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The Impact of AI in BIM-to-Digital Twins on Facility Management Handover

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ABSTRACT

The present paper will consider how Artificial Intelligence (AI) will help in the shift by Building Information Modeling (BIM) to Digital Twins (DTs), specifically in relation to facility management handover. It deals with the main industrial concerns in the fragmentation of data, lack of interoperability, and ineffective regulatory compliance process by using AI-based solutions to enhance data validation, predictive analytics, and real-time synchronization. The data collection was conducted with the help of a qualitative method based on an interpretivist worldview and grounded theory approach, which allowed collecting data through semi-structured interviews with BIM professionals. The findings prove that AI could be effective to increase the accuracy, effectiveness, and quality of BIM-DT handover procedures, which, in its turn, leads to more efficient operations, proactive maintenance of facilities, and sustainable facility management.

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INTRODUCTION

The introduction of information and communication technology (ICT) has spawned several applications that have resulted in the wave of innovations and upgrades that have transformed how individuals undertake their daily chores in various fields and industries globally. Accordingly, such developments have significantly influenced the architectural sector and have made it possible to use applications and technologies such as virtual reality to enhance architectural design and visualization (Fakahani et al., 2022). The building projects can also be advantaged by the scientific innovations that enabled the teams and managers to communicate across borders (Manea et al., 2020).

Therefore, BIM is the modelling technology which involves the utilization of various digital applications to conceive, create, keep track, and manage the effectiveness and delivery of a construction venture (Ismail et al., 2022). It may be deployed in a workflow which begins with a stage, during which designs are described and construction of the project is developed, and information c After design and completion, the project is maintained as an asset. In this case, the project is transferred to the building owner and becomes the part of the asset management model (AIM) (Hull et al., 2020).

To facilitate the transition from BIM to DTS, from design and construction to management, new technologies can be used, most notably AI. AI is the latest peak of the ICT revolution since it resembles human intelligence and can compute mathematical transactions, which can assist integrate it into the building sector. AI can also design buildings, make decisions, and manage (Shah & Sahastrabuddhe, 2024).

BIM use may have increased due to construction industry challenges. To elaborate, rising costs, time constraints, unexpected project-delay factors, construction material waste, and the high error margin can force construction managers to use BIM to improve work efficiency and performance and minimize these challenges (Mahmood et al., 2022). Technical constraints limit BIM, requiring extensive component and function examination and revision (Ma et al., 2023). BIM also loses information as it interacts with geographical, environmental, and urban data, in addition to interoperability issues that prohibit it from being integrated with other systems. BIM's interoperability issues also hinder its adoption and implementation in other sectors (Jia et al., 2024).

Insufficient data format and protocol standardization hinders BIM, AI analytics, and digital twin technology integration. The data fragmentation complicates the collection and analysis of data to attain efficiency in the facility management (Kinani, 2022). Migration of traditional BIM to DTs technologies is a complex system that does not necessarily communicate. Complexity can complicate system interoperability, and balancing a facility management approach hard (Revolti et al., 2024).

Another issue of the application of AI-provided analytics to enhance BIM-related project handovers in the construction industry is that (Khan et al., 2024; Zhu et al., 2021): 1) **Management Issues:** The lack of good decision making, confused corporate strategies and lack of coordination in the organization hinder AI and BIM integration. The resistance to the use of integrated BIMAI solutions is caused by the absence of guidelines on how to implement AI in the different stages of the building projects. 2) **Financial Constraints:** The expensive cost of software installation and training is an impediment to the majority of construction firms to adopt BIM-AI. Companies also hesitate to use these technologies due to ROI concerns. 3) **Data Integration and Handover Issues:** The handover process is impeded by the lack of information fidelity, incompatibility of BIM with facility management technology and ignoring of end-users. The solution to these difficulties is crucial to facility management digital twin implementat

Consequently, the central research question (CRQ) will be articulated to encapsulate the defined parameters of the research topic and the essential elements to be addressed succinctly within the literature and methodological dimensions of the present study. The CRQ can be articulated as follows: **“What is the impact of AI in the transition from BIM to digital twins on facility management handover?”** Furthermore, this CRQ can be addressed with the subsequent secondary research inquiries: How can the data-exchange features of AI be used in BIM-to-DTS on the preparation of facility management handover?, What is the extent to which the predictive-analysis feature of AI be used in BIM-to-DTS on the testing of facility management handover?, Within which level does the automated feature of AI, which checks for regulatory issues, be used in BIM-to-DTS on the documentation phase of facility management handover?.

This research seeks to examine the influence of AI-driven analysis of BIM on the facility-management handover of construction projects. This can be accomplished through the following objectives: To research data exchange in facility management handover preparation based on AI, To evaluate predictive analytics testing in BIM-DT to minimize wastage and errors, To contrast AI-based regulatory compliance checking regarding the documentation phase for facility management handover, To improve the level of decision-making by project managers and enhance regulatory and administrative efficient when AI is used to help make an effective transition from BIM to digital twin.

The research is important because it addresses the transition from BIM to DTS in facility management handover through AI integration. Integration strives to reduce interoperability issues, data fragmentation, administrative inefficiencies, and regulatory compliance issues. The research examines how AI improves data exchange, predictive analytics, and self-regulatory controls to improve construction sector decision-making and project productivity. The study narrows technology divides, improves project transition, and develops AI-based digital twin solutions for increasingly complex building projects.

LITERATURE REVIEW

Global ventures grow because they add socioeconomic value. Remote planning and management needs are growing, thus digital 3D models must be reliable. The construction industry uses BIM because of its cutting-edge characteristics. This modern concept uses artistic and historical patterns and constructive structures to transform building models. BIM is an emerging construction software system that helps professionals analyze and document-built heritage for market presentation and restoration (López et al., 2018).

BIM-based public works projects now follow DEVB principles that emphasize critical architectural applications. BIM software is used to construct project models, which requires property cost and schedule details and produces drawings and schedule outputs. Design Reviews allow stakeholders to visualize models and conduct virtual walkthroughs to verify client needs and design characteristics like illumination accessibility and acoustic performance. BIM models of existing sites are created using photogrammetry or laser scanning to create editable georeferenced models with architectural and structural separations and building services elements for design planning (Architectural Services Department, 2024).

BIM technology is expanding in many industries, especially architectural design. The complicated operating system solves architectural design issues. Construction and architectural design solutions benefit from national strong expansion. BIM technology needs modernization and conceptual progress by designers to fulfill evolving architectural design requirements so the nation can improve design outputs (Yuan & Yang, 2021).

BIM adoption created a variety of project-oriented technologies, some of which serve numerous construction objectives. BIM solutions facilitate multi-discipline coordination workflows by modeling 3D objects and maintaining information systems. Four popular engineering coordination and design software are AutoDesk Navisworks Bentley Navigator and Vico Office. These apps coordinate and analyze 3D models for scheduling and project design. Gehry Technologies' Digital Project Suite is a design management system, and Tekla Structures creates three-dimensional models. Solibri Model Checker's quality control and Synchro Professional's planning and scheduling boost BIM's management system integration (Tahir et al., 2018).

BIM evolved over decades. BDS and GLIDE, design applications and estimation methods, emerged in the 1970s. BPM improved BIM by facilitating estimating, building, and stakeholder engagement in the 1980s. GBM was created in the 1990s to unify building technology standards, constructability, and corporate management. In the 2000s, current BIM framework offered building life cycle management, software integration, project controls, efficiency gain, and 3D simulation. From its design application roots, BIM has grown into a complete digital construction management system (Latiffi et al., 2014).

Digital Twin (DT) has grown through aerospace flights from 1970, becoming widely used in 2021. NASA released its first formal description of DT in 2010 after the University of Michigan (Grieves) created its theoretical foundation in 2003. DTS were widely accepted by industries worldwide in 2016. The digital twin area grew in 2021 as companies implemented it in manufacturing, healthcare, and smart cities (Agnusdei et al., 2021).

Digital technologies evolved from 1985 till now. Between 1985 and 2002, the Information Monitoring Model created a Digital Twin research and development sector. Digital Simulation established a global business unit connectivity system and enabled web-based simulations and workflows from 2003 to 2014. In 2014-2016, IoT devices gained implementation that increased communication and data transmission and enabled big data, cloud computing, and IoT. Decision-Making Tools with AR/VR for real-time simulations and AI & Machine Learning for real-time optimization, defect detection, and decision-making were implemented from 2017 to the present. Through advancement, digital transformation integrates smart technology better (Warke et al., 2021). Digital Twin development covers a historical timeline from its beginnings to its current uses.

Modern AI is interactive human-designed systems that collect and analyze environmental data to make knowledge-based decisions and achieve difficult goals in physical or digital environments. AI systems analyse their environment to identify how prior acts affected the outcome (Azamat, 2021).

BIM organizes functional qualities in physical facility models for large construction projects. 4D modeling adds time-related data to BIM models to help students learn and set visual communication standards. BIM technology helps AEC professionals improve construction management. Project efficiency can be optimized by integrating virtual 3D models to project time and cost in BIM software (Parmar et al., 2017). BIM's three-dimensional building model framework limits its growth. BIM is sometimes confused with Revit and Archicad in the sector, leading novices to believe "BIM is Revit". Incomplete descriptions affect BIM processes and tools in existing definitions. The wide range of BIM vocabulary confuses users when explaining simple topics. Thus, its whole value must be defined (Borkowski, 2023).

According to Ma et al. (2023), BIM lifecycle displays functionalities for different construction phases. BIM helps architects, engineers, and builders create digital building models. BIM supports an integrated system from planning to design, construction, operation, and maintenance through a circular flow. Digital models, construction equipment, structural components, and facility management systems show how BIM improves cooperation, accuracy, and life-cycle efficiency.

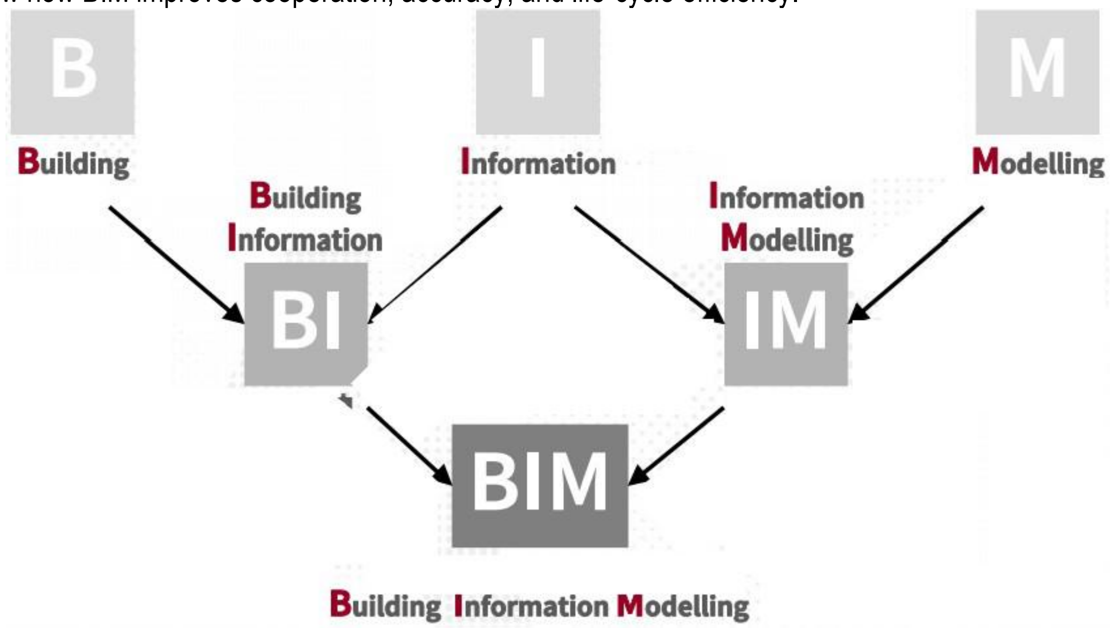

Figure 2.1: BIM Components. Source: (Huang et al., 2022, P. 2)

Figure 2.1 shows the evolution of BIM, or BIM. The diagram depicts how Building (B), Information (I), and Modelling (M) make BIM. The figure shows Building Information (BI) laying the groundwork while Information Modeling (IM) develops separately before becoming BIM. Verbalized letters emphasize how BIM connects architectural structures and information systems with modeling approaches to better digital project management and construction methods.

Fast advances in ICT and AI are changing building maintenance practices through data-driven techniques. Predictive maintenance (PdM) is a key operational strategy that helps maintenance teams predict system failures. PdM research and development is hampered by the rapid adoption of ICT in building infrastructure. Existing frameworks are not very universal or scalable since they serve certain types of facilities only. The field of failure prediction is not considered in the study where the emphasis is placed on condition monitoring and fault detection. The costly and time-consuming service was a liability to PdM because it had to create tagged datasets. Buildings can be managed internally to achieve performance (Hu, 2024).

Digital environment optimization reduces delays and resource costs to improve operational efficiency in the digital construction environment. The system runs on DTs, BIM IoT, and AI. Lean construction approaches and BIM improve workflow management and efficiency (Piras et al., 2024). Convergent technologies like DTs, BIM, and AI are used in construction. This technology integration strategy helps innovators improve current solutions and processes. Technology improves practices, but it's mostly used to build DTS for mixed-reality. BIM and DT work well together to give new construction industry research methodologies (Sepasgozar et al., 2023).

FM involves several regular and exceptional functions that keep a physical area working as designed from its construction to its end (Abd Rahim, 2024). FM is a global practice that handles property, financial, change management, human resources, health and safety, contract execution, construction services, engineering, housekeeping, and service delivery systems. The management system ensures high-quality operations and design parameter preservation throughout the building's lifespan. FM's operational activities range from cleaning to corporate real estate management, making it an intriguing scholarly topic. To preserve building efficiency, aesthetics, and structural health, managers must address them throughout their operation (Grazianova & Mesaros, 2024).

During operation and maintenance, the FM collects and manages data from many sources for future decision-making. The data allows statistical models-built AI to improve FM decision-making. BIM organizes data and information into structured information for utilization (Pedral Sampaio et al., 2022). FM demands ongoing access to large volumes of data, yet many firms still utilize paper documents that can be destroyed. Poor interoperability, communication, and this key O&M expense raise building costs. Due to affordable technologies, the construction industry has digitalized significantly in recent years (Siccardi & Villa, 2022).

Intelligent building management requires substantial information documentation and various technologies. Analytic tools and BIM interoperable platforms can improve building information management systems during FM's digital transformation, which faces hurdles. BIM use in FM reduces overhead expenses and enables seamless electronic information sharing with IoT and AI technologies (Pedral Sampaio et al., 2023).

Theoretical Framework

- **Systems Theory**: Systems theory says information technology makes operations and maintenance systems methodical, improving user experiences. Modern building structures and equipment are more complicated, requiring improved maintenance methods. Unmanned energy-efficient safe management is being enabled by AI, IoT, 5G, and BIM in operation and maintenance (Jiao et al., 2023). Integration of data tools gives construction management real-time information. Instant data availability between factories and construction sites prevents inaccurate estimates. Construction management is supported by integrated DT simulations of both systems. The collection of data between manufacturing and construction zones helps big data specialists analyze and improve forecast models. Continuous data aggregation occurs automatically when systems create data. A defined integrated DT describes objectives, procedures, data, and tools in three layers. System integration optimizes project execution during unanticipated delays (Čustović et al., 2023).
- **Digital Twin Theory**: Technology advances in IoT, big data, cloud computing Blockchain and AI increased interest in Digital Twin hypothesis in intelligent manufacturing. Modern engineering construction procedures exhibit little digital improvement but great potential for digital processes. DT and BIM are remarkable digital transformation tools that empower construction and

manufacturing technology (Faraji et al., 2023). Industrial Revolution 4.0 relies on DTS, which are becoming more important in building. DTS are defined before examining their important characteristics and how life cycle activities enable their application in building methods. A method for synchronizing and binding heterogeneous data is described. A project data structure must be defined absolutely to apply to all model components and additional data sources (Zinke et al., 2023).

AI-supported BIM-to-DTS interaction affects facility management handover, according to Systems Theory and Digital Twin Theory, which focus on operational optimization technologies. AI, IoT, and BIM integrated through Systems Theory improve facility management by improving systematic operations. DTs and Data Warehouses let facility operations and construction sites to share data in real time, eliminating imprecise estimations. AI-based analytics improve predictive maintenance by processing continually streaming data. A well-structured three-layer integrated DT system optimizes projects despite unforeseen delays for smooth facility transfer. IoT, big data, and AI-based complex data management activities are synchronized in Digital Twin Theory to show how DTs influence digital transformation in construction and facility management.

Real-time monitoring, predictive analytics, and effective decision-making make BIM-DT project lifecycle management more efficient. A coordinated effort improves facility management coordination and handover quality. Industry 4.0 improves AI-powered DTS in construction, supporting automated processes, data-based decision-making, and building operation improvement. The investigation shows that AI and BIM-to-DT solutions improve facility management by improving data-driven and intelligent handover processes.

RESEARCH METHOD

The study used the qualitative approach, which Ahadi et al. (2021) defined as “an approach characterized by a subjective nature and quality in the information complex, relies on non-digital examination and interpretation, and also derives information through personal interviews, observations, and discoveries from available documents.”

Howe and Robinson (2018) defined the study population as "a subset of the target population obtained through sampling from the target population and used to reach inferences about the target population." The current study population consists of all BIM specialists. The study sample will be drawn using a simple random method, which includes (7) employees from the study population.

Since the study is qualitative, the researcher produced a set of open-ended questions to help determine how AI in BIM twins and DTS affects facility management delivery. A semi-structured paradigm was used for all open-ended interview questions. This methodology uses pre-set interview questions and any extra questions that arise during the interview. The interview's pre-prepared open-ended questions were:

- **Question 1:** How can AI improve the accuracy and efficiency of data exchange between BIM models and DTS in facility management handover?
- **Question 2:** To what extent does your organization rely on predictive analytics to assess the quality of facility management handover via DTS?
- **Question 3:** What are the major challenges facing the integration of AI with BIM during the transition to DTS in facility management?
- **Question 4:** How does AI-powered automation contribute to reducing organizational errors in facility management handover documentation?
- **Question 5:** To what extent do organizations rely on AI to detect and analyze potential issues in facility management handover processes?

- **Question 6:** How can machine learning techniques be used to improve proactive maintenance processes in facilities managed via DTS?
- **Question 7:** What role does live sensor data play in improving the efficiency of AI-powered DTS?
- **Question 8:** How can AI enhance the reliability of information exchanged between BIM and DTS?

The Validity and Reliability of the Tool:

After interview preparation and question creation, trained arbitrators will evaluate the tool's efficacy and study goals. This ensures each question's clarity, linguistic soundness, and fitness for its intended purpose. They may also recommend deleting, adding, rephrasing, or otherwise improving it.

After retrieving the peer-reviewed copies from the arbitrators and considering some arbitrators' ideas, the researcher rebuilt the interview, deleting and rewriting several questions as agreed upon by over 80% of the arbitrators. After verifying its veracity, the interview has (8) questions.

Data Collection Procedures:

Due to the democratic premise that people have the right to choose to engage in the study, interviews will be performed by phone, online utilizing Zoom, or face-to-face between the researcher and the participants. All interview information will be transcribed verbatim into Microsoft Word from audio recordings. Next, the researcher will clear up non-essential data for the study. Next, the researcher codes the data. The researcher will group the data and code each group after coding. This code will help extract study findings.

Data Analysis Procedures:

The sample's personal interview responses are processed using Braun and Clark (2012)'s typological analysis formula in this qualitative study. Typological analysis is one of the most precise methods for qualitative personal interview analysis. This formula has six steps, which can be addressed as follows:

1. **Stage One**: involves reading the sample's interview replies and taking notes to have a comprehensive knowledge of the data.
2. **Stage Two**: each interview response is coded with a statement expressing its meaning and thoughts.
3. **Stage Three**: Classify and organize comparable codes into a pattern, expressed by a statement expressing their meaning and concepts.
4. **Stage Four**: patterns are reviewed for consistency with primary data and sub-patterns.
5. **Stage Five**: finalize pattern names and meanings by inferring replies to ensure conformity with primary data.
6. **Stage Six**: Finalize the report based on prior processes.

RESULT AND DISCUSSION

Results of the Study

Q1: How can AI improve the accuracy **and efficiency of data exchange between BIM models and DTS in facility management handover?**

The participants had a clear picture of how artificial intelligence can enhance data transfer between Building Information Modeling (BIM) models and the digital twin particularly in the facility management handover phase where correct and effective data transfer is required.

The interventions of the participants focused on automated data validation. Over one of the participants mentioned that technologies based on artificial intelligence can be used to automate metadata validation and identify inconsistencies and require less human input and enhance the reliability of data. This type of verification plays an important role in massive projects with thousands of parts that have to satisfy the needs.

The other important discovery was that AI can be able to correlate data with the facilities management standards such as EIR and AIR. One of the interviewees has mentioned that AI-based tools can be used to check that the information handover corresponds to client EIRs or the Asset Information Requirements (AIR), i.e., AI analyzes client or operator requirements, but not the data itself.

This assists organizations in reducing the risks of loss or incorrect data transfer which is a common construction-to-operation issue.

The use of AI is also in the so-called real-time synchronization or real-time BIM-digital twin integration. According to one respondent, machine learning and AI algorithms enable sensor data sent to the BIM model to be transformed into real time so that AI can process live sensory data such as temperature data or motion data and convert it into information useful in the BIM model. The qualitative change of facilities management is the transformation when the operators are dynamically engaged with the digital model and make real-time decisions on the basis of real data.

The respondents pointed out the optimization of workflow and processes. We emphasized that AI makes the data analysis time significantly shorter. The respondent added that one can save time and human resources, improve the results, and accelerate delivery with the help of AI, which is why one participant said, "Improve results and saves time reviewing the data," to demonstrate that AI can help save time and human resources and achieve better results and faster delivery.

The other one claimed that AI can be used to streamline processes and make them more accurate, proving its relevance in the streamlining and optimization of processes. Individuals also appreciated the interaction factor since AI was used to develop smart data interfaces. One of the participants stated that AI offers smart user interfaces to manage data better and improves communication through natural language processing, which demonstrates that it can be used to improve communication between humans and machines. The natural language processing has made the development of intelligent user interfaces that enable non-technical individuals to use complex BIM models or digital twins to expand the scope of data use to the other stakeholders in the business.

Other participants simply stated energy, which suggests that there is an understanding that AI can be used to increase the efficiency of energy or to introduce energy management systems to BIM and digital twins, which is already evident in a few contemporary smart facility management models.

Q2: On a scale of 1 to 5, how extensively does your organization rely on predictive analytics to evaluate the quality of facility management handover through DTS?

This question demonstrates that the digital twin-based facilities management is managed in digital twins through predictive analytics in different ways by firms.

Most participants (46.2) of (7) rated 4 out of five (1-5) which means that most of them adopted it but not the highest (5, in case there was no answer to this). This indicates that predictive analytics technologies are not fully adopted by many organisations that have begun to use them. The third highest number of responses was "3" (30.8%), which expressed a moderate or a middle attitude towards these technologies. A significant proportion of the sample (medium to high) expresses actual and practical interest in predictive analytics, although these companies are yet to reach the necessary level of analytical maturity.

The lowest adoption (2 points) was recorded by 15.4% of the respondents and those who barely use these analytics by their firms were 7.7% (point 1). Such percentages are not high, yet, they suggest

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that there are still certain companies that are only starting to adopt predictive analytics or might have a problem in the digital infrastructure, technical expertise, or data culture.

Funny enough, none of the respondents found the rating of 5, which could refer to the fact that the companies, listed in the question, do not have fully developed apps or well-developed predictive analytics offerings. This can be an indication of a lack of connection between technical capabilities in the market and organizational implementation, more particularly in the delivery of facilities management, where there should be a tight integration between BIM systems, digital twins, and smart analytics.

Q3: What are the major challenges facing the integration of AI with BIM during the transition to DTS **in facility management? Multiple Choice (select all that apply):**

The findings indicate that the implementation of AI and BIM during the process of converting digital twins to the facilities management is heterogeneous and entails complex technological, organizational, and competency aspects.

The most prevalent problem was integration complexity (30.8%), which proved the fact that the coordination of systems and platforms, in particular, BIM and digital twins, was not an easy task. This issue may be occasioned by the diversity of tools, models, and data integration and standards protocols. Next in line was skill gaps (23.1), which is nearly 1/4th of the participants, which suggest professionals are realize that the existing human resources might be unprepared to handle the new advanced AI, BIM, and DTs functions. The staff of facilities management and engineering designs does not usually have data analysis, machine learning, digital modeling, and asset management skills required in this industry.

Financial constraints (Poor data quality) and high cost of implementation were each other significant hindrances at 15.4% of the total, but this is particularly true of medium- or small-sized enterprises (SMEs), which might lack the funding to invest in an extensive digital infrastructure. The quality of data input into models as a technological hindrance is a serious problem as the quality of the training and analysis data defines the quality of AI performance.

The group of All was only a result of 7.7 of the total, proving that the majority of the population was able to pinpoint the issues of critical concern but not view them as the ones that have the same influence. This is a demonstration that the practical experience depends on the setting.

The last category, which was 7.7% of the total, was the resistance to change, regulatory compliance issues, data security concerns... which means that some participants view organizational and cultural issues such as data security as significant impediments to the change process, although it was not the most common one. Lastly, there is the standardization and interoperability between BIM and DTs platforms, which got 0, which is impressive. Poor platform compatibility would be a significant problem that they would not have perceived as a discrete issue or complexity of integration.

Q4: How does AI-powered automation contribute to reducing organizational errors in facility management handover documentation? Agree AI will be helpful for reducing errors during construction to achieve handover stage smoothly?

There is an increasing awareness among the participants on the role of AI-powered automation of processes in reducing regulatory errors in facility management delivery papers. One of the similarities is the presence of ability to automatically analyze and identify problems prior to delivery. An interviewee stated that one usefulness is that it can be used to identify flaws in the process and fix them, thus minimizing human error when entering data or transferring the model to the platform.

Findings A significant number of the attendees cited the importance of AI in data format standardization and verification. One of them describes the way AI-based automation can minimize mistakes in documentation of facility management handover by standardizing data formats, retrieving and verifying information about assets, and providing its accuracy based on rules.

This definition demonstrates that AI finds and solves issues through accurate verification standards, enhancing reliability of delivery data. The respondents also commented that AI has Automated Compliance Checking and checking compliance against standards. check the compliance with international standards such as COBie.

Rather than reading data, this type of verification verifies that information is used as per the pre-defined requirements like asset information, operational information or that information is related to facility locations or functions. According to some participants, automation is useful to maintain the document versions and ensure that the right version is used, which is essential in the facilities management projects with multiple forms and frequent changes.

Besides minimizing errors, automation also "simplifies the processes to reduce manual input" and contributes to a better collaboration among interested parties, enhancing the efficiency of operations and collaboration among the technical and administrative teams. One respondent provided the figure of 69 %, which suggests that the rate of error reduction of AI is about the same. This, despite the absence of facts, is indicative of a relative faith in the power of this technology.

Q5: To what extent do organizations rely on AI to detect and analyze potential issues in facility management handover processes?

The responses to this question reveal that companies are just partially utilizing AI to identify and examine matters of problems in facilities management delivery processes. Most of the respondents responded with Slightly and Moderately with 38.5% and 30.8, respectively. This indicates that over a third of the sample have a dependency that is modest or moderate on AI, despite the fact that it exists and is currently in use in assessment.

This dispersion indicates that there are numerous companies investigating the opportunities of AI in this context and are yet to implement it. This can be attributable to the immaturity of digital infrastructure, inadequate knowledge of the corporations, or the integration of AI systems with BIM models and digital twins. Already, digitally advanced companies are utilizing AI-powered solutions to process data and identify operational or documentation problems as 23.1% of respondents indicated that they highly utilize AI. The best digitally developed firms are technologically invested and have a skilled labour force to manage predictive algorithms and machine learning.

Adoption was rated as very high by only 7.7% which indicates that AI is still primarily applied to certain projects or fields. This question did not have the option of not at all, which means that the majority of the participants recognize moderate usage.

The idea reflected by this distribution is that the sector is slowly moving towards adopting AI, although at varying levels among companies. The partially implemented ones seem to be miles behind the fully adopted ones.

Q6: How can machine learning techniques be used to improve proactive maintenance processes in facilities managed via DTS?

Respondents found that machine learning has the potential to enhance facility maintenance in a digital twin by actively helping to do so. These strategies enable the shift of the reactive to predictive and data-driven campaigns, as most think. According to one of the participants, with the help of machine learning methods, facility managers will be able to transition to proactive, rather than reactive, maintenance approaches.

This transformation minimises downtime and enhances the reliability of assets since the machine learning is able to forecast failures with respect to the past and sensor data. One more participant stated, "Machine learning methods can help to improve proactive maintenance in the facilities controlled through digital twins through the analysis of past and real-time sensor measurements to reveal the patterns, anticipate equipment malfunctions, and suggest the best maintenance plans.

This is indicated that machine learning algorithms predict, optimize, and warn about bizarre tendencies or performance decay. The models also monitor the trends of anomalies and performance to make data-driven decisions. The fact that the predictive algorithms are created based on historical data also attracted our attention. One mentioned that, training on historical data can be used to forecast the occurrence of issues prior to them by contrasting the historical data with real-time data.

It seems that machine learning algorithms require past data of failures or reduced performance to learn and predict it. By combining these models with the digital twin, it will be possible to do maintenance work in terms of continuously monitoring the condition or operational monitoring.

This balances the cost and efficiency by ensuring that maintenance is done at the right time neither before nor after. Another respondent indicated that the strategies enable optimization of resource allocation, minimization of downtime as well as asset life, not just the minimization of downtime but also optimization of resource allocation in operations and reduction of time and expense loss.

One participant replied that step by step will initially feature in the trigger events works in construction, which was the old technology applied in digital twins of oil and gas fields. The statement is ambiguous though it suggests that such technologies have been applicable in key industrial sectors and are currently being applied to facilities management.

On the other hand, two inhibited and inaccurate responses (e.g., Operation and Sorry, I do not know) demonstrate a difference in concept knowledge among the members of the samples, and it could be their technical backgrounds or experience.

Q7: What role does live sensor data play in improving the efficiency of AI-powered DTS?

The most effective way to use live sensor data to enhance the performance of AI-powered digital twins is real-time monitoring, as 58.3% of the respondents have indicated. Real time monitoring enables the quick reaction to risk warning signals and performance anomalies in systems, equipment and infrastructure. This is one of the pillars that transform data into operational decisions that are fast to make and increase efficiency, downtime, and safety of the facilities.

The respondents realized the importance of using machine learning models supported by sensor data to anticipate issues with the second position of Predictive Maintenance (16.7). Such technique gives the opportunity to construct models using historical data and real-time inputs to predict failure before it occurs, minimize operating costs, increase asset life, and enhance maintenance.

The participants that selected All of Them demonstrated a good understanding of live data and that all of the roles are complementary. They say this data affects an intertwined operating system comprising predictive analysis, energy efficiency, safety, and decision-making. This trend indicates the sensational digital maturity and capability of some businesses to apply sensor-based intelligence in the lifecycle of the facility.

At 8.3% of the respondents, the Energy Optimization feature received a low score considering the potential of digital twins to enhance energy efficiency. The consumption can be tracked using sensor data and losses can be determined to control the operation of the system more sustainably, but the safety and efficiency of its operation might be more important to the participants than the environmental friendliness of its operation.

Real-time information was also appreciated to allow making decisions based on data and enhance safety levels. AI systems receive real-time data provided by sensors to make better and faster decisions (particularly in high-stakes scenarios such as factories, government buildings, and critical infrastructures). This tendency indicates the use of tactical data to enhance operations.

Occupant Comfort also received the lowest possible votes (0%) in the digital twin setting, which depicts a near-complete lack of concern with the human comfort. This aspect is paramount to smart building projects, but technical or operational vision can be taken to the fore of end-user experience. This implies that the technological goals and the human experience must be rebalanced by smart facility management systems.

Q8: How can AI enhance the reliability of information exchanged between BIM and DTS?

The respondents consented that Artificial Intelligence (AI) enhances the credibility of the information conveyed between Building Information Modeling (BIM) models and digital twins. 76.9% claimed agreement and 15.4% strongly claimed agreement. This means that more than 92 per cent of interviewees thought, to different extents, that AI is effective in guaranteeing data authenticity and integrity across the two digital space.

This is the unanimous opinion of the smart technologies on minimizing the number of mistakes in the manual data transfer and data entry and the standardization of the data structures that are often divided between the architectural design tools and smart operating platforms. AI evaluates, refine and checks data to ensure BIM data supplied to the digital twin is accurate, standardized, and interoperable. This is necessary in the Facility Management Handover step to minimize the differences and make data ready to work.

The fact that there are no responses of Disagree or Strongly Disagree shows that the community that participated in the study is unanimous about the idea that AI helps in integrating digitally. The small amount that decided on the third variant (Neutral 7.7%), could be the result of having no direct experience of smart integration technologies or the scientific reluctance to overestimate the numbers but does not change the general trend towards positive acceptance.

Such a great rate of consent confirms the assumption that the introduction of AI into the BIM-digital twin information sharing mechanisms has stopped being an experiment or a complement but a tool in the strategic quality of the data, minimization of errors, and acceleration of the data lifecycle of smart buildings.

Findings of the Study

An in-depth review of the responses of the participants regarding the initial question reveals that artificial intelligence will have the ability to speed up the exchange of data between BIM models and digital twins in the context of facilities management delivery. According to the participants, artificial intelligence assists in the quality enhancement and automatic data validation, standard and outcome compliance, and real-time system integration. Administrative processes, human labor reduction, and ease of use, including interactive and smart interface, was also facilitated by AI. Therefore, the introduction of AI at this point of the building lifecycle is not only a technical supplement, but also a radical change in the ways of managing and transferring information between parties that will enhance the operational services and facilitate the digital transformation of the facilities management industry.

The second question is also biased towards using predictive analytics in the context of measuring the facility management delivery through digital twins, where the majority of the responses fall in the medium to high category. Despite the fact that adoption is not high previously, the findings indicate that AI and advanced analytics are enhancing information sharing and forecasting operational issues. The lack of response in the highest level (5) reinforces the fact that digital infrastructure, technical workers, and predictive analytics require investment as a strategic resource to ensure operation of active and intelligent management of the life cycle of assets.

The third question reveals that the combination of AI with BIM and digital twins is not an easy task and is not certified to be performed by a human. Technical and human barriers are more significant than financial or legislative limitations, and it is possible to presume that efficient interoperability between systems and professional skills can speed up the adoption of technology. In the future, when standards and resistance to change are not crucial, businesses need to develop efficient training and digital integration strategies to utilize AI in all its potential in terms of managing the assets lifecycle and operating efficiently. The results indicate an adult understanding of the challenges, and scholars and policy-makers can develop personalized solutions that respond to the needs of the sector.

The fourth question shared agreement with the participants that the AI-powered automation decreases organizational errors in facilities management delivery papers. Large functions contributing to this impact include automated data validation, COBie compliance verification and data format standardization. The productivity of a process is also enhanced with AI that reduces the extent of manual entries and accurately tracks document versioning to have up-to-date and correct data on the delivery. The system also assists the project stakeholders in collaboration and therefore, no overlaps and dispute arise that might result in documentation errors. Therefore, the use of AI in delivery operations is not a luxury that is technologically possible but rather a requirement towards professional, error free delivery operations that benefit the operations of a given facility in the long term.

The data provided in question five indicates that the majority of companies remain partial or moderate in the application of AI to detect and analyse difficulties in the delivery of facilities management. The adoption of AI is not very high, but a majority of participants indicated its usage. The adoption seems to be constrained by technical or organizational challenges such as poor integration or lack of knowledge. Nonetheless, the high proportion of respondents who chose the category of high adoption is an indicator that some businesses already invest in AI significantly which is a good indication of its future development.

According to these results, training, digital infrastructure, and data culture are some of the key factors that have to be strengthened so that AI could be used in this industry more efficiently and sustainably.

Answers to question 6 support the fact that the use of machine learning technologies is crucial to preventive maintenance in digital twins.

Their ability to analyze past and current data in order to discover patterns, anticipate faults and plan optimal maintenance saves money, enhances performance and increases the life of assets.

Digital modelling and artificial intelligence algorithms transform maintenance management into performance-based intelligent management instead of being reactive. Even though the understanding of these technologies was different among the participants, the majority of them discussed numerous advantages of these technologies and demonstrated the increasing awareness of the necessity to consider the implementation of machine learning in the future facility management.

Question 7 depicts that real-time monitoring and maintenance Vision based on predictive maintenance are most useful and ubiquitous applications of live sensor data, and less attention is paid to energy optimization and decision support. The rising awareness of the necessity to combine all the functions to exploit live data is demonstrated by some comments. The role of data in comfort of the user is not stated, which shows that there is no correlation between technical usage and facility requirements. Thus, companies that want to achieve full digital maturity will have to reconsider their approach to data utilization and strike the right balance between efficiency in operations and comfort among consumers.

In question 8, the participants indicated that they strongly concur that AI enhances the dependability of BIM-digital twins, which remove potential errors and enhance the quality of the data. This demonstrates the fact that intelligent solutions are becoming vital to the data management of the architectural and operational levels, and there is the necessity to invest in AI technologies to provide correct digital integration among design, construction, and functioning. The future of the smart integration in the facilities management projects looks promising and there is no evident opposition.

Discussion

The digital strategy adopted by BIM-using organizations needs to be an integrated approach that incorporates AI at the beginning of a construction project that provides a smooth and intelligent transition to a Digital Twin environment during the Facility Management Handover. This initial relationship allows automated data processing and good application of Automated Data Validation and Real-Time Synchronization applications, which minimize human error and enhance reliability of information.

To have real-time and all-encompassing monitoring of the facilities, it is suggested that a mature digital environment that is founded on live sensor data is required. The research observed that real-time monitoring was the most preferred model which demonstrates the necessity to invest in the IoT network and connect it with the AI systems to enhance the efficiency of operation and real-time reaction.

Stakeholders should enlarge Machine Learning Algorithm-supported Predictive Maintenance solutions, which process historical and real-time data and predict faults and react to them in advance.

This approach reduces the maintenance expenses, increases the life of the equipment, and increases the availability of the assets, making facilities highly technically sustainable. Energy Optimization and Occupant Comfort have minimal use of live data hence they ought to be enhanced particularly in the view of the global attitude towards smart buildings which are sustainable.

Connections between energy management systems and AI-based systems in the digital twin can enable the analysis of energy consumption and automatic adjustment of performance with no human involvement to lower emissions and enhance environmental efficiency. Decision-makers and senior management should be trained and thought empowered on digital twin decision-making processes that are based on AI.

Judgments can be quicker and better with the help of AI, and this was proven with the help of data-driven scenario modelling and automated decision loops. When properly perceived and applied, the skills can revolutionize complex processes in the running of operations.

The success of this digital transformation is of importance on the administrative and institutional levels. According to some players, AI would not be successful without managerial commitment, regulatory and technical necessities to accommodate AI in the corporate processes, and technology. Offer clear data management principles, model and standardization and align technologies to world standards such as COBIE and ISO 19650.

Since the participants perceived the positive effect of AI on the sustainability of the environment and the long-term strategic planning, AI-powered DTS is expected to be employed on the lifecycle of a facility instead of the construction or delivery process. DTS driven by AI should be incorporated into the working system to track, appraise, and streamline processes. This assists in building intelligent facilities that are balanced in terms of performance, efficiency and environmental sustainability.

Recommendation

- The implication of machine learning approaches in predicting issues and improving proactive maintenance in the development of DTS.
- The effectiveness of AI-driven DTS in managing the management of large facilities by improving the decision-making of managers.
- The technological and organizational challenges of AI implementation during the lifecycle of a facility that is using BIM.

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