Article

Not peer-reviewed version

Digital Twins and BIM Toward the Smart Managemen of Post Occupancy Public Buildings

Jorge Pablo Aguilar Zavaleta *

Posted Date: 14 March 2025

doi: 10.20944/preprints202503.1070.v1

Keywords: BIM; digital twins; public buildings; intelligent management

Article

Digital Twins and BIM Toward the Smart Managemen of Post Occupancy Public Buildings

Jorge Pablo Aguilar Zavaleta

Faculty of Engineering and Architecture, Professional School of Architecture, César Vallejo University; joaguilarz@ucvvirtual.edu.pe

Abstract: Digital twins and Building Information Modeling (BIM) are transformative technologies reshaping the smart management of public buildings post-occupancy. A virtual representation of a physical asset that utilizes real-time data to monitor performance, while BIM involves the generation and management of digital models throughout a building's lifecycle. The integration of these technologies allows for enhanced operational efficiency, predictive maintenance, and improved decision-making, ultimately driving sustainability initiatives and tenant satisfaction in public infrastructure. The emergence of digital twins, rooted in advancements such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, marks a significant evolution in building management. This shift, which began in the early 2000s, enables the continuous updating of digital models based on live data, bridging the gap between physical structures and their digital counterparts. Research initiatives have highlighted the potential of these technologies to create predictive models that enhance operational strategies and support comprehensive building performance analysis. The synergy between digital twins and BIM offers significant benefits for the management of public buildings, paving the way for smarter, more efficient environments. However, overcoming the existing challenges is crucial for realizing the full potential of these innovations in enhancing facility management, energy efficiency, and occupant safety.

Keywords: BIM; digital twins; public buildings; intelligent management

---

1. Introduction

Digital twins and Building Information Modeling (BIM) are transformative technologies reshaping the smart management of public buildings post-occupancy. A digital twin is a virtual representation of a physical asset that utilizes real-time data to monitor performance, while BIM involves the generation and management of digital models throughout a building's lifecycle. The integration of these technologies allows for enhanced operational efficiency, predictive maintenance, and improved decision-making, ultimately driving sustainability initiatives and tenant satisfaction in public infrastructure. [1–3].

The emergence of digital twins, rooted in advancements such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, marks a significant evolution in building management. This shift, which began in the early 2000s, enables the continuous updating of digital models based on live data, bridging the gap between physical structures and their digital counterparts. [4–6]. Notably, research initiatives have highlighted the potential of these technologies to create predictive models that enhance operational strategies and support comprehensive building performance analysis. [1,2,7].

Despite their advantages, the adoption of digital twins and BIM is not without challenges. Issues such as a lack of common understanding regarding digital twin definitions, unclear business models, and high implementation costs hinder their widespread acceptance. Furthermore, the complexity of integrating diverse data systems and achieving semantic interoperability presents technical barriers that must be addressed for successful deployment. [8–10]. As cities worldwide increasingly leverage

 doi:10.20944/preprints202503.1070.v1

these technologies for urban planning and resource management, the need for effective integration and collaboration across stakeholders becomes paramount. [11,12].

In conclusion, the synergy between digital twins and BIM offers significant benefits for the management of public buildings, paving the way for smarter, more efficient environments. However, overcoming the existing challenges is crucial for realizing the full potential of these innovations in enhancing facility management, energy efficiency, and occupant safety. [13,14].

2. Materials and Methods

Historical Context

The concept of digital twins has evolved significantly over the past two decades, gaining traction primarily due to advancements in related technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics. Initially, the idea of a digital twin emerged in the early 2000s, rooted in product lifecycle management and 3D modeling techniques, which allowed for the creation of virtual representations of physical objects and systems [1,4].

As industries sought more efficient ways to manage assets and operations, the in- tegration of building simulation technology with existing asset management theories became increasingly important. This shift laid the groundwork for the development of sophisticated digital twin architectures that could enhance maintenance strategies and operational control in both existing and new buildings [1,5].

The interaction between digital twins and Building Information Modeling (BIM) has also played a crucial role in the evolution of smart building management. Digital twins serve as dynamic models that continuously update based on real-time data from their physical counterparts, thus bridging the digital and physical worlds [2,6]. This integration has not only facilitated predictive maintenance but also enabled a more efficient approach to managing complex building systems, reinforcing the need for smarter technologies in the construction industry [7].

Research initiatives, such as those funded by the U.S. National Science Foundation, have further elucidated the transformative potential of digital twins. Reports have emphasized their ability to create predictive models that inform decision-making processes, thereby delivering tangible value across various sectors, including public infrastructure [1]. As digital twins have matured, their application has expanded bey- ond single assets to encompass entire organizations, allowing for a comprehensive understanding of operational dynamics and enhancing overall building performance- [2].

Key Concepts

Integration of Digital Twins and BIM

The integration of digital twins and BIM leverages the strengths of both technologies, resulting in significant benefits for the management of built assets. While BIM provides a rich, information-dense model during the design and construction phases, digital twins utilize real-time data to create a continuous feedback loop that enhances operational efficiency and decision-making after construction [3,15]. This synergy allows stakeholders to monitor performance, identify potential issues early, and optimize operations throughout the lifecycle of a building [2,16].

Definition of Digital Twins and BIM

Digital twins are virtual replicas of physical assets, processes, or systems that provide real-time data and behavioral insights. They represent a dynamic model that captures the operational status of their physical counterparts, facilitating monitoring, analysis, and autonomous behavior in various contexts beyond just construction and architecture [16,17]. On the other hand, Building Information Modeling (BIM) is a methodology focused on generating and managing digital representations of a building's aesthetic and functional attributes throughout its lifecycle. BIM enables enhanced collaboration and visualization during the design and construction phases while serving as a comprehensive digital database once the project is completed [18].

Characteristics of BIM Objects

 doi:10.20944/preprints202503.1070.v1

BIM objects serve as the fundamental components of a 3D model, encapsulating more than just geometric representations of physical elements. They include detailed information about the characteristics, properties, and behaviors of real-world components. For example, a BIM object representing a door would encompass geometric data such as dimensions and swing direction, as well as specifications like material and fire rating, enabling informed decision-making regarding their selection and placement [19].

Role of Data in Digital Twins and BIM

Both digital twins and BIM rely heavily on data for their functionality. Digital twins require robust, real-time data to maintain an accurate virtual representation of physical assets, while BIM uses detailed information collected during the design and construction phases. The effective management and integration of this data is crucial for ensuring the accuracy and utility of both technologies, enabling predictive analytics and enhancing the overall performance of built environments [15,17,20].

Benefits of Integration

Integrating digital twins with BIM offers numerous advantages, including enhanced visualization, improved decision-making, and greater operational efficiency. This combination facilitates a comprehensive perspective of a building's lifecycle, from initial design through ongoing operations and maintenance. Stakeholders can utilize this integration to streamline processes, reduce costs, and improve the quality of building management, ultimately delivering better outcomes in public building occupancy and sustainability [2,3,18].

Applications

Overview of Digital Twins and BIM in Building Management

Digital twins (DT) and Building Information Modeling (BIM) are revolutionizing the management of public buildings post-occupancy. These technologies provide compressive tools for monitoring, analyzing, and enhancing building performance through real-time data integration and predictive analytics. By leveraging these advanced systems, facility managers can optimize operations, improve tenant satisfaction, and drive sustainability initiatives.

3. Results

Facility Management

Digital twins play a critical role in facility management by offering an accurate digital representation of a building. They allow for the continuous monitoring of building performance and facilitate data-driven decision-making processes. This capability helps in enhancing operational efficiency, reducing maintenance costs, and improving overall tenant satisfaction [7,21]. By integrating IoT sensors and data analytics, digital twins provide insights into energy consumption, space utilization, and predictive maintenance needs, which can lead to significant cost savings [16].

Urban Planning

The application of digital twins extends beyond individual buildings to entire urban environments. Cities like New York and Helsinki have adopted digital twin technology to optimize urban planning efforts, manage public infrastructure, and enhance resource allocation [11]. By creating digital replicas of urban spaces, city planners can simulate various scenarios, assess the impact of potential developments, and engage citizens in the planning process, ensuring that community needs are addressed.

Sustainability Initiatives

Digital twins are instrumental in driving sustainability efforts within the built environment. They enable building managers to assess the environmental performance of their facilities, optimize energy efficiency, and reduce resource consumption. For instance, through the analysis of operational data, managers can identify patterns in energy usage and implement measures to improve efficiency, contributing to overall sustainability goals [7,21].

Safety and Security Enhancements

Another significant application of digital twins is in improving safety and security within buildings. By tracking movements of people and equipment, digital twins can help identify potential hazards and enable rapid responses to emergencies. For example, if a digital twin indicates that a person is in a hazardous area, automated security systems can be triggered to ensure their safety [16]. This capability not only enhances building security but also improves the overall safety of occupants.

Integration with Building Lifecycle Management

The integration of BIM and digital twins facilitates seamless building lifecycle management. By evaluating the interoperability and application interface of these technologies, stakeholders can determine the most suitable technology for their projects. This integration allows for enhanced collaboration among project teams, leading to more informed decision-making throughout the building lifecycle—from design and construction to occupancy and eventual renovation [22,23].

Challenges

Digital twins (DTs) and Building Information Modeling (BIM) technologies, while offer- ing transformative potential for the management of public buildings post-occupancy, face several challenges that hinder their successful implementation and operation.

Non-Technical Challenges

Awareness and Definition

One of the primary social challenges identified is a lack of common understanding regarding what constitutes a digital twin. This confusion can lead to difficulties in collaboration between clients and partners, necessitating extensive discussions to align expectations before project initiation [8]. Furthermore, the fuzzy definition of digital twins presents a barrier, with over 59% of experts perceiving it as a moderate challenge [8].

Business Model and Financing

From a legal and business perspective, the absence of clear business models and financing strategies poses significant barriers to the widespread adoption of digital twins. This issue is regarded as one of the most severe challenges, with many experts advocating for more defined frameworks to guide implementation [8].

4. Discussion

Technical Challenges

Semantic Interoperability

The complexity of integrating various data systems and formats remains a critical technical challenge. Semantic interoperability is often cited as the most severe issue, as different domains typically operate in silos, resulting in significant gaps in technology and standards. This lack of integration complicates the creation and maintenance of effective digital twins [8,9].

Implementation Costs

The high costs associated with deploying digital twins, including the need for extensive sensors and computational resources, limit accessibility—particularly in developing regions. This financial burden can deter organizations from investing in such technologies despite their long-term potential for return on investment [9,10].

System Integration

Integrating heterogeneous systems to construct functional digital twins can increase implementation complexity exponentially. Many experts acknowledge that the challenge lies not just in data sources but also in managing different versions and formats of data, which complicates real-time and bidirectional information flow essential for effective digital twin functionality [8,9].

Cultural and Organizational Challenges

Company Culture

Successful adoption of digital twins requires a cultural shift within organizations. Companies must foster an environment that embraces change and continuous improvement, which is often a significant hurdle for traditional business practices. Without an open mindset towards innovative technologies, the integration of digital twins may face resistance [10].

 doi:10.20944/preprints202503.1070.v1

Real-time Data Utilization

Challenges related to the utilization of real-time data also exist. Designers often struggle to replicate complex social behaviors and environmental factors that cannot easily be quantified, thus limiting the effectiveness of digital twins in addressing sociopolitical issues and sustainability concerns [7,9].

5. Conclusions

Future Trends

Integration of Digital Twins and BIM

The integration of Digital Twin technology with Building Information Modeling (BIM) is expected to play a crucial role in the future of smart management for post-occupancy public buildings. This amalgamation offers the potential to create a comprehensive virtual model that not only supports the design and construction phases but also extends into the operational and maintenance stages of a building's lifecycle [4,17]. As BIM methodologies advance, the synergy with digital twins can lead to improved asset management, operational efficiency, and predictive maintenance, ultimately enhancing the user experience and sustainability of public facilities [13,17].

Predictive Maintenance and Cost Efficiency

Future implementations of Digital Twins are anticipated to significantly shift facility management from reactive to predictive maintenance. By leveraging real-time data and advanced analytics, facility managers will gain better visibility into asset conditions, enabling just-in-time procurement strategies to mitigate supply chain disruptions [4,12]. Such strategies can reduce maintenance costs by 25-30% and potentially increase property values by 7-20% through optimized performance and reliability [4,17]. This predictive approach is particularly vital given the rising concerns around parts and equipment shortages highlighted by facility managers [12].

Smart Cities and Energy Efficiency

As the concept of smart cities continues to evolve, the role of Digital Twins will expand beyond individual buildings to encompass entire urban environments. Integrated digital twins can replicate not only the built structures but also the underlying infra- structure and networks [13]. This holistic view facilitates better resource management and operational strategies, leading to significant energy savings—up to a 20% reduction in energy usage has been observed in buildings that utilize digital twin technologies [4]. The global market for digital twins is projected to reach $48.2 billion by 2026, indicating strong growth in this area [4].

Challenges in Adoption

Despite the promising future of Digital Twins, several challenges remain, particularly in terms of integration with existing systems. Many organizations face complexities due to legacy systems and multi-layered IT architectures, which can hinder seam- less communication between physical assets and their digital counterparts [14,17]. Addressing these integration issues will be essential for organizations looking to fully exploit the capabilities of Digital Twins and BIM in facility management.

References

1. Digital twins beginning to deliver real-world benefits
2. Digital Twin and How Is It Revolutionizing Building Management ...
3. (PDF) Digital Twin Architecture for Buildings and Cities - Academia.edu
4. BIM vs Digital Twin: When and How to Use Them - Intelvision
5. Digital Twins in Action: Unveiling the Best Use Cases for Buildings and ...
6. What Challenges do Digital Twins Solve in Buildings? - Thoughtwire
7. Boosting BIM Adoption with Digital Twin Technology: A ... - Twinview
8. Exploring Digital Twins: The Natural Future for BIM? - Twinview
9. My Top 5 Uses of Digital Twins with BIM for AECO - Plannerly

 doi:10.20944/preprints202503.1070.v1

10. Decoding the Differences: BIM and Digital Twins Explained
11. What is the Difference Between BIM vs Digital Twins? - Indovance Inc
12. What is BIM? | Building Information Modeling - BIMcollab
13. Digital twins inch closer to reality in building construction
14. Digital Twins: A Powerful Tool for Design and Construction
15. The Rise of Digital Twins: How Cities Are Creating Virtual Models ...
16. The Role of BIM in Integrating Digital Twin in Building ... - MDPI
17. My Top 10 Best BIM Software Programs - Plannerly
18. Uncovering the challenges of urban digital twins
19. Digital Twin Technology Challenges and Applications: A ... - MDPI
20. Digital Twins and BIM for Facility Management- LinkedIn
21. Enabling smart facility management with digital twins - Intellias
22. Riding the Wave of Digital Twins for Facility Management - Intellias
23. Top 3 Challenges in Digital Twin Adoption. - LinkedIn