A Review of BIM, Digital Twin, Visual Programming, and Simulation in Construction

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Abstract

Building Information Modeling (BIM), digital twin, visual programming, and simulation are transformative tools that have been increasingly adopted across various disciplines, particularly in the construction sector. BIM facilitates the creation of digital representations of physical assets, commonly called digital twins, which can be integrated with process simulations to predict and evaluate scenarios before they unfold in the real world. Dynamo, a visual programming tool, enhances this interconnection by automating data exchange and workflows, positioning BIM as a central repository for information. Despite their widespread use, these technologies are often applied in isolation, resulting in fragmented practices and limited holistic understanding. This study reviews 107 peer-reviewed articles from journals and databases, focusing on the integration and applications of BIM, digital twin, visual programming, and simulation. The analysis provides quantitative information on the applications of technologies in construction. The findings categorise these technologies according to their applications, illustrating how they can be applied, offering a structured and comprehensive perspective on their potential, and demonstrating future trends of these technologies to advance construction practices and enable more cohesive and effective implementation in the field.

Keywords**:** BIM, digital twin, visual programming, simulation, construction

1. Introduction

In recent years, Building Information Modeling (BIM), digital twin, visual programming, and simulation have played a crucial role and gained widespread popularity across various disciplines, particularly in the construction sector, which is characterized by its complexity and high precision requirements. These tools have been utilized in academic research by numerous scholars and have been applied to solve various problems. At present, the construction sector is facing the challenge of the transformation from the application of digital technology to enhance efficiency, reduce errors, improve construction processes, and address other related aspects.

Building Information Modeling (BIM) is a process that facilitates the creation and management of digital representations of building information. BIM-created model provides a digital representation of physical assets, commonly called digital twins, which can be integrated with process simulations to predict behaviors under different conditions and evaluate scenarios before they unfold in the real world. Dynamo, a visual programming tool, enhances this interconnection by automating data exchange and workflows, positioning BIM as a central repository for information. Despite their widespread use, these technologies are often applied in isolation, resulting in fragmented practices and limited holistic understanding in construction.

This study presents a review of articles related to BIM, digital twin, visual programming, and simulation, collected from journals and databases. The review was conducted following established research methodologies, through which this study explores how these technologies and tools have been applied in the construction sector, in order to analyze and synthesize the information from existing studies. The results of the study are divided into two parts: the first part summarizes the applications of these technologies, providing quantitative information across construction-related tasks, while the second part categorises these technologies according to their applications. This research contributes to reducing fragmented practices and limited holistic understanding, offering a structured and comprehensive perspective on their potential to advance construction practices and enable more effective implementation in the real world.

2. Review Approach

A total of 107 peer-reviewed articles were selected based on keywords related to BIM, digital twin, visual programming, and simulation. These technologies have been increasingly adopted across various disciplines, particularly within the construction sector. The review sourced the information from journals and reliable databases, such as Scopus, IEEE Xplore, ScienceDirect, and Web of Science. This study examined both the isolated applications and the integration of these technologies with complementary tools in order to determine the number of applications. Subsequently, these technologies or tools were categorised according to their applications to provide a structured and comprehensive perspective on their potential. The findings from the analysis help reveal possible future trends for these technologies, contributing to the advancement of construction practices and enabling more cohesive and effective implementation in the field.

3. Applications of Technologies

3.1 Building Information Modeling (BIM)

3.1.1 Isolated BIM applications

The application of Building Information Modeling (BIM) in the design of marine architectural structures enhances accuracy in offshore building design [1]. Design and optimization of prefabricated building system based on BIM Technology in the stage of construction and production [2]. Procedural modeling-based BIM approach for railway design reduces errors and improves efficiency in design, construction, and management processes [3]. The application of BIM for creating key parametric models in the railway electric and electronic systems engineering construction management to address time constraints or short project period [4].

The automated generation of BIM-based draft schedule in reinforced concrete-framed buildings, encompassing both sequential and overlapping scheduling methods, enhances efficiency by reducing project duration and construction management [5].

BIM use assessment (BUA) in the early stage of implementation for planning and design phases [6]. BIM implementation analysis in the Egyptian construction industry to create better opportunities and value, leading to the development of national policies to facilitate BIM implementation [7].

The challenges in takeoffs and cost estimation using BIM technology, applied to the example of a road bridge model, are based on internal communication within workgroups or teams, resulting in better information flow [8]. The impact of BIM-based quantity takeoff for accuracy of cost estimation is examined through a comprehensive literature review, revealing that BIM-based cost estimation outperforms traditional CAD-based methods [9].

The application of BIM technology in budget control for port construction cost helps mitigate economic pressure, supports budgeting, and enhances cost management [10]. Exploring the application of BIM in the whole process of construction cost management in China utilizes computational intelligence to minimize cost-related risks and improve efficiency across various project stages [11]. The development of life cycle cost management of marine engineering projects through BIM technology enhances decision-making, cost reduction, and overall project management efficiency [12].

BIM-enabled facilities management (FM) applications help identify key areas where BIM can be practically utilized to enhance FM processes [13]. Monitoring and maintenance of highway super-large bridge in China using BIM technology integrate manual inspection with digital modeling and automated data retrieval, improving data management and continuous updates [14].

The evaluation of BIM supports energetic analysis by assessing parameters such as exterior walls and floors, contributing to reduced carbon emissions, energy consumption, and costs. This further demonstrates BIM's capability in decision-making support for stakeholders during project development [15]. Energy efficiency assessment of a public building resourcing a BIM model, aiding in decision-making for energy efficiency improvements during the operational phase [16].

The comprehensive performance evaluation method of green materials for coastal buildings based on BIM improves assessment accuracy and strengthens material reinforcement capabilities [17]. The construction of integrated evaluation system for green port construction based on BIM provides reliable and precise insights into the environmental impact of green buildings [18].

A BIM-based method to managing buildings safety in coastal areas during typhoons addresses limitations in traditional wind resistance calculations. The study finds that conventional methods yield near-minimum standard values, while the BIM-enhanced method achieves higher-than-minimum standards, proving its effectiveness [19]. New technology of risk control for port waterway construction based on BIM demonstrates superior risk assessment accuracy compared to traditional methods [20].

3.1.2 Integrated BIM applications

The use of BIM technology in designing construction using Revit enables the creation of 3D building information models. This capability facilitates interoperability with other software programs and incorporates Dynamo visual programming module, which aids in reducing both design errors and project completion time [21]. Shading coefficient (SC) calculation of shading devices using BIM, which includes Revit and Dynamo, follows the computational guidelines outlined in the Building Energy Code (BEC). A comparative analysis of SC calculations between BEC and Revit indicates high accuracy, making the approach applicable to other types of shading devices. This enhances SC computation efficiency while saving time [22].

Building lifecycle energy performance evaluation efficiency based on BIM, supported by Multi-objective Particle Swarm Optimization (MOPSO), demonstrates that MOPSO can efficiently operate within Dynamo by generating multiple non-dominated solution sets [23].

Seismic analysis utilizing BIM in Revit, driven by visual programming through Dynamo, is applied to existing reinforced concrete buildings. A conceptual framework is developed using contemporary modeling guidelines and integrating Autodesk Revit with SeismoStruct. The study highlights a framework for assessing seismic performance through nonlinear analysis and the export of data from Dynamo to SeismoStruct, thereby enhancing BIM modeling. Additionally, incorporating wall elements into buildings contributes to improved seismic resilience [24].

The change of the Level of details in Building Information Modeling (BIM) enables Information resolution adjustments tailored to specific applications. The study demonstrates the effectiveness of these approaches, each with distinct advantages and limitations [25].

An integrated BIM-Power BI approach for information extraction and visualization leverages Dynamo and Power BI to streamline data retrieval and representation in the architecture, engineering, and construction (AEC) sector. Applications include cost estimation, clash detection, project information retrieval, and automation of BIM information extraction, leading to reduced processing time and costs. The visualization is facilitated through dashboard representations [26].

A BIM-based automated assessment tool for green building index has been developed to transition from traditional assessment methods to automation. Revit was chosen as the primary tool for this method, with Dynamo enhancing Revit's capabilities [27].

The development of the Building Handover Information Model (BHIM) for facility management and maintenance considers the construction operation building information exchange standard and Level of development specifications. The process involves using Revit as the primary BIM tool and Dynamo to enhance Revit's parameter functionalities, facilitating model verification, data extraction, and documentation for facility handover requirements [28].

An automated parametric BIMs generation framework based on hybrid video and laser scanning data enhances building scanning and data collection. Given the multidisciplinary challenges and environmental constraints, including spatial relationships and feature recognition, integration with automated modeling processes is expected to reduce time and resource consumption [29].

Positioning of prefabricated building components based on Building Information Modeling (BIM) and laser scanning technology in the of Internet of Things environment has demonstrated precise component placement, improving construction quality and efficiency. The proposed methodology supports smart prefabrication construction policies via BIM [30]. Building space design using BIM under background of Internet of Things integrates diverse information sources, facilitating improved construction process intelligence and smart facility management [31]. A web-based GIS and BIM-integrated framework for building management reveals that the proposed system is applicable to web-based facility management. Stakeholders can access building model updates and reports without expertise in BIM-GIS [32].

The application of "BIM+VR" in designing energy-efficient maritime architecture in coastal cities enhances architectural comprehension and optimizes resource utilization in construction [33]. Construction safety analysis using Virtual Reality (VR) and BIM simulations of crane lifting operations improves safety efficiency and reduces on-site accidents [34].

The application of BIM technology in port breakwater construction enhances the impact resistance of wave barriers compared to traditional construction methods. Using Revit for BIM modeling and Navisworks for simulation, the study demonstrates improved engineering quality for port breakwater structures [35].

BIM-based digital green building evaluation model integrates open databases with assessment software, enabling automated calculations, reducing computational complexity, and verifying evaluation procedures [36]. BIM-based verification of total building energy consumption for material transportation and construction optimizes energy efficiency by linking BIM models with external databases. Scenario analyses integrate diverse resource data to minimize energy consumption [37]. The integration of BIM and construction process information exchange within a decision-support framework enhances information recording, storage, retrieval, and interoperability across software platforms [38].

Lean principles applied to BIM workflows utilize value stream map as a key tool. Comparing conventional and optimized workflows, the study demonstrates efficiency gains through Dynamo-generated material scheduling scripts, reducing processing time and benefiting BIM modelers at an organizational level [39]. Building Information Modeling applications in sports infrastructure management in Peru explore BIM-Lean integration to optimize resource utilization. The proposed BIM-framework workflow enhances access to comprehensive facility component data, improving operational efficiency compared to traditional methods [40].

The integration of Building Information Modeling (BIM) and blockchain for digital twin applications in construction projects facilitates improved information management, project traceability, and cross-disciplinary collaboration. This is particularly relevant for handling sensitive data and critical infrastructure [41]. The construction site management of concrete prefabricated building by ISM-ANP network structure model BIM under big data text mining, significantly reduce resource and energy losses [42].

Building Information Modeling (BIM) and digital twin applications for intelligent building construction management provide an overview of construction and maintenance systems. The study highlights the potential for enhanced implementation and improved construction management efficiency [43]. The integration of Building Information Modeling (BIM) and SCADA for dynamic Digital twin applications showcases the feasibility of embedding BIM models within SCADA systems. The study defines dynamic digital twin capabilities through BIM-SCADA integration, linking real-time data to digital models for enhanced operational decision-making [44].

3.2 Digital twin

3.2.1 Isolated digital twin applications

The Evolution of digital twin Concepts Research indicates that the expansion of digital twin capabilities extends beyond enabling cyber-physical systems to functioning as a platform for integrating product lifecycle data and processing. This expansion allows for the prediction of outcomes and serves as a comprehensive product lifecycle map [45]. The evolutionary process and levels of digital twin implementation, incorporating various technological components, highlight the effectiveness of digital twin modeling when considering its evolutionary direction and levels of advancement, which further guide future applications [46].

The development of digital twin technology is transforming the construction industry, demonstrating a journey for digital transformation that leverages digital twin to achieve cost savings and enhance process efficiency. Moreover, digital twin models facilitate predictive learning to proactively assess potential asset failures and recommend preventive measures [47]. A Smart City framework based on digital twins defines the concepts of digital twins and digital twin cities, explaining the relationship between digital twin and smart cities. By analyzing characteristics of smart cities through digital twins, schematic diagrams discuss the future development of smart cities based on digital twins [48].

A comprehensive review of digital twin applications in advanced industries assesses the current state of digital twin development and its applications across various sectors. This review reveals that digital twin remains a rapidly evolving concept, attracting significant research interest for directing future studies and applications [49]. Digital twin application in the construction industry is examined through a literature review, indicating the significant potential of digital twin in addressing challenges across different construction phases, including design and engineering, construction, operation and maintenance, and demolition and recovery [50].

The development of digital twin technology review highlights its role in future design and manufacturing technology development [51]. Developing human-centered urban digital twins for coastal community infrastructure resilience emphasizes the necessity of integrating multi-agent interactions, artificial intelligence, and natural-physical-social systems alongside urban digital twin frameworks. The study's findings enhance the resilience of community infrastructure [52].

In manufacturing, a categorised literature review on digital twin identifies publication types based on integration levels concerning manual and automatic information flow exchanges. The differentiation among digital model, digital shadow, and digital twin is emphasized, with findings showing that digital twin research, while categorised into Concept, Case-study, Review, and Definition in descending order of frequency, still lacks maturity compared to digital model and digital shadow [53].

A multi-dimensional modeling approach for machining process using digital twin focuses on the design and operation of intelligent machining processes. The proposed method ensures reliable virtual modeling, improving quality and efficiency while enabling continuous process database expansion [54]. A five-dimensional structural modeling approach of digital twin, applied to active distribution networks highlights its advantages in enhancing operational decision-making efficiency [55]. The application of digital twin in constructing electrical control cabinets streamlines the workflow from system design to installation planning, this integration facilitates improved interdepartmental communication, reduces production time, and minimizes errors [56].

An effective methodology for modeling university campuses for digital twin simulation integrates buildings and road networks into the CARSA project on unreal engine. This method utilizes computer-based traffic simulation and autonomous driving experiments [57]. The methodology creates a model using a digital twin to enhance strategic communication, modeling, and simulation, serving as a key tool for evaluating and optimizing communication channels, while also providing a platform for real-time testing [58].

The Digital twin approach for road and bridge construction inspection and maintenance in West Java, Indonesia, as a pilot project, aims to improve efficiency and cost-effectiveness. The study identifies 15 data types but also highlights ongoing challenges in digital twin implementation, including map accessibility, licensing ownership, security systems, coordination, dashboard speed, and operational issues that require resolution [59]. A Digital twin concept utilizes electrical resistivity tomography for monitoring seawater intrusion into groundwater systems near coastal regions, demonstrating high accuracy in its implementation [60].

3.2.2 Integrated digital twin applications

This research explores an intelligent dispatching system management platform for construction projects by leveraging digital twin (DT) and BIM technologies. The study proposes a Hybrid (DT-BIM) model that integrates these two technologies seamlessly. The model employs BIM to support predictive simulations and visualization of construction projects, as well as data storage through Artificial Intelligence and digital representation of real-world processes. Consequently, the proposed Hybrid (DT-BIM) model outperforms standalone BIM and digital twin models, demonstrating that Hybrid technology help in assisting the dispatch systems in the construction projects to a greater extent [61].

In the context of construction innovation, the digital twin platform is applied to smart grid systems and substations in Zhejiang, China. This study highlights that the digital twin model enhances the efficiency of traditional operations and maintenance of smart grids and substations. Moreover, it improves business performance, reduces overall costs, and creates business value [62].

An intelligent diagnosis method of network fault detection in distribution systems is introduced, incorporating a digital twin coordination system using the decision tree algorithm. This method continuously enhances fault diagnosis capabilities through various algorithmic models. The study findings indicate that the proposed method provides an intelligent fault diagnosis framework for distribution networks in digital twin systems. Furthermore, comparative analysis shows that the C4.5 algorithm achieves higher accuracy than the Bayesian Network, CART, and SVM algorithms, respectively [63].

The concept of digital twin is explored for managing the lifecycle of industrial capital construction projects, encompassing real-world construction processes and Internet-enabled applications. This study integrates the digital asset concept to optimize the economic efficiency of assets, save time, enhance asset safety, and address environmental and social challenges. Most importantly, it facilitates interaction with operators and, in some cases, enables necessary actions to maintain the actual rate of physical change in construction areas [64].

3.3 Visual programming: Dynamo

3.3.1 Isolated Dynamo applications

The modeling approach for numerical analysis using Dynamo presents initial testing challenges due to its complexity and the delays in algorithm development. Both internal and external testing contribute to the conceptualization of the software and provide essential feedback for enhancing automated data flow systems. Consequently, the modeling method for numerical analysis using Dynamo demonstrates the potential to achieve the intended objectives [65].

Visual programming for building information modeling (BIM) has been applied in a case study involving energy and shading analysis. This study highlights the feasibility of a workflow for sustainable design simulation, demonstrating how Dynamo enables greater flexibility in data customization [66]. Surface-specific solar simulation using BIM has been explored in this research. The study presents a BIM-based approach for outdoor simulations, utilizing the properties of photovoltaic (PV) panels and categorising various surfaces associated with different building elements, such as walls, roofs, certain facades, and windows [67].

A BIM-based framework for the quantitative assessment of steel structure deconstructability has been proposed. This study introduces a framework for evaluating the deconstructability of steel structures using Autodesk Revit and Dynamo. The findings demonstrate how the framework facilitates comparative analyses of innovative design alternatives through automated family modeling for steel structure deconstructability processes. Additionally, the proposed approach enhances and improves disassembly capability [68].

The Dynamo platform for automation within Revit aims to reduce costs and data exchange time in the construction industry. However, this study identifies shortcomings in the data import process for IFC-compliant models. The research suggests a standardized collaborative modeling platform to enhance accuracy through automation, particularly by leveraging the embedded Dynamo platform within Revit [69]. A BIM-based information extraction method for digital concrete printing (3DCP) path design has been developed using a Dynamo script. This approach has been applied to large-scale construction processes and effectively minimizes data loss between 3D BIM models and printing path generation. Additionally, it facilitates real-time testing, ensuring seamless BIM-3DCP integration [70].

3.3.2 Integrated Dynamo applications

The optimization model for parametric design (Generative Design, GD) using Dynamo for construction site layout planning has been explored [71]. Revit Dynamo facilitates the design of complex objects with its comprehensive toolset and automated process features, demonstrating its effectiveness in optimizing the design of intricate structures. Additionally, the use of Dynamo introduces new paradigms for modeling non-standard objects, and such automation techniques contribute to reducing time losses in the design process [72].

The feasibility of Revit for conceptual modeling and visual programming (Revit-Dynamo) in enhancing design and construction efficiency has been investigated. This study reveals that Dynamo provides a systematic approach to management and offers extensive application possibilities, reinforcing its viability in construction workflows [73]. The integration of 3D road design and pavement structural analysis based on BIM has led to the development of a framework that enhances BIM applications in highway engineering. This framework integrates BIM with structural analysis to minimize design defects and redundancy in road design. The application of Dynamo enables the creation of parameter-controlled 3D road models, facilitating designers in surface regulation and optimization [74].

The application of Dynamo in modeling of variable cross bridges aims to reduce errors and improve model accuracy. The implementation of Dynamo addresses the limitations of Revit in modeling by leveraging visual programming, thus expanding the potential applications of BIM-Dynamo [75].

The application of BIM in tunnel design with compaction pile reinforced foundation assessment and carbon dioxide emissions evaluation has been examined through visual programming with Dynamo in a case study in China. This research demonstrates how the integration of BIM and tunnel engineering enhances the understanding of emission reduction and environmentally sustainable construction practices [76].

The application of 5D BIM for quantity surveying, incorporating Dynamo and 3D printing technologies (3DP), facilitates accurate and rapid quantity takeoff for bill of quantities preparation and decision-making in the early project stages. The integration workflow of 5D BIM-3DP supports cost estimation and the fabrication of complex construction models [77].

A real-time productivity tracking framework integrating Survey-Cloud-BIM with Dynamo-based processing has been proposed. This study indicates that the developed Framework provides a cost-effective and adaptable real-time construction activity monitoring solution, particularly beneficial for small- to medium-sized construction firms [78].

The use of Dynamo for asset data delivery based on BIM models has been studied. Dynamo operates as a Revit module to extract and export data to an internal SQL database in a structured format, allowing seamless data upload to CMMS. A case study on a large-scale educational institution renovation project demonstrates how asset data collection, delivery, and Revit integration ensure structured data export compliance [79]. The linkage of Building Information Modeling (BIM) construction lifecycle data with Facility Management (FM) systems has been explored. This study develops a workflow utilizing Dynamo to extract and export asset data, supporting enhanced FM processes. The effectiveness of Dynamo-driven workflow in automating asset data extraction and export, facilitating direct integration with FM systems [80].

The application of Dynamo as a visual programming tool to streamline construction operations building information exchange for design professionals has been assessed [81]. BIM2PHPP, a tool based on Building Information Modeling for Passivhaus design using the Passive House Planning Package (PHPP), has been developed. The workflow enables automated data exchange between BIM and PHPP through Dynamo platform in Revit. The study highlights the automation of Passivhaus assessment and facilitates the collaboration of geometric and non-geometric data between BIM models and PHPP [82].

The integration of environmental sensors with BIM using Arduino, Dynamo, and the Revit API has been explored through a case study. The study highlights the necessity of a virtual-physical prototype as a foundation for testing intelligent building façade systems before full-scale model implementation. The findings suggest the feasibility of linking environmental sensors to BIM models through Arduino, Dynamo, and the Revit API [83].

3.4 Simulation

3.4.1 Isolated simulation applications

The conceptual modeling framework for discrete event simulation (DES) specifically within the construction domain serves as a problem-solving approach for managing complex construction projects. Additionally, it enhances construction processes to be more widely accepted for DES applications and fosters stakeholder confidence [84]. The proposed framework is based on intelligent simulation for automated concrete construction planning, facilitating a comprehensive understanding of construction plans and automated scheduling through the presented framework [85].

A novel method for automatically generating bridge construction schedules incorporates structured construction methodologies and constrained simulation. This approach utilizes Preparator software based on a 3D model for DES systems, providing essential information for automated construction scheduling by integrating standard scheduling software [86]. An ontology-driven framework is developed to enhance the reusability of distributed simulation modeling for industrial construction processes [87].

A systematic literature review explores the role of conceptual modelling in advancing construction simulation studies, emphasizing the benefits of conceptual modeling frameworks and linking these benefits to current research topics in construction simulation [88]. The challenges in application of Petri Nets in manufacturing systems are examined through a literature review, reflecting contemporary advancements and potential future research trends [89].

The dynamic simulation approach of the equipment repair support system based on Object-oriented Petri Nets (OPN) due to the mathematical complexity of large-scale models. This study utilizes Colored Petri Net (CPN) software, demonstrating that the OPN-based simulation is rational and efficient [90]. A comprehensive review of construction simulation approaches is presented, focusing on fundamental and hybrid simulation techniques to improve accuracy in productivity estimation and resource management [91]. An intelligent transportation system for smart city road networks is developed using 5G networks. The proposed algorithm is compared with Long Short-Term Memory (LSTM), Convolutional Neural Network (CNN), recurrent neural Network (RNN), Visual Geometry Group Network (VGGNet), and Bayesian Network (BN), demonstrating superior performance [92].

The application of discrete event simulation is systematically investigated in the context of asphalt concrete paving processes for a new construction project on Interstate 74 (I-74). The simulation results are validated against real field measurements, along with sensitivity analyses of critical resources. The resource dataset enables real-time monitoring, thereby optimizing construction process efficiency and supporting data-driven decision-making [93].

A Colored Petri Bet (CPN) model is proposed for simple sensor node DES applications, assessing real-time sensor signal processing capabilities [94]. A method of verification of software based on CPN is demonstrated. This study employs conceptual review and hierarchical search techniques to ensure completeness, using a sensor network model as an example. The results confirm the accuracy and efficiency of the CPN model, supporting its implementation on development platforms [95].

A Timed Continuous Petri Net (TCPN) model with immediate transitions is applied for performance evaluation and control. This study employs TCPN to illustrate rapid event transitions and simulation outputs through TCPN+I. The findings suggest that continuous instantaneous transitions offer solutions to specific challenges. The results indicate that applying these recommendations enhances predictive performance evaluation and control in production systems [96]. An analysis of structural controllability in TCPNs under an unbounded server assumption examines exponential system growth. Structural methodologies are applied to study the net rank-controllability (NRC). Under the assumption of Liveness, the structural properties of TCPNs show that NRC is a sufficient condition for controllability [97].

A hybrid Petri Net-based flow modeling approach is applied to hybrid systems, specifically in cement production process management. The modeling and simulation analysis conducted on the Visual Object Net++ platform enables optimal analysis of complex systems [98]. A hybrid Petri Net modeling approach is proposed to support simulation-driven direct current motion control. The simulation conducted on Visual Object Net++ confirms that the hybrid model, integrating continuous and discrete, supports the expansion of the proposed method. It also facilitates the development of specific command structures, including Petri Net-based code generation for software control tools and enhancing control precision [99].

The study evaluates the COSMOS software ecosystem for domain-specific construction process simulation by comparing it to both domain-specific and general-purpose approaches. COSMOS demonstrates accuracy compared to simulations based on case study experiments. The results suggest that this software or tool is applicable to the modeling and simulation of construction processes, providing expressive advantages for domain experts [100].

This study presents the development of an iconic animation (2D) tool designed for activity-based modeling and simulation is presented. Iconic Animation dynamically visualizes simulation processes on computer screens, enabling users to understand system transitions and validate simulation accuracy. Additionally, the tool facilitates real-time status reporting of construction process changes, enhancing decision-making and project monitoring capabilities [101].

Human activity recognition and motion detection in construction simulation are achieved using mobile sensors in combination with machine learning techniques. This approach collects data and recognizes human activities to analyze workflow, productivity, and bottlenecks [102]. Cluster finding in Petri Nets is implemented using GPenSIM. This study applies the method to a flexible manufacturing system, demonstrating its feasibility [103]. The optimization of autonomous guided vehicle dispatching is examined through the Platform Independent Petri Net Editor (PIPE), contributing to intelligent manufacturing systems [104].

3.4.2 Integrated simulation applications

The simulation modeling of construction processes can facilitate the integration of lean principles in the prefabricated housing industry. This approach is based on 3 process simulation methods: discrete event simulation (DES), agent-based modeling (ABM), and system dynamics (SD). This study focuses on how process simulation modeling can better integrate flexibility, energy efficiency, and low-carbon design strategies [105].

Engineering simulations for the market value of construction materials involve the development of engineering methodologies to model market price fluctuations using mathematical and statistical methods, with data stored on the SpagoBI platform. Additionally, a hybrid intelligent forecasting model has been designed to automate the feasibility of engineering methodologies for price prediction and advanced market value analysis of construction materials [106].

A new software tool for modeling and controlling discrete-event and hybrid systems has been developed using PN2ARDUINO based on Petri Nets. This tool aims to enhance complex and modern production processes in Industry 4.0 [107].

As reviewed in these articles, various technologies, including BIM, digital twin, Dynamo visual programming, and simulation, have been applied both in isolation and through integration with other advanced technologies or tools, such as Internet of Things (IoT), virtual reality (VR), and artificial intelligence (AI).

4. Results and Discussion

4.1 Summary of information on the applications of technologies

A review of articles on BIM, digital twin, visual programming, and simulation was conducted to examine their applications in both isolated and integrated forms with other complementary technologies or tools. Based on the findings from the previous review section, the researcher summarized information on the applications of technologies, which offer significant benefits to construction, which is shown in Fig. 1.

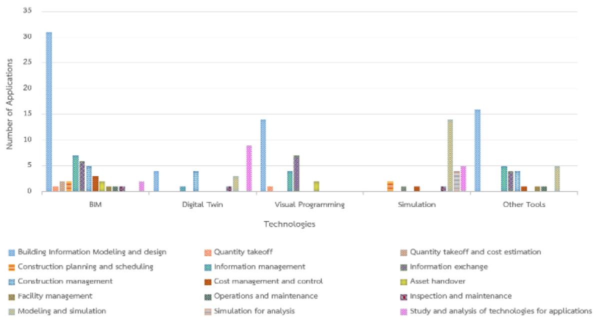

Fig. 1 Information on the applications of technologies

The detailed explanation in Fig. 1 illustrates the relationship between various technologies and the number of applications in the construction. These applications were divided into 15 tasks, including Building Information Modeling and design, quantity takeoff, quantity takeoff and cost estimation, construction planning and scheduling, information management, information exchange, construction management, cost management and control, asset handover, facility management, operations and maintenance, inspection and maintenance, modeling and simulation, simulation for analysis, and study and analysis of technologies for applications. The information analysis revealed that BIM was applied the maximum in building information modeling and design with 31 applications, followed by information management with 7 applications. Digital twin was applied the maximum in study and analysis of technologies for applications with 9 applications, followed by building information modeling and construction management with 4 applications. Visual programming was applied the maximum in building information modeling and design with 14 applications, followed by information exchange with 7 applications. Simulation was applied the maximum in modeling and simulation with 14 applications, followed by the study and analysis of technologies for applications with 5 applications. Additionally, other supporting technologies and tools, which enhance the functionality of primary technologies, were most frequently applied in building modeling and design with 16 applications, followed by information management with 5 applications. Therefore, the results of these analysis provide quantitative information for various construction-related applications.

4.2 Categorising technologies according to their applications

The review focused on the integration and applications of BIM, digital twin, visual programming, and simulation, considering both the isolated applications and the integration of these technologies with complementary tools. The summary of information on the applications of technologies, provided quantitative information regarding their use in various construction-related tasks. Subsequently, these technologies and tools were categorised according to their applications. The categorisation method was based on information derived from the applications of technologies, with the number of reviewed articles serving as a limitation of the study. Technologies were grouped into similar categories to illustrate their applications. This approach helped reduce fragmented practices and offered a clearer, more comprehensive perspective on their utilisation. The findings from this study are presented in Table 1.

Table 1 Categorisation results of technologies according to their applications

Applications in the construction	BIM	Digital twin	Visual programming	Simulation	Other tools
(1) Building Information Modeling and design	x	x	x		x
(2) Quantity takeoff and cost Estimation	x		x		
(3) Information exchange and management	x	x	x	x	x
(4) Construction management	x	x	x	x	x
(5) Modeling and simulation		x		x	x
(6) Study and analysis technologies for applications	x	x		x	

The analysis of information presented in Table 1 showed the results of categorising technologies according to their applications. The categorisation is divided into six categories: (1) Building information modeling and design, (2) Quantity takeoff and cost estimation, (3) Information exchange and management, (4) Construction management, (5) Modeling and simulation, and (6) Study and analysis technologies for applications. Each category of applications in construction applies effective technologies and tools to solve specific problems according to the objectives of the reviewed articles. Based on the information analysis, the key findings can be summarized as follows: Building modeling and design apply BIM, digital twin, visual programming, and other tools. Quantity takeoff and cost estimation apply BIM and visual programming. Information exchange and management, along with construction management, apply all technologies listed in Table 1. Modeling and simulation apply visual programming, simulation, and other tools. And the study and analysis of technologies for applications apply BIM, digital twin, and simulation. Therefore, the results of the categorisation of technologies according to their applications helps reduce fragmented practices and provides a more structured and comprehensive perspective. Additionally, it serves as a strategic guideline for advancing construction practices, enabling practical implementation.

5. Future Trends of These Technologies to Advance Construction Practices

The consideration of the analysis results, as obtained from the study and previously discussed, consists of two parts. The first part summarizes the applications of technologies, providing quantitative information on the most widely used technologies. For example, BIM and visual programming were applied in building information modeling with 31, 14 applications, respectively. Digital twin was applied in the study and analysis of technology for applications with 9 applications. Meanwhile, simulation was applied in modeling and simulating construction with 14 applications. The second part categorises these technologies according to their applications to reduce fragmentation and offer a clearer, more holistic perspective. For example, modeling and simulation to study and analyze events in construction apply simulation to information exchange and construction management. It can apply all technologies, namely BIM, digital twin, visual programming, and simulation.

The findings presented lead to significant future trends of BIM, digital twin, visual programming, and simulation, along with other tools that enhance their effectiveness. This allows the researcher to recognize the possibility of important future trends in these technologies to advance construction practices and further implementation in the field.

BIM has been applied for building information modeling and design as a central database for building management. The future trend of BIM is anticipated to become an increasingly important standard in construction, with further development in dimensions such as 4D, 5D, 6D, and 7D.

Digital twin has been applied in the study, concept development, and analysis of the capabilities of a digital representation of physical assets for construction management. The future trend of digital twin is expected to become a core element of construction management, enabling real-time tracking and analysis through connections with the Internet of Things (IoT).

Visual programming has been applied in building information modeling and design to manage and exchange construction information, which automates design and information management processes. The future trend of visual programming is expected to focus on reducing repetitive tasks, minimize errors, and increase accuracy.

Simulation has been applied to simulate event in construction to study the behavior of models and analyze scenarios before they unfold in the real world. The future trend of simulation is likely to be more extensively utilized to reduce risks and improve construction processes.

Overall, these technologies are expected to play a significant role in enhancing the construction sector by improving efficiency, reducing costs, and contributing to more sustainable construction practices.

6. Conclusions

Building Information Modeling (BIM), digital twin, visual programming, and simulation are transformative tools that have been increasingly adopted across various disciplines, particularly in the construction sector. BIM facilitates the creation of digital representations of physical assets, commonly called digital twins, which can be integrated with process simulations to predict and evaluate scenarios before they unfold in the real world. Dynamo, a visual programming tool, enhances this interconnection by automating data exchange and workflows, positioning BIM as a central repository for information. Despite their widespread use, these technologies are often applied in isolation, resulting in fragmented practices and limited holistic understanding.

This study conducted a review of 107 peer-reviewed articles from journals and reliable databases, focusing on the integration and applications of BIM, digital twin, visual programming, and simulation, along with other complementary technologies that enhance efficiency in the construction sector. The results of the study are presented in two parts: the first part summarizes the applications of these technologies, providing quantitative information into the extent to which each technology has been applied across various construction-related tasks. The second part categorises these technologies according to their applications, illustrating how they can be effectively applied. The findings of this study contribute to reducing fragmented practices and enhancing a more holistic understanding, offering a structured and comprehensive perspective on their potential, and demonstrate the future trends of these technologies to further advance construction practices and enable more cohesive and effective implementation in the field. Finally, this review highlights the importance of research as a contributing factor in driving continuous transformation and sustainability within the construction sector.

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