International Journal of Digital Civil Engineering and Building Information Modeling
Volume 1 Issue 2, 2025

Analyzing BIM and Simulation as Digital Portrayals of According to the idea of the digital twin

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Research Article
Received:19-02-2025 **Revised:22-03-2025** **Accepted:05-04-2025** **Published:15-04-2025**

Abstract. A potential method for digitalization in the building business, Building Information Modeling (BIM) is used extensively in contemporary construction projects to digitally depict facilities. However, as far as depicting building processes is concerned, it does have some limits. Similar to how the digital twin idea transformed product lifecycle management in manufacturing, it has the ability to overcome these limits and launch advanced digital transformation in the construction sector. The use of digital twins in the building sector is examined in this study. In all, 140 publications were culled from relevant journals and databases. The building information modeling (BIM) and simulation components make up the digital part of twinning. Digital models of real-world construction sites and structures have been generated using these two methods. Still, there hasn't been enough research into the digital twin concept's implications for combining and using BIM with simulation modeling. By conducting thorough analyses of building information modeling (BIM), simulation modeling (SIM), and digital twins, we can lay the groundwork for this study and determine the future of digital twins in the construction industry, taking our management of projects to the next level of digitalization.

Keywords: Construction industry digitalization, construction management, Building Information Modeling (BIM), digital twin, simulation.

1. Introduction

Simulation modeling and Building Information Modeling (BIM) have been widely used in both academic and commercial building projects in the last ten years [1]. Several studies and real-world applications have shown that building information modeling (BIM) and simulation are valuable tools [2, 3]. Project owners and associated governmental bodies across the world now consider them to be essential needs and alternative options [4]. up order to fill up the gaps and innovate in industrial practice, research and development on BIM and simulation is ongoing [5]. Construction management sector applications are advanced by the integration of building information modeling (BIM) and simulation modeling [6]. Simulation uses the data extracted from a building model for targeted analysis, in contrast to BIM's data extraction [7]. Most construction projects will nevertheless have complications even with well planned and timed schedules [8].

The digital twin—a digital copy of an actual asset or system—is one idea that might help the construction sector deal with these problems. Both the industrial and automobile sectors have already confirmed and embraced the idea. The importance of using digital twins in the construction business has been highlighted in several studies [9]. Digital twinning has the ability to revolutionize the construction sector by addressing systemic problems, according to other research [10].
This study adds to the existing literature by providing in-depth analyses of building information modeling (BIM), simulation modeling (SIM), and the digital twin idea. It also suggests possible future paths and uses for BIM and simulation in the construction sector as virtual representations based on the DTP.

2. Review Approach

Through the integration of historical, thematic, and theoretical methods uncovered in a literature research, a review of simulation modeling, BIM, and digital twining is carried out. This study was organized and structured using the theme method. An examination of the historical context and foundations of simulation modeling, building information modeling (BIM), and digital twin was conducted using a chronological method. We used the theoretical technique to determine where our

current scientific understanding is lacking, to formulate outstanding research questions, and to identify areas that may be improved. Based on literature shortages and areas for improvement, the purpose is to examine digital twin directions and potentials in the construction sector by understanding the developmental backdrop and principles.

The primary sources for the literature reviews that were conducted were the Scopus and Google Scholar databases, which are extensive sources of citations that include prominent works from several disciplines. Only academic journal articles and conference papers were considered for inclusion because of the high quality of the data they provided. The following words were defined for the purpose of locating relevant literature: digital twinning, modeling and simulation, simulation, and simulation modeling. Since simulation and digital twin did not start out in the construction business, unlike building information modeling (BIM), their applications are not industry-specific.

3. Modeling via Simulation

3.1. Process Simulation's Functions

One important function of process simulation is to mimic the behavior of actual processes or systems. Manufacturing, supply chains, corporate operations, transportation, healthcare, and construction are just a few of the many industries that may benefit from simulation's system design and analysis applications [11].
The manufacturing industry often use simulation modeling for control of production processes [12], design of assembly lines, enhancement of productivity, optimization of resources, management of inventories, and supply chain operations [13].

The supply chain industry has found several uses for simulation, including its use for system optimization and design. Furthermore, it helps with supply chain management by facilitating system evaluation and forecasting [14]. In order to enhance system performance, simulation effectively investigates logistics issues in industrial plants, increases warehouse utilization efficiency, and decreases operational expenses [15].

In the realm of business management, simulation-based techniques have found use in areas such as strategy and model development [16], process improvement [17], result prediction [18], and risk management [19].

System interaction, feedback loops, chaotic behavior, and causation in transportation-related issues can only be studied by simulation [20]. It aids decision-makers in resolving certain situations by making the proper choices [21]. More environmentally friendly transportation systems, with less traffic and waiting times, are the result of transportation sector simulations [22].

Simulation has been used in healthcare to assess the operational performance of systems [23] and to develop management guidelines and strategies for optimizing operations [24].

In the building industry, simulation encompasses several facets. Construction project planning and scheduling is one such use. There are greater benefits to using simulation to level building resources compared to using more conventional approaches. The traditional approach assumes that activity periods are constant, while simulation permits uncertainty in this regard, leading to more accurate outcomes [25]. Construction schedules and resources may be dynamically modified via the use of simulation, which is an optimization tool for time-cost tradeoff analysis [26]. Additionally, it helps in managing changes to the cost baseline by keeping the project status updated regularly [27].

Many of these industries have already seen the benefits of process simulation. But there's still space for

development in building when it comes to how well ideas integrate with one another and how easy they are to put into practice.

3.2. Building Simulation

In 1977, Halpin spearheaded the first attempt to apply simulation to the construction industry by introducing CYCLONE, a system for modeling and simulating construction activities [28]. The first stage of building simulation was carried out effectively in the realm of academic research, with only a small number of industry applications [29]. Construction tool and process constraints; industrial culture; time, money, and expertise needed to build and simulate models; and a lack of trust in simulation technologies are all factors that impede industrial execution [30].

As technology has become more integral to many industries in the last decade, construction simulation has grown in popularity as an analytical tool for solving operational issues, planning construction sequences, and making the most of available resources [31]. A slew of simulation research approaches with a focus on the construction sector emerged in response to CYCLONE and other technological developments.

A number of research applications on construction simulation software were supplied by object-oriented programming languages around the start of the 1990s [32]. These languages included Python, Ruby, C++, Java, and C#. Multiple building simulation programs, including MicroCYCLONE, Disco, COST, STROBOSCOPE-CPM, CIPROS, and COOPS, have relied on object-oriented programming as a foundation for their development.

With the proliferation of complicated building projects in the 2000s, AbouRizk et al. [33] developed Simphony to streamline the modeling process using simulation. The developer has easy control over simulation behaviors, graphics, statistics, and animation using Simphony. Additionally, it facilitates the development of purpose-built simulation models using special purpose simulation. This function improves efficiency and resource optimization in the construction industry by moving certain tasks from the site to off-site planning [34].

The use of 3D visualization tools, with their scalable and extensible features, has helped to make the description of simulation processes easier to understand within the last decade [35]. The construction industry can make better use of simulations with their help, and more realistic systemic models can be built [36]. The integration of process simulation with 3D visualization technologies enables the viewing of building sequences and work progress using 3D models [37]. As a result, building information modeling (BIM) has grown in popularity and is now used in construction simulation. Additional information is much enhanced for construction management when simulation and BIM are integrated [38].

The extensive nature of simulation approaches is a challenge to their widespread use in the building sector. Nevertheless, discrete-event simulation (DES) has been proposed in a number of studies as a means to simplify simulation methodologies [39]. A crucial function of DES is the creation of simple simulation approaches. DES features are compatible with the culture and nature of the construction sector. As a result, several simulation methods have been created, including the extensively used CYCLONE and Petri nets in a number of sectors, including the construction industry [40]. Carl Adam Petri [41] created Petri nets in 1962 as a mathematical and graphical tool to represent non-deterministic, stochastic, concurrent, asynchronous, distributed, and parallel information processing systems. Petri nets, as graphical models, provide visual communication by depicting concurrent and dynamic system processes. Mathematical analysis may be carried out using many equations when using Petri nets as a model. Underlying systemic behaviors may be described by their analysis processes [42]. The generalizability, adaptability, and extensibility of Petri nets' functionalities have led to their adoption for a wide range of applications.

The four components of a Petri net model are locations, transitions, arcs, and tokens. Having input

resources or being in a location where resources are found is what a place signifies. What we call a "transition" actually denotes a process, job, or event. Connecting locations and transitions is done via arcs. In the Petri nets, they show the flow of tokens and the direction of flow. In order for Petri nets to dynamically connect locations and transitions, tokens are first set up at a place and stand in for resources [42].
Numerous established methods now rely heavily on Petri net-based simulations. A number of variants of the Petri net simulation have been developed and launched in recent years, including time Petri net [43], deterministically timed Petri net, stochastic timed Petri net, generalized stochastic Petri net, and colored Petri net [44].

Hillion [43] suggested a temporal Petri net to make it possible for conventional Petri nets to permit delays after the activation of transitions, rather than being instantaneous. The Petri net becomes deterministically timed if the transition times are deterministic. A stochastic timed Petri net is used when the transition times are arbitrary variables. Generalized stochastic Petri nets are used when there are two sorts of transitions: timed and instantaneous [44].

Building projects make use of a wide variety of resources, yet the original Petri nets only let you define one kind of token (resource). Tokens allow Petri nets to simulate a variety of things, however this is not possible. Jensen suggested using token colors as a way to make Petri nets able to describe several kinds of resources. Various resources may be recognized and examined using these colored Petri nets [45-48]. By introducing the construction-oriented simulation modeling system (COSMOS), Damrianant [49] shown that Petri nets may be significantly extended for use in modeling and simulating the building process. In COSMOS, not only are classic Petri nets available, but a number of extensions called header, follower, pipe, and buffer were also built. These additions allow for overlapping modeling across activities [50]. It is also possible to model and simulate situational interruptions that occur throughout the operating time utilizing the modeling components extensions switch, POI arc, and control arc [51]. By including the novel features of multiple-branch arc, alternative arc, and alternative place, COSMOS enables more effective allocation of resources [52].

When evaluating building projects including such complicated systems, simulation software is essential. Knowing the ins and outs of the software used for building simulation is crucial, since the field is highly dependent on it.

3.3. Software for Construction Simulation

With the advent of computer programming languages came a slew of construction simulation programs meant to mimic the ever-increasing complexity of actual building projects [33]. A number of analytical activities in construction management now need the program. Optimizing construction time and resources, scheduling operations, and resolving operational issues are all within its capabilities [31]. Figure 1 shows a sequence of models used for building simulation.

The current trend in the subject is to combine simulation with data from other disciplines. Building Information Modeling (BIM) has been extensively researched to build more effective modeling and simulation in construction, and it is a highly promising development in the AEC areas. New, in-depth studies combine building information modeling (BIM) with simulation to develop cutting-edge apps.

The integration of 3D models with construction schedules is now standard practice in the industry. This allows for the visualization and evaluation of constructability of building sequences [37]. In the same way that building information modeling (BIM) supplies data to simulation models, simulation models assess the efficacy of construction projects and provide useful information back into BIM to aid in decision-making [7]. Materials needed for a project may be estimated with the use of BIM, which is a vital competency. Project schedules may be generated by the use of such data by use of simulation modeling [53]. Building information modeling (BIM) was connected with supply chain building material models to avoid construction delays due to material shortages [54]. Improving the project procurement timeline is possible using BIM-based information aids, which allow simulation modeling to assess dynamic productivities [56].

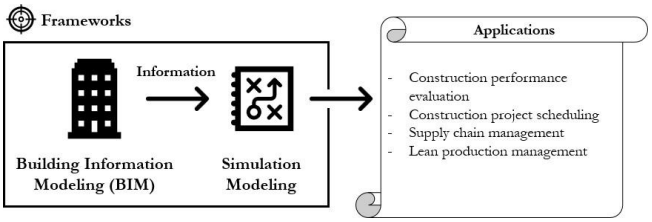


Fig. 1. Integrating of BIM and simulation.

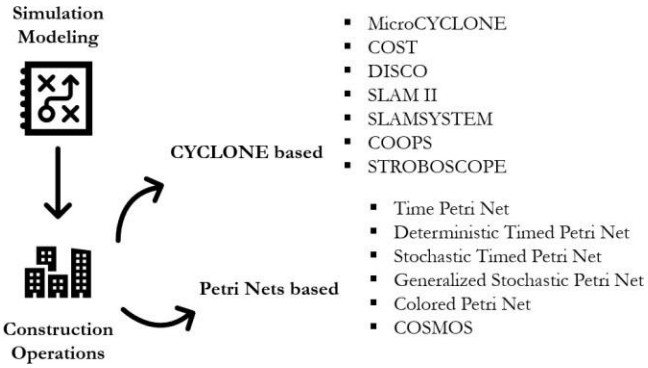


Fig. 2. Series of construction simulation modeling.

Technological advancement offered innovations in simulation software capabilities in flexibility, design improvement, and heightened efficiency [56]. In 1977, Daniel W. Halpin introduced CYCLONE, the first significant effort in construction simulation language [28]. Later, it became a prototype for modern construction simulation software.

MicroCYCLONE was the first construction simulation software developed following the CYCLONE concept, offering flexible adaptive characteristics for construction practice. MicroCYCLONE has been adopted for many uses, such as modeling and simulation repetitive construction processes [57], cost optimization of earthmoving operations [58], and construction process planning and analysis [59].

Object-oriented programming plays a significant role in developing construction simulation software by simplifying coding and improving model readability [60- 61]. Together with discrete-event simulation, it generates an automated system for selecting optimal fleet configuration and providing a vehicle for estimating construction time and costs, by considering different practical scenarios [62].

Although MicroCYCLONE notably contributed to promoting CYCLONE, it was a DOS-based program

and was not updated since the introduction of Windows- based computer operations systems. To modernize MicroCYCLONE, construction operation simulation tool (COST) was introduced as an improved version of MicroCYCLONE. COST is able to model uncertain events by using a fuzzy data simulation function [63].

Meanwhile, Huang and Halpin [64] introduced an alternative construction simulation approach, dynamic interface simulation for construction operations (DISCO), applying visual simulation to facilitate construction operational planning and analysis activities. The application allows system dynamic behavior to be visualized as the simulation is executed.

Since 1979, in addition to CYCLONE, a simulation language for alternative modeling (SLAM II) was also influential in construction simulation as a general- purpose language. It enables the modeling of different manufacturing, transportation, and communication systems. SLAM II language user facility was significantly increased by the development of SLAMSYSTEM and SLAMSYSTEM Version 4.5 in 1988 and 1994, respectively [65].

Ioannou and Liu [66] introduced a construction object-oriented process simulation system (COOPS), using modeling elements to create interactive onscreen graphical networks. COOPS can simplify complex systems by exploiting graphical networks dedicated to the modeling construction process.

In the 2000s, STROBOSCOPE and Simphony became mainstream simulation approaches in the construction field. STROBOSCOPE was introduced by Martinez and Ioannou [67] as a modeling and simulation language with an open platform for generating models from open-environment source coding. It can model many simulation systems, including CYCLONE. Simphony was introduced by Hajjar and AbouRizk [68] as a platform for creating tailor-made simulation instruments for general applications, including construction.

Basically, the aforementioned simulation systems require profound knowledge and understanding of process modeling and simulation mechanisms. The knowledge required becomes a barrier to adopting industry-wide simulation [69]. In 1999, activity-based construction (ABC) was introduced to simplify such impediments, designed to use a single element, rather than multiple ones, for construction process modeling. In this way, knowledge required is minimized and construction simulation difficulties addressed [70].

Simplification is a key to spreading practical adoption of simulation. Therefore, AbouRizk and Mather [71] introduced a 3D-based simulation approach to further simplify the modeling and simulation process by using 3D-CAD.

Similarly, to minimize required skill, Chua and Li [72] proposed a resource-interacted simulation (RISim) approach, enabling users incompletely informed about simulation technology to generate a simple simulation model by emphasizing model resource and process levels.

Generating efficient construction schedules is challenging, especially in complex construction projects. Therefore, optimization techniques were combined with discrete-event simulation to generate a multi-method optimization package (MOPACK), a computer-based optimization framework. MOPACK enhances construction planning and scheduling processes more optimally [31].

Since 3D visualization systems have become essential to the industry, they have been integrated into simulation to conduct construction sequences and work progress visualization for 3D modeling [37]. To integrate simulation with 3D visualization, Kamat and Martinez [73] introduced VitaScope as a 3D visualization extension for construction simulation, allowing the process model to link with 3D objects to visualize and validate the operation.

While CYCLONE-based modeling and simulations developed over time, Petri net-based systems were also present industrially. Although Petri nets derived from a different industry and application areas, its generality and flexibility allowed for adaptation to the construction industry [42].

Petri nets are graphical and mathematical modeling approaches capable of performing static and dynamic analyses. Damrianant [49] adapted these capabilities for construction process modeling and simulation. COSMOS, a simulation modeling methodology, was developed based on these capabilities. COSMOS is a Petri net-based modeling methodology with several modifications to the original Petri nets. For example, it provides capabilities for modeling overlapping activities [50], interrupting situations during the operational period [51], and efficient resource allocation [48].

A COSMOS simulator was developed as computer software to emphasize the practical execution of COSMOS, allowing for modeling and simulating construction processes created with COSMOS methodology. COSMOS simulator reliability and performance were verified by using coloured Petri nets [74], the Arena simulator [75], and critical path method [76].

Although simulation is essential in the construction industry as a powerful analytical instrument for different application areas, it requires sufficient reliable information, collection of which is challenging in practice and adds further material for examination.

3. Building Information Modeling (BIM)

3.1. Overview of BIM

4. Eastman et al. [77] first proposed the idea of building information modeling (BIM) as a BDS for storing and manipulating design information. Afterwards, in 1992, Nederveen and Tolman were the first to adopt the term BIM [78]. Both BIM and BDS rely on models to store and manage data, which is why the two concepts are comparable. Project stakeholders with different views on the building project data may work together more effectively using BIM. Building Information Modeling (BIM) has become a game-changer in the industrial sector as an integration platform that contains participant-specific data. A prominent software business, Autodesk, released a white paper in 2003 to showcase their BIM-based software. It was the catalyst for building information modeling (BIM) software development and the distributor of a large suite of BIM applications with extensive features [79]. Nevertheless, it proved difficult to alter long-established business practices. The development of CAD software, which assists in the design process, was a major factor. The shift from 2D to 3D data was accelerated in large part by computer-aided design (CAD), which allowed for the evolution of labor-intensive drafts into more efficient documentation [80].
A building information model (BIM) is a digital representation of a building that includes detailed information about its physical and operational aspects [81]. Aside from being a standard 3D model, it also serves to represent semantics by storing and manipulating data. All of its objects have both the physical properties anticipated from a 3D geometric representation and the functional properties that are inherent to it [82].
Building Information Modeling (BIM) has been successful in a number of scholarly and commercial contexts throughout the last 20 years. Throughout a project's lifespan, it encourages cooperation among many stakeholders and makes it easier for them to share information and resources [83]. During the pre-construction phase, BIM greatly improves the design and engineering process. It can comprehend and remove problems between multiple parties using digital representations, and it can do this as a physical representation. Building sequences may be better understood by the construction crew with the use of functional building visualizations [84]. Using BIM, construction operations can be better monitored and controlled, which is particularly helpful for complicated architectural projects. It makes it easier to allocate resources and consider several sequencing options for systems that create complicated buildings [88]. In order to cut down on waste and make sure everything was done well, Jiang [89] used BIM throughout the building phase of a large-scale construction project. According to his research, building information modeling (BIM) helped with project management and, by reducing waste, allowed for more sustainable growth of the project. By carrying out five massive public projects, Jian et al. [90] highlighted increased construction productivity. In order to assess the effects of changing orders throughout the building phase, Handayani et al. [91] created a BIM-based system. Not only can users assess the effects on project costs and schedules, but the technology also helps them see and visualize the effect of change orders using 3D BIM models.
Building information modeling (BIM) is useful for asset management after construction has ended. Using its digital model, it is possible to document and update physical facility modifications [84]. With this feature, BIM has been customized for many uses. Facility decision-making in the areas of operation, maintenance, repair, and replacement is a typical use case for building information modeling (BIM) [87]. In addition to delivering more accurate and extensive data, building information modeling (BIM) speeds up building management and operation [92, 94]. Because of this, traditional AEC procedures have been transformed into more efficient workflows, and stakeholder participation has been greatly improved [79].
Interoperability problems and process-related contractual and organizational hurdles were among the many difficulties that businesses faced in the early stages of building information modeling (BIM), prior to the establishment of standards and guidelines [95]. In an effort to address these issues, the government and its subsidiary bodies championed the publication and implementation of building

information modeling (BIM) standards and protocols [82]. Building Information Modeling (BIM) has been extensively used and played a crucial role in the last decade to streamline the integrated design and construction process. To further integrate data from all phases of a building's lifespan, Lee et al. [96] presented nD Modeling, often called nD CAD, in 2003 as an expansion of BIM. The three-dimensional model depicts the object's geometric dimensions; the four-dimensional model incorporates time sequencing into the three-dimensional model. A 3D model may be used to graphically portray a series of events on a timeline [97]. Additionally, the 4D model may show the building's construction procedures prior to the start of real construction [98]. The 4D model was further enhanced by include cost-related data, resulting in a 5D model. This new model enables the visualization of building progress and associated expenses over time. Being aware of possible extra expenses helps with project management and makes it easier to see how much money is being spent on operating costs connected to building progress [99].

To meet the challenges posed by the ever-increasing complexity of modern manufacturing, BIM-based frameworks have undergone constant development for a number of reasons. Using building information modeling (BIM), Jeong et al. [6] created a system for predicting the dynamics of productivity during the planning stage of steel structure erecting. Reliability of schedules, allocation of resources, optimization of costs, and elimination of material waste were all areas where the framework was said to be efficient. A building information modeling (BIM) system was created by Handayani et al. [91] to assess the effects of modifying orders on time, money, and physical conditions during the construction process. To show how effective and practical the method is, it was used on a real-life 18-story construction project. The project owner and contractor were able to resolve disputes over construction claims that arose after the orders were changed because it thoroughly evaluated and reported on all three types of effects. In their introduction to a system built on the BIM idea, Song et al. [100] made it possible to compare several building schedules in order to find the most efficient and cost-effective ones for large-scale projects.

To assess the necessary construction activities, estimate the tasks involved, and arrange the tasks in a logical order, Kim et al. [101] put forward a framework. Consequently, the suggested framework can retrieve pertinent data from the BIM model and automatically provide building schedules. A scheduling method based on building information modeling (BIM) was created by Liu et al. [5] by using optimization algorithms and simulation modeling methodologies. The method allows for the creation and optimization of construction schedules with the use of continuously updated resources.

To simplify the development sequence, BIM-based frameworks scheme is shown in Fig. 3.

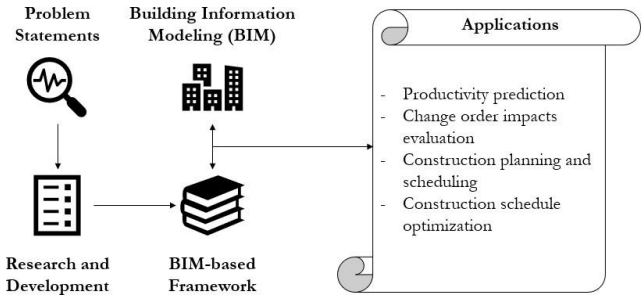


Fig. 3. Basic BIM-base frameworks scheme.

Many studies have attempted to develop BIM-based frameworks according to increasing industrial competition and complexity. These developments contribute to industrial advancement of BIM applications. However, practicality is another vital factor that must be considered along with advancement of the applications.

5. Digital Twin

5.1. Overview of Digital Twin

Michael Grieves first proposed the term "digital twin" in 2002 to describe a system or asset's virtual counterpart in the field of product lifecycle management [102]. During that period, digital twins were

used to provide details on the characteristics, states, and actions of the physical assets that were modeled and simulated. A physical item, a digital copy of that thing, and the link between them are the three parts that make up a digital twin, according to Grieves.
A taxonomy of digital twins was subsequently proposed by Grieves [103]. It has four levels: prototype, instance, aggregate, and environment. He went on to say that a digital twin prototype is a computer model of an entity that has all the information needed to create a physical twin. An individual product's digital twin is an exact replica of that product that stays connected to that product all through its lifecycle. Information gathered from sensors, testing, and inspections during the life of the asset is stored there. All instances of a digital twin may be accessed using an aggregate collection called a digital twin aggregate. A digital twin environment is a digital copy of the real-world product's surroundings that incorporates all of the aforementioned digital twin taxonomies and links all pertinent parts.
There are many types of digital twins, each with its own unique degree of integration between the real and virtual worlds. Digital models, digital shadows, and digital twins are the three tiers of integration that assess the object's and data's interplay [104].
One definition of a digital model is a representation of a physical object, either actual or proposed, in a digital format. At this degree of integration, the transfer of data from a real-world item to its digital counterpart is not incidental. The term "digital shadow" might be used to describe the integration that occurs when data transfer from the real world to the virtual world becomes automatic. If the state of the real item changes, the virtual object's state will also change automatically at this degree of integration. A digital twin may be defined as an integrated system in which data interchange between real and virtual items is automated. At its most advanced level of integration, digital twins enable virtual objects to take the role of actual ones in command and control scenarios. Consequently, the states of the physical and virtual objects are closely related; modifying one causes the other to change. Figure 4 depicts simplified setups for digital models, digital shadows, and digital twins.

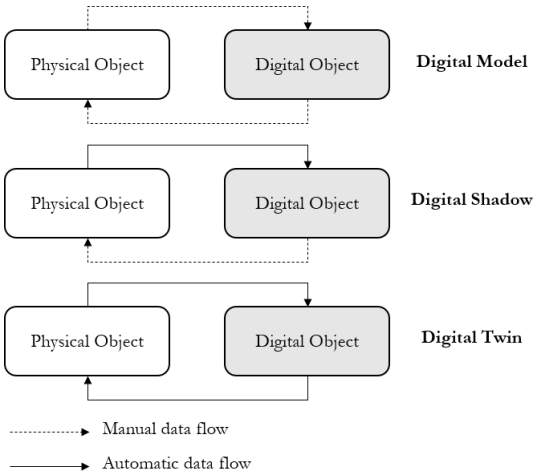


Fig. 4. Digital twin integration level [104].

The interest in digital twin has significantly increased academically and industrially, as seen by the growth of many related publications [105]. Apart from product lifecycle management, manufacturing system optimization is another favored research area. For instance, Schluse et al. [106] applied a digital twin-based approach to optimize systematic parameters and structures for various areas of applications. Zhang et al.

6. Conclusions and Future Research

This research contributes to the body of knowledge by presenting a review of simulation modeling, BIM, and digital twin from fundamental and domain application perspectives. The goal was to shed light on current limitations and prominent areas for future research and development, knowledge gaps, significant issues and challenges, developmental directions and potential applications for BIM and simulation following the digital twin concept.

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