Analysis of Digital Twins in the Construction Industry: Current Trends and Applications

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Abstract. The construction industry has a significant impact in terms of financial and environmental resources but is vastly behind other sectors in terms of digitalization. The potential of this industry to be improved by new technology has been reflected in huge trends in research for terms such as "digital twins". However, the purpose of such technologies and how they can be applied to specific needs and assets in the construction sector is not always clear. This paper proposes an analysis of the purpose, current and future states of digital twins in the construction industry, based on a review of the evolution of research in the topic and recent market applications. Even though there is a discrepancy between research and level of development of tangible applications, it is undeniable that the digital transformation will reach the construction industry. The efforts should then be focused on technology that can be translated to its assets, such as smart management, and will generate tangible results that can survive outside the theoretical realm.

Keywords: Digital Twins · Construction Industry · Construction Sector · Smart Infrastructure · BIM

1 Introduction

The construction industry is simultaneously one of the largest in the world and one of the least digitized sectors [1, 2]. By 2030, the volume of construction output is expected to grow by 85% to $15.5 trillion, with China, India, and the US accounting for 57% of that growth [2]. At the same time, by 2025 it is predicted that full-scale digitalization will lead to annual global cost savings of 13–21% in the design, engineering, and construction phases, and 10–17% over the operations phase [1]. Therefore, there is still a great deal of unexplored potential to bring the digital transformation to a rapidly growing industry, which is expected to lead to significant savings in resources.

Bringing transformation to the construction industry usually takes time, as its assets have long life spans, and the sector can be quite resistant to change. However, the sector must find ways to adapt, as the era of digital transformation is already a reality. The existing small-scale intelligent physical worlds, like smart factories, intelligent cruise ships and automated ports, will grow into smart neighborhoods, cities, and countries, where massive digital twins will mirror physical reality [3]. Digital twin technology is

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believed to be the answer to the main challenges the construction sector faces: poor productivity and profitability, timing and budget issues, shortages of skilled labor, and sustainability concerns [2]. The global digital twin market, valued at $3.21 billion in 2020, is expected to reach $184.5 billion by 2030 [3].

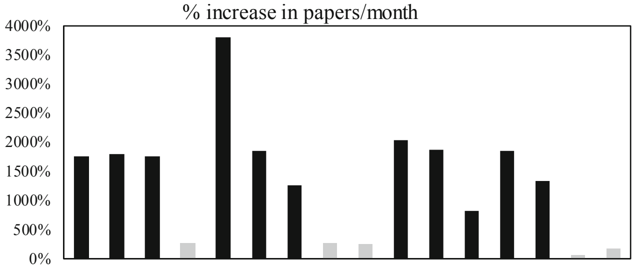
In this context of high trust in the potential of digital twins associated with huge monetary prospects to the industry, the research on the topic has skyrocketed – as demonstrated in Sect. 2. When a new technology trend emerges, other industries are more advanced in its development by the time it normally takes to reach the construction sector. Once it does, it usually starts in academia, where time and resources can be focused on analyzing how the technology can be translated to solving the industry's needs and issues, and results can be more transparently shared. Making up for lost time and catching up to other sectors then results in a peak in research. However, there is often not enough time to evaluate if the advantages of a trendy technology are translatable to the needs and assets of a segment. It is important to consider whether people in the frontline will adopt it, if the investment is properly directed to where it can make a difference, and if that technology is overall necessary for the purpose it is being investigated.

This paper proposes a discussion on what is the purpose of digital twins in the construction industry, especially within civil structures. The growing body of research generated a buzz around the term, but there is still misconception of the scope of a digital twin for the sector. A brief review of the advances in digital twin applications in other industries is presented, followed by a discussion on why and how they can be translated to the needs and challenges of the construction segment. The future of digital twins is also reviewed and later discussed through the lenses of civil engineering.

2 Digital Twin Research

A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making [4]. In 2020, a systematic literature review study [5] focused on digital twins for asset management of bridges performed searches in Scopus following a structured method. The method consisted in dividing the topic in strings of research in five groups of words: BIM (Building Information Modelling), bridges, digital twins, management, and maintenance. Sixteen searches were performed with different combinations of the keywords for each group: one with the five groups, five with four groups, and ten with three groups of keywords. The results were limited by time of publication in a range from 2010 to 2020. This process was now repeated for this study, with a new time constraint for the sixteen searches from 2021–2023. By calculating the average number of papers published per month in each search combination, and comparing the results from 2010–2020 and 2021–2023, the number of publications has increased enormously. The main difference was between groups that contained and did not contain the keywords for "digital twins". The highest increase for a combination including the keywords for "digital twins" was almost 4000%, while the increase in combinations without "digital twins" did not reach 500%. This analysis quantitatively shows how digital twins have significantly grown as a subject of interest in academia, due to the appeal and demand from the industry.

Figure 1 presents a graph with the percentual increase from 2010–2020 to 2021–2023 in published papers per month for combinations 1–16. Below the graph in Fig. 1, a table is found with the respective groups of keywords present in each search. Identified in grey, with much lower percentual increase, are the combinations that did not contain the keywords for "digital twins".



Combinations:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
BIM	X	X	X	X	X		X	X	X	X	X					X
BRIDGES	X	X	X	X		X	X	X	X				X	X	X	
DIGITAL TWINS	X	X	X		X	X	X			X	X	X	X	X		
MANAGEMENT	X	X		X	X	X		X		X		X	X		X	X
MAINTENANCE	X		X	X	X	X			X		X	X		X	X	X

Fig. 1. Percentual increase in papers published per month from 2010–2020 to 2021–2023, in 16 different keyword combinations.

3 Digital Twin Applications

New technologies such as artificial intelligence (AI), machine learning (ML) and predictive analytics have expanded the use of digital twins in several industries beyond its original intended purpose of manufacturing and engine design [6]. Digital twins provide a platform that allows collecting, storing, managing, and sharing data between stakeholders, facilitating its transfer, and ensuring its preservation. Companies can use digital twins to reduce costs by testing new ideas and assets before launching them, as it is more expensive to rectify any problems once something is operational [2].

Digital twin technology can improve the safety of an oil rig, improve the efficiency of a production plant, or ensure that a building meets sustainability or regulatory requirements [2]. In this section, digital twins' potential and challenges, level categorization and examples of applications in different industries are presented.

3.1 Digital Twins: Potential, Challenges, and Levels

In engineering, digital twins bring an additional dimension to management processes (visits, inspections, training) previously limited by manual and 2D tools, as they provide a platform for augmented and virtual reality views that are intuitive, data-rich, and accurate [7]. For new buildings, safety, practicality, and sustainability can be tested within the simulation environment, providing accurate feedback that would mirror the outcome of a test in real life [2]. These improvements reduce time and resources while increasing safety, by preventing workers from physically attending environments that might be dangerous.

In manufacturing, digital twins allow companies to better predict when a particular component or machine will need to be serviced or replaced, so costly and unforeseen production downtime can be avoided, and repairs can be better planned [8]. This advantage goes beyond manufacturing, as using predictive learning technology from current condition information to identify failures before they happen, and offer solutions on how to prevent them, can be applied to operation and maintenance of different assets [2]. This kind of digitalization means stakeholders can access data on demand and in a graphic format that allows for deeper insights than a traditional CAD instance or computer dashboard [7].

Companies have stated that the main challenges faced when building a functional digital twin are understanding the best technology options available, cutting-edge expertise required in different areas, and data-related issues (amount of data, continuous data updates, multiple data sources, securing clean and complete data) [6–8]. As a digital twin is such a comprehensive task to achieve, it is common that companies divide them in different levels of development. Table 1 presents the level classification for digital twins in four different institutions: B&N, AFRY, IBM and Autodesk.

3.2 Applications: Examples

Digital twins can help improve efficiency within complicated machinery and engines, like jet turbines, automobiles, aircraft, and other mechanically complex projects [4]. They also excel at helping streamline process efficiency, like in industrial environments with co-functioning machine systems and manufacturing projects [4]. Therefore, digital twin applications are constantly expanding as they can succeed in several sectors, such as: engineering (systems), automobile, aerospace, building construction, power utilities, health, manufacturing industry, energy, and smart cities [4, 11]. This subsection brings different examples of real digital twin applications used by companies across different industries.

In 2022, the managing director at Accenture Technology Vision has cited two examples of the expanding possibilities in the applications of digital twins [6]. In the first, a Ski Resort is using a digital twin to monitor real-time weather conditions and improve ski conditions, and Port of Rotterdam has built a digital twin that tracks ship and container movements and is being used to optimize operations [6].

BMW has built digital twins of 31 different factories, in which real-time data is used to recreate a 3D environment that mirrors everything from the machines on the floor to the people working at stations [3]. This environment is used for a wide range of functions, including training robots to navigate the factory, bringing together designers from across the globe to experiment with new line layouts and training simulations for individual tasks [3].

Ericsson developed a digital twin for a network simulation study, in which data about the city environment was collected – detailed to the level of building materials, roof shapes and windows –, imported, and used to create a set of simulated models [12].

Table 1. Levels of Digital Twins by B&N, AFRY, IBM and Autodesk [4, 8–10].

Levels	B&N [9]	AFRY [8]	IBM [4]	Autodesk [10]
Level 0	-	Unconnected digital simulation model, an aid to design the object or simulate how it responds to different scenarios	-	-
Level 1	Virtual, static, 3D "snapshot" of a specific moment	Smart: digital simulation model connected to the real object in real time, able to present results to the user in a value-based way	Component twins: basic unit of digital twin, the smallest example of a functioning component	Descriptive twin: visual replica with live, editable design and construction data, including 3D models and BIM
Level 2	Virtual, fully integrated; remotely monitors and controls a facility	Smart: the digital twin can diagnose how the object is operating right now	Asset twins: interaction of components that generates performance data that can be processed and turned into actionable insights	Informative twin: increased integration with sensors and operations data for insights at any given time
Level 3	-	Smart: the digital twin can forecast and calculate when parts of the object will have a reduced function or getting a downtime	System twins: provide visibility regarding the interaction of assets and may suggest performance enhancements	Predictive twin: captures real-time data, contextual data, and analytics to identify potential issues
Level 4	-	Intelligent: with built-in AI and ML, the twin proposes actions itself	Process twins: can evaluate interaction between systems and help determine the precise timing schemes that ultimately influence overall effectiveness	Comprehensive twin: advanced modeling and simulation for potential future scenarios, prescriptive analytics, and recommendations
Level 5	-	Intelligent: the digital twin takes its own decisions and handles the object itself. At this level, it replaces operators and employees	-	Autonomous twin: can learn and make decisions through AI; advanced algorithms for simulation and 3D visualization

On the left side, Fig. 2 shows a car connected to Ericsson's cellular network driving down a street in Stockholm; on the right side, the digital twin dynamically illustrates the resulting massive multiple-input, multiple-output antenna, and signal propagation paths, thereby making it possible to analyze them [12].

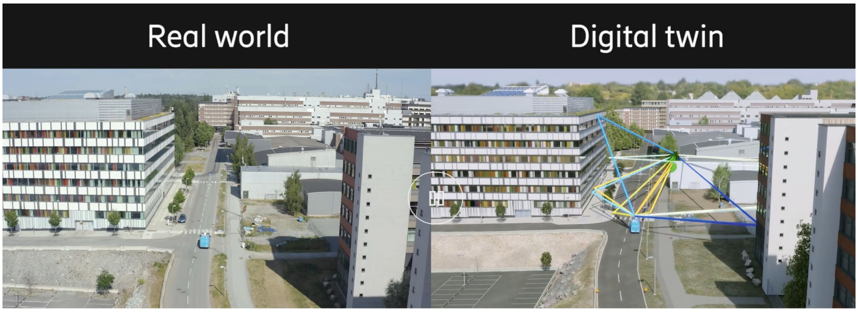


Fig. 2. Network digital twin example by Ericsson [12].

Within civil engineering, Digital Twins enable engineers to keep track of roadways, bridges, pipelines, wastewater treatment plants, and other infrastructure assets that need regular inspection and maintenance [9]. For example, B&N employs virtual, static 3D level Digital Twins for bridge inspection [9]. However, "static level" means that what is provided is a snapshot highlighting the current condition of an asset at a specific moment, rather than a continuous monitoring situation as in other given examples. In this case, engineers capture the 3D model using a drone to scan the structure, replicating the asset, and these Digital Twins can be used for quantity take-off and construction scheduling [9]. This technology was applied in the Waterholes Canyon Bridge inspection in Arizona: a static digital twin was created via drone scanning to track surface area deficiencies in the replicated bridge at that moment, so that engineers can compare and monitor the deficiencies in the next inspection within a few years [9]. B&N also replicated the Jackson Pike wastewater treatment plant to provide a comprehensive view of the facility's current condition and recommend design upgrades to extend the plant's life [9].

4 Future of Digital Twins

Now, like it was in the early years of the web, businesses are racing towards a future utterly different from the one they were designed for [3]. Over the next decade, nearly every environment in which companies do business will be transformed, and the expectation is that digital twins will be used to invent products, design experiences, and run businesses in completely different ways [3]. Another relevant component of this transformation is augmented reality: by combining AR glasses and digital twins is clear, any environment can be made digital or overlaid with a digital experience [3].

Much of what is seen as digital twin applications now still speaks in terms of what it can do, and how it can improve current processes, so it is easy to get a picture of what a future with digital twins will look like. From the applications exemplified in the previous section, digital twins can make investments more profitable, streamline the use of resources and optimize the urban environment in the smart cities of the future [8].

For civil engineering systems, this digitalization is not only an improvement from an overall design perspective, but also embodies the backbone of the logical next step of the infrastructural management system, i.e., smart infrastructure [13]. Smart infrastructure is defined as the integration of a sensing network, which provides real-time digital information about the state of an asset, with physical infrastructure to improve decision making and management of infrastructure assets [13, 14].

Even if it takes longer for processes within civil engineering to adapt to new technology, it is almost inconceivable to visualize a future for infrastructure management that does not include technology such as BIM and digital twins, considering the amount of technology already available. It might still take time before the technology reduces comparatively in value, so that it is more broadly adopted inside the industry and the investments have clearer returns. Besides, due to safety concerns and to facilitate dissemination, processes in construction require standardization, which also takes time. Therefore, these are the expected next steps in the future of digital twins in the construction industry.

5 Discussion

While digital twins are prized for what they offer, not every object is complex enough to need the intense and regular flow of sensor data that they require, nor is it always worth the investment from a financial standpoint [4]. Creating a functional digital replica of an asset updated in real time is an expensive venture. Therefore, it is necessary to reflect upon the benefits of investing in a digital twin and how to translate them to specific assets.

In the automotive industry, for example, a need for efficiency in the production of repeatable products justifies investing in the ability of mirroring fabrication. In aerospace, that is the case mostly due to the very high cost per object produced and the concern with safety. In the construction industry, assets usually are unique and have very long life spans, much longer than automobiles and aircrafts in general. Therefore, investments in digital twins should focus more on improving maintenance of these structures, as their service life greatly surpasses their construction time. Life cycle assessment of structures aiming at prolonging their life spans is more resource-effective both financially and environmentally than replacing them entirely. Amongst the multitude of approaches to structural health monitoring as a mean to increase service life of structures, the digital twin is gaining increasing attention [13]. Based on the current reality of other industries, as well as the predictions for the future, digital twins applied to smart infrastructure and smart management is the optimal focus for the purpose of this technology in the construction industry.

One aspect that is more difficult to translate to infrastructure as an asset is the two-way data flow of a digital twin. Digital twins are designed around a two-way flow of information that first occurs when object sensors provide relevant data to the system processor and then happens again when insights created by the processor are shared back with the original source object [4]. So far, in this situation the flow from the digital back to the physical would occur indirectly by the maintenance activities that are triggered by the insights from the sensor data in the digital twin.

Autodesk defends that BIM is the most efficient path to the creation of an accurate, high-value digital twin [10]. BIM is currently used mostly for planning, design, and pre-construction purposes, despite its significant unexplored potential post-construction. A digital twin extends data capture to the construction and operational phases of the asset—and can also inform planning and design for future projects [10].

6 Conclusion

This study analyzed the purpose, current and future states of digital twins in the construction industry, based on a review of the evolution of research in the topic and recent market applications. Tangible examples of real applications of functioning digital twins are not yet widely available. Still much of what is published about digital twins speaks in terms of what it "can do" to improve current processes, even in reports or articles published by companies. This type of publication was the main source for this specific research due to its purpose of identifying the most recent advances reported by the industry.

The discrepancy between the increased research on digital twins, demonstrated in Fig. 1, and the number of actual digital twins in operation might be due to a number of reasons. The technological challenge might still be too big, or technology too expensive to tackle for most companies. Companies might be investing in digital twins to fit specific needs, which makes it harder to propagate the technology and share the intellectual property. However, considering the huge trend in research, the confidence level on digital twins both in academia and in the industry, and the evolution technology is taking on every aspect of daily life, it is undeniable that this digital transformation will be a reality even for the construction industry. The main point then is to focus the efforts on what makes sense to the industry, invest on technology that can be translated to specific needs of its assets, and will generate tangible results that can survive outside the theoretical realm, regardless of trends and buzzwords.

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