, Xie, Parlikad, & Schooling, 2020; Miskinis, 2018; Patterson & Rush, 2019; Walters, 2020; Xue et al., 2020).

This review allows also reflections highlighting gaps within the literature. The elements preventing the state of art from being complete are: the absence of an ontological definition of this approach in the sector; the missing of a guideline for its implementation and application; the lack both of an application example including all the enabling technologies described and a technological architecture capable of connecting them; and the shortage of information relating to resource management and digitization of the economic framework.

# 4 Conclusion

## 4.1 Limitations

This research work allows collecting and evaluating, in an integrated way, different aspects related to DT and its use in the AEC/FM industry. However, the inaccessibility of some documents constitutes a limitation for this research work. In addition, the fact that this is such a topical issue also constituted a limitation for this work as the research was carried out in 2020, for about three months, collecting only the documentation available up to that time and revealing several gaps on the chosen subject. In fact, carrying out a new search seven months later, through keywords as in Section 3.1, it showed that several papers were published afterward.

## 4.2 Concluding remarks

The DT concept is developed especially in the last years in construction and it is a topic on which the debate is still heated. The two reasons responsible for the DT development in this industry are the limits of current tools to provide a meaningful contribution to the dynamic aspect of constructions management, and the growth encouraged by Industry 4.0. As a direct consequence of the analysis on the application fields and the functionalities of this new practice, the DT is defined as an approach adopted to manage structures and infrastructures in their entire lifecycle. The reviewed papers converge to the idea that this approach is intended to make their management more effective and efficient. From the planning to the decommissioning, this practice reaches its goal to the maximum at the O&M stage, when the asset needs to be managed to facilitate use and context interaction.

About functionalities, the main task of the DT is to set up a sound basis especially for M&C, Decision Making and Optimization. The promotion of digital transformation represented by the DT, and the sustainability processes it supports, underpins development of current practice to check asset irregularities, take decisions about developments and future projects and improve consumptions and services. In this sense, the DT is linked to both the concept of Smart Building and Smart City.

Compared to BIM and GIS the DT is a complementary analysis tool to achieve their maximum efficiency in management.

About the enabling technologies involved into the approach, they work together so that DT performs properly reflecting the current condition of the asset which refers to and predicting its feature behaviours.

In addition, the findings of this work were triangulated with those of the new research (Section 4.1) showing a convergence of intentions and results. For example, also (Deng et al., 2021) reveals the need for a comprehensive and all-encompassing definition of DT in the AEC-FM industry, thus sharing the same objectives of this submitted work. Also here, through a systematic literature review, the evolution of DT is traced, from the reasons that led to the development of the new approach. While underlining that this system is still at the beginning of its implementation, also these authors define this innovation as a system for managing an asset at each stage of its life cycle, in particular at O&M phase. Furthermore, by referring to BIM as the main data source, the paper describes the requirements and expected characteristics of an ideal Digital Twin. Another recently published paper goes one step further, if compared to these results. Focusing on smart construction project management, and identifying the need to overcome the gaps identified in Section 3.6, (Pan & Zhang, 2021) proposes and verifies a hypothetical DT framework in a practical BIM-based project.

### 4.3 Future works

Considering the gaps identified in Section 3.5, future research could examine appropriate case studies. Bearing in mind that this approach is only at the beginning of its implementation in the sector, it would be interesting to analyse a frame of asset management, studying an already started experimentation of a system that is managing the maintenance process of properties. Moreover, another case could interface with the world of infrastructure and the possibility of DT introduction in a project which has yet to be developed. These complementary cases could be analysed in parallel as they are both representatives of the construction industry.

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