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REVIEW ARTICLE

A systematic review of the BIM in construction: from smart building management to interoperability of BIM & AI

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ABSTRACT
The main purpose of this study is to provide insight into the trend of AI-BIM integration, which has been studied by scholars around the world. To begin, a systematic review and bibliometric analysis was conducted to investigate English articles published between 2015 and 2022. This paper presents a systematic, scientometric, science mapping analysis through qualitative and quantitative evaluation and co-occurrence methods using VOSviewer, CiteSpace, and Gephi software. Conclusions indicate future research should concentrate on integrating AI and other smart systems with BIM to enhance digitalization and improve outcomes throughout the construction project life cycle. Based on the qualitative and quantitative evaluation of each scope (BIM and AI) and their status quo, this study suggests integrating the following domains with BIM to reduce complexity in the construction industry in the future: robotics, cloud systems, AIOT, digital twins, 4D printing, and block chain.

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Building information modeling (BIM); artificial intelligence (AI); construction industry; smart building; interoperability; systematic literature review (SLR)

1. Introduction

Development of the construction industry and technology in the building sector is the main manifestation of progress in human societies, population growth, and improvement in living standards (Begić and Galić 2021). Building projects face problems such as incidents on building sites, weak planning, insufficient schedules, and lack of cooperation. High energy consumption, rising material costs, waste management, high risk, low productivity, and environmental issues pose challenges to the Architecture Engineering-Construction (AEC) industry worldwide, threatening Our Planet's Existence (Anumba et al. 2021).

According to sustainable development, the issue of 'Smart Construction' should be taken into account to meet the needs of future generations and mitigate existing challenges through construction policies and intelligent approaches (Abuimara et al. 2021). Regarding these issues, a decision-making environment is required in the Architecture, Engineering, Construction, Operation, and Facility Management (AECO/FM) industry (Mashayekhi and Heravi 2020). Despite policies and legislation passed by the United States of America, the European Union, and Australia to reduce building energy consumption, they may not be enough to meet the challenges. Building performances often differ from initial plans, designs, and approvals, necessitating Comprehensive Tools and Platforms to address these challenges (Ferrando et al. 2020).

'Building Information Modeling (BIM)' has emerged as a simulation tool for managing building construction, facilities, the built environment, and life cycle, predicting building energy use, overcoming obstacles, and facilitating smart building design (Durdyev et al. 2022). The first development of BIM in architecture, engineering, and housing, encompassing automation systems, productivity, and renewable and sustainable energy, can be traced back to the 2000s (Li, Afsari, et al. 2020). BIM has since been recognized as an important parameter in construction progression. Additionally, BIM is characterized as the "advanced portrayal of the physical and functional qualities of a building" (Al-Ashmori et al. 2020; Bui, Merschbrock, and Munkvold 2016). BIM is a platform that uses diverse design perceptions and methods employing computer-assisted technologies in the construction industry (Li et al. 2021). BIM, also known as N-D modeling and virtual prototyping innovation, (N-D model is an extension of the Building Information Model that incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility, including scheduling, costing, accessibility, crime, sustainability, maintainability, acoustics, and energy simulation). BIM, as an inevitable requirement of construction projects, has become more widely accepted in the building industry due to its great efficiency in cost and time reduction (Othman et al. 2020). However, to obtain precise outcomes, the BIM platform has to be integrated with new Virtual Reality (VR) technologies like Artificial Intelligence (AI), Machine Learning (ML), the Internet of Things (IoT), and three-dimensional technologies to provide thorough construction requirements and solutions for building smart optimization (Altohami et al. 2021).

The term Artificial Intelligence (AI), as a branch of computer science, was first presented during the Dartmouth conference organized by researchers with a keen interest in machine

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intelligence (McCarthy and Hayes 1969). AI acts as the backbone that changes the method of performance in construction projects. AI aims to accept and use the same logic, learning and cognition capacities, reasoning, problem-solving, planning, and data storage capabilities as human beings. AI is a key technology field that assists everyday social life and activities and is driven by the progress of Information and Communication Technology (ICT) and Robotic Technology (RT) (Pan and Zhang 2021). Artificial intelligence (AI) can understand its environment and act to achieve objectives logically. It develops in a predictable sequence and achieves its goals through analytical and intuitive actions. The desire for AI research and investment in AI has rapidly increased since the mid-twentieth century as it has provided solutions and addressed various engineering and scientific challenges in an intentional, intelligent, and adaptive manner (Abioye Sofiat et al. 2021). AI systems' performance in immersive learning phases can be used to classify large databases and visualize, explain, and interpret their models. The analysis of probable scientific data, machine learning, cognitive science, and data theory provides access to the area of problem explanation and interpretation, enabling automatic programming, optimization, information compression, and modeling (Rao et al. 2021). Machine learning in AI exclusively plays a major role in learning sufficiently strong data from numerous sources and then making an intelligently adaptive decision using insights from structured and unstructured data (Erharter and Marcher 2021).

While a significant amount of engineering information is generated in construction projects, the application of AI technologies in building management lags behind. Therefore, there is a growing interest in applying various AI techniques in the construction and building sector to achieve optimal results (Na et al. 2022).

The development of construction procedures for reducing building resources through efficient planning and environmentally conscious facilities is employed for mapping, site analysis, technical drawings, and design plans. Moreover, AI has been used for controlling functions, selecting the best options, optimizing processes and outcomes, and automating systems and equipment (Sacks, Girolami, and Brilakis 2020).

The construction industry, which has undergone a fundamental revision through BIM, has had the opportunity to integrate new creative solutions using AI. Integration of AI methods into the BIM platform could benefit the construction sector by improving planning, construction, maintenance, and operation through digitalization (Huang, NiniÄ, and Zhang 2021).

2. Review methodology

In this study, a systematic literature review was conducted to summarize and assess available technologies in particular research domains, aiming to identify the research trends concerning BIM, AI, and their integration as smart techniques within the construction industry. So far, some studies have used this method to explore the research areas of BIM and AI. The SLR method was carried out in this study to not only identify research questions by gathering, analyzing, and interpreting existing academic articles via science mapping and bibliometric analysis but also to justify the necessity of further studies in these areas. Therefore, 'keyword co-occurrence', 'co-authorship relations', and 'citation relations' were common methods in scientometric surveys (science mapping) and analysis in this study through bibliometric and qualitative analysis. These analyzes provide a general view of the current status of BIM and AI and grounded theory.

This study is the first stage of a larger research project aiming at using BIM and AI for construction in order to reduce the construction challenges and risks of the current generating methods. To be able to define the research focus, initially, current studies in BIM and construction and their characteristics were investigated. Then, AI and construction were explored to examine how AI can contribute to the construction. In addition, the related works with regard to BIM and AI integration were studied to examine the current solutions and to identify existing limitations.

Generally, an SLR systematically gathers previous research papers using a search engine and selects relevant papers based on inclusion and exclusion criteria to answer research questions. Therefore, to guide the SLR process, the following five research questions were formulated:

- **RQ1.** What is the research trend on BIM in construction projects?
- **RQ2.** What is the research trend on AI techniques in construction projects?
- **RQ3.** What are the paradigms and technologies associated with BIM and AI integration?
- **RQ4.** what are the technical methods to integrate BIM and AI?
- **RQ5.** What is the construction industry's future research directions, trends, and insights?

The SLR process is divided into the following five stages, which are elaborated on throughout the article:

1. Programming and defining stage
2. Organizing stage
3. Categorizing stage
4. Describing and giving report stage

2.1. Programming and defining stage

This stage involved setting up the search criteria and parameters for the preceding papers through the SLR process. Additionally, defining the research scope and background and identifying the keywords used for gathering information were conducted in this stage. The search was performed by segregating the research papers into the scope of BIM and AI.

In the past few decades, numerous studies have been published on BIM and AI, owing to the remarkable growth of their applications in the construction industry. The academic articles and background information on BIM and AI were identified and collected from various online databases. A broad range of academic databases, such as Scopus, Web of Science (WOS), Wiley Online Library, PubMed, ScienceDirect, ResearchGate, Taylor and Francis Online, and Google Scholar, were selected to gather journal articles, with the Scopus database covering more journals and publications than other databases.

To conduct a comprehensive search via the Scopus database, we used the search terms 'title/abstract/keyword/author keywords/

keyword plus'. The search process began with the following Boolean operators and search queries: TITLE-ABS-KEY (BIM OR 'Building Information Modelling') AND construction AND 'building management' AND (AI OR 'artificial intelligence') AND construction AND 'building management'.

Given the emergence of BIM and AI as relatively new technologies, the study limited and systematized the search to research papers published between 2015 and 2022, for a meaningful investigation. As a result, the search yielded 11,368 research papers for the BIM scope and 8,574 research papers for the AI scope, all of which were in English.

2.2. Organizing stage

Based on the proportion of articles to the research domain, the selection of previous papers in the programming and defining stage was done by using 'title/abstract/keyword' search. The study eliminated duplicated and irrelevant articles to the research scope by using inclusion and exclusion criteria (refer to Table 1). Furthermore, in addition to the inclusion and exclusion criteria, full-text scanning was conducted to select suitable papers. Several software tools, such as Office (Excel), VOSviewer (bibliometric data analysis), CiteSpace (visualize network layouts and clusters), Gephi (mapped graphs), and Mendeley Library, were utilized to demonstrate the academic article input based on the title, abstract, keyword, journal, publication, and author, to perform bibliometric analysis and filter research papers. This study selected a total of 1843 papers in the BIM scope, 985 papers in the AI scope, and 453 papers in the AI and BIM integration scope. Although many studies have utilized BIM in the construction field, most of them only highlighted the value of BIM in a specific area and presented a limited perspective rather than a general view of BIM performance within AEC and AI. These articles were thoroughly reviewed to determine the relevant articles to the research questions and targeted domains. Figure 1 demonstrates the increasing tendency towards the publication and research on BIM, AI, and their integration from 2015 onwards.

Table 1. Inclusion and exclusion criteria' in the organizing stage.

Inclusion criteria	Exclusion criteria
Papers that discuss 'BIM in construction'	Non-English papers
Papers that discuss 'AI in construction'	Duplicated Papers
Papers that discuss 'BIM & AI integration in construction'	Irrelevant articles
Papers that focus on building management systems, BIM in construction industry, smart technology, etc.	Conference articles

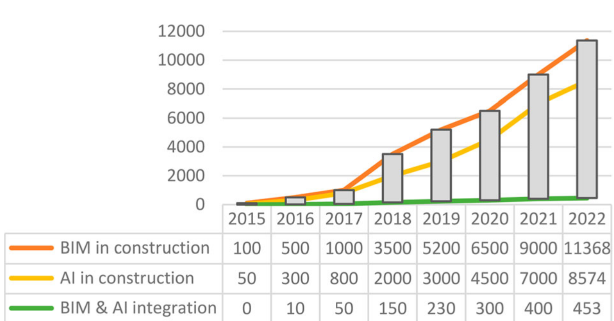

Figure 1. Number of research papers on BIM & AI from 2015 to 2022.

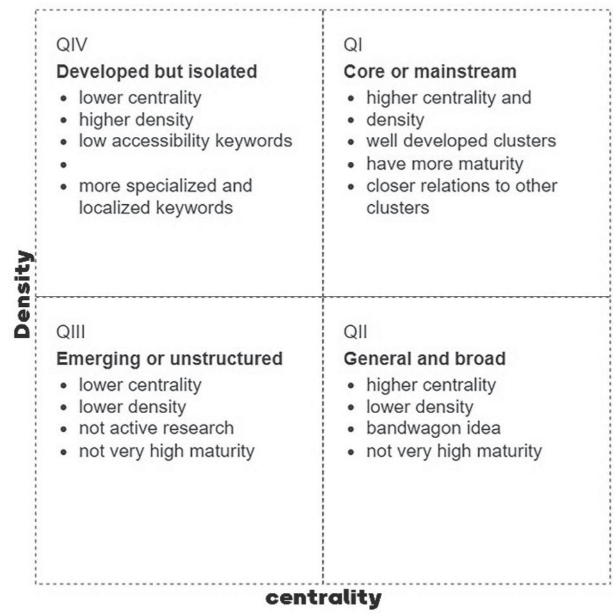

Figure 2. Strategic analysis diagram.

2.3. Categorizing stage

In this stage, data analysis and co-occurrence analysis were conducted by evaluating the connections among the keywords of the research papers selected in the categorizing stage. The VOSviewer software was used to analyze the data published on BIM and AI and generate network visualizations. The following techniques were applied for the co-occurrence analysis: (I) Keyword Co-occurrence Analysis, (II) Co-authorship Relations, and (III) Citation Relations.

2.4. Describing and giving report stage

In the description and reporting stage, a strategic analysis diagram was used to define and describe the position of each cluster in the research domain. This diagram is presented as a 2×2 matrix with four research topics (see Figure 2). The strategic matrix shows the level of centrality (importance of the cluster) and density (cohesion and uniqueness of the research themes) on the X and Y axes, respectively.

3. Current status quo of BIM and AI

The research topics related to BIM and AI in the construction industry were determined through a qualitative and quantitative review in this stage. The outcome of the strategic analysis diagram and the co-occurrence analysis was used to evaluate the current status quo of BIM and AI as well.

3.1. Bibliometric analysis

The study presents a bibliometric analysis of the BIM and AI domain in the construction industry to show the current status of research papers and identify common emerging areas of BIM and AI application in the available papers. Table 2 shows

Table 2. Bibliometric analysis on research papers.

Ref (Author & year)	Methodology	Experiment/case study	Software	Function/functionality	Parameters & criteria clusters
(Pan and Zhang 2021)	LS/LR/SR/SA/QA	–	–	CEM	KRR/IF/CV/NLP/IO/PM/BIM/AI
(Xu, Mumford, and Zou 2021)	LS/LR/SR/ AP	–	–	IE/ DR/ERQC/ LCC/RTO/MM	BIM & E
(Pan and Zhang 2020)	LS/CS/FS/DM/DA/ DAP/PE	✓	TF/P/AR	L	HP/ BIM/AI
(Sacks, Girolami, and Brilakis 2020)	LS/DA/LR	–	–	VR/AR	CT/RDP/BF/FB/BIM/AI
(Li, Lai, et al. 2020)	LS/HA/BM/SA/ KA/ QA	–	–	LCE–B	LCA/LCEA/LCCA/CE/BE/ BIM/AI
(Li, Afsari, et al. 2020)	LS/CS/FS/NA/LR	✓	–	GD	AEC/BIM/AI
(Oraee et al. 2019)	LS/LR/TR/QA/IR	–	–	CM	BbCNC/ BIM/AI
(Ansah et al. 2019)	LS/SR/PA/CA	–	R	LEED/BREEAM	GBAS
(Tang et al. 2019)	LS/LR/SR/KA/PA/D A	–	MS Access/ MySQL/BIMSL /Esper/ SPARQL	SOA	IoT/ BIM/ SB/SC/SBE
(Kamel and Memari 2019)	LS/LR/SR/CS/PA	✓	P/R/GBS/OS/IES/ DB	BS	BIM/gbXML/BEM/EP/IFC
(Farzaneh, Monfet, and Forgues 2019)	LS/LR/SR	–	LOD/MVD/ EndNote X6	CF	BIM/BEM/DP
(Garwood et al. 2018)	LS/LR/SR/HS	–	SAT/PLC/EMB/DES/ PSO/R/ EPSE	OF	BIM/MPS Manufacturing Process, Simulation/EU
(Chong, Lee, and Wang 2017)	LS/LR/SR/PR/SE/DE	–	R	ESE	BIM/S
(Bui, Merschbrock, and Munkvold 2016)	LS/LR/CS/KA/PRO	✓	–	CBF	BIM/DC/IS
(Gao and Pishdad-Bozorgi 2019)	LS/CA/LR/KA	–	–	–	BIM-O&M
(Tashakkori, Rajabifard, and Kalantari 2015)	IRM/LS/SA/EA/CA	✓	–	PF/EIA	IFC/ IESM
(Chen et al. 2015)	LS/SA/MAT/TDVRP	✓	–	BIM-converted graph/ PF	MAT/ TDVRP
(Bloch and Sacks 2018)	LS/SA/SE	✓	BIM	CEM/ RA	AI/ ML/SE
(Bloch, Sacks, and Rabinovitch 2016)	LS/SA/LR/C/PS	✓	laser scan	EIA	as-built BIM/as-damaged BIM/MACA
(Wang et al. 2015)	LS/IRM/EA/R	✓	Fire Dynamics Simulator	BIM-based system/ EA/ ERP/ SE/EM	EA/ ERP/ SE/EM
(Wetzel and Thabet 2016)	LS/LR/I/O/C FM staff/ DMADV/R	–	Safety	Should be tested by pilot study	FM/ DMADV
(Ferrando et al. 2020)	LS/LR/C/BM/SOA/R	–	–	–	UBEM

All nomenclature is listed in the appendix.

the research papers on BIM and AI based on reference, methodology, case study, applied software, function, and evaluated criteria to provide a brief bibliometric analysis.

In addition to Table 2, the following studies were identified from databases:

- Li, Lai, et al. (2020) provided a review of building information modeling (BIM) education and research in China. This article was used in the literature review and as a case study to examine the status of BIM in Chinese education.
- Ansah et al. (2019) presented a comprehensive and systematic review of the integrated application of BIM in green building assessment.
- Oraee et al. (2019) proposed an approach with innovative, agential, and administrative segments. They emphasized that the coordination of information and communication technology (ICT) in the housing industry is crucial for the development of BIM.
- Krygiel, Nies, and McDowell (2008) defined BIM as 'data about the whole structure and a total set of configuration reports stored in an integrated database'.
- Smith and Tardif described BIM as 'a tool to transform information into data to gain the knowledge that enables us to act with intelligence' (Kamel and Memari 2019).
- Tang et al. (2019) conducted a review of the integration of building information modeling (BIM) and Internet of Things (IoT) devices.

3.2. Keywords co-occurrence analysis

Given the importance of keywords in determining the core concepts of research themes, co-occurrence analysis of keywords was used to identify the paradigm of study topics. The primary analysis of keywords was conducted on various databases to provide a comprehensive review of construction using BIM and AI. To achieve qualitative analysis purposes, the bibliometric survey was classified into three keyword clusters to examine the relevance of the research scope.

3.2.1. BIM and construction

For this cluster, the Boolean operators were as follows: (BIM OR 'Building Modeling Information') AND construction AND 'building management'. Overall, 11,368 research papers in the BIM domain were imported to VOSviewer and CiteSpace software to perform the co-occurrence analysis of keywords. The analysis revealed 203 nodes among the keywords and 1471 connected lines. Figure 3 illustrates the co-occurrence network mapping of BIM and construction in different subdomains, such

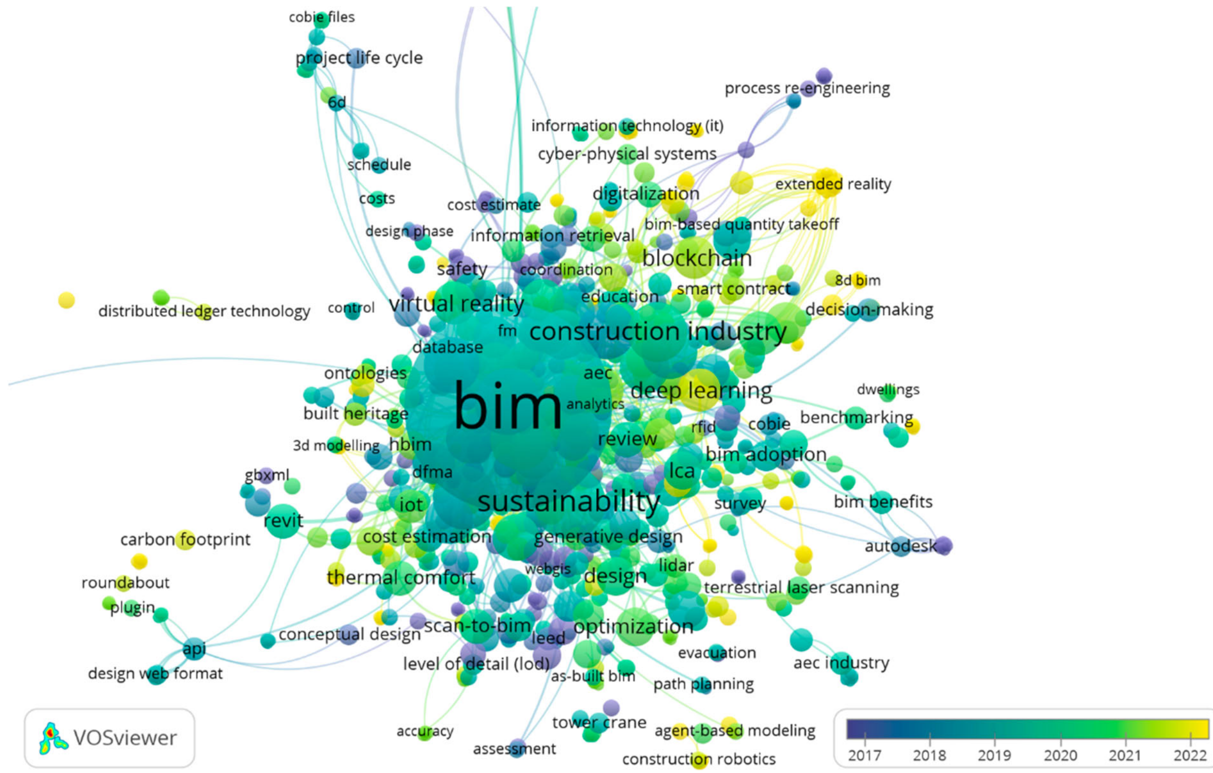

Figure 3. Keywords co-occurrence analysis of BIM in articles and publications using VOSviewer.

Figure 4. Three core concepts of BIM.

as BIM's applications and potential in construction, engineering, and management, which includes BIM concepts, standards, platforms, functions, and dimensions. Similar and repetitive keywords have been merged to indicate high-frequency co-occurrence.

According to the literature review and analysis, the underlying concept of building information modeling (BIM) is to provide a comprehensive environment for the entire project lifecycle (Grilo and Jardim-Goncalves 2010). Therefore, BIM is more of a collaborative process than just a piece of software. Although technology provides a vehicle for its implementation, the impact of BIM on organizations primarily reflects a better collaborative work practice and early involvement of stakeholders, which is more from a sociological perspective (Ozturk and Tunca 2020). Furthermore, BIM extends beyond the use of an electronic drawing tool or the adoption of technology; it represents the process of implementing technology to develop, refine, simulate, manage, and communicate virtual representations (form and functions) of buildings to optimize the construction delivery process. This clearly demonstrates that BIM is underpinned by three main concepts: collaborative practices, technology as a digital delivery vehicle, and integrated project data, as shown in Figure 4 (Eastman et al. 2021; Sacks et al. 2018).

3.2.1.1. BIM is more than just software or technology. Building Information Modeling (BIM) has been a buzzword in the construction industry for years now (Succar 2009). It is a powerful tool that can help architects, engineers, and construction professionals to better design, construct, and manage buildings (Eastman et al. 2021). However, BIM is much more than just software or technology. It has much richer implications for the industry as a whole. Some of the ways in which BIM is more than just software or technology are indicated below:

1. BIM is a process, not just a technology. It involves collaboration, communication, and coordination among different stakeholders throughout the building life cycle (Azhar, Khalfan, and Maqsood 2012; Azhar et al. 2012).
2. BIM enables the creation of smart buildings that can be monitored and managed in real-time, leading to better operational efficiency and cost savings (El-Sayegh 2008).
3. BIM supports interoperability, which means that different software applications can communicate and share information seamlessly (Eastman et al. 2009). This can lead to fewer errors, better decision-making, and more efficient workflows (Arayici et al. 2011; Gu and London 2010).
4. BIM supports the use of artificial intelligence (AI) in construction. By providing accurate and reliable data, BIM can help AI algorithms make more informed decisions (Dave and Dave 2020).
5. BIM can facilitate sustainable design and construction practices by enabling energy modeling, life cycle assessment, and other tools (Katsigiannis and Aretoulis 2021). This can lead to more environmentally friendly buildings with lower carbon footprints.

In general, Building Information Modeling (BIM) is much more than just software or technology. It is a process that enables collaboration, communication, and coordination between different stakeholders throughout the building life cycle. BIM also supports the creation of smart buildings, interoperability, the use of AI, and sustainable design and construction practices. As such, it is an essential tool for any construction professional looking to stay ahead of the curve (Succar 2018).

The increasing adoption of BIM has revolutionized the AEC industry by improving system interoperability, information sharing, visualization of 3D models, speed of delivery, and decision-making processes (Azhar 2011; Steel, Drogemuller, and Toth 2012). Most importantly, BIM provides a platform for seamless collaboration among stakeholders from different fields of the industry, as shown in Figure 5. As such, BIM knowledge is accumulated from various fields, and the expectations of BIM are cut across these disciplines (Singh, Gu, and Wang 2011).

The top 10 BIM software used in the industry include Autodesk Revit, Bentley Architecture, Graphisoft ArchiCAD, Nemetschek Vectorworks, Gehry Technology Digital Projects, Nemetschek AllPlan, Trimble SketchUp, 4MSA IDEA Architectural, Tekla Structure, and RhinoBIM (Waterhouse and Philp 2016), as shown in Table 3.

As researchers have recognized the potential value of BIM in various fields, its usage is increasing. While BIM is reported to be used for structural and energy analysis with a frequency of 27% and 25%, respectively, its primary use still appears to be for the faster development of 3D geometric models and 3D coordination, with a frequency of 60%. BIM's application is not limited to the engineering and construction industry. There are also reasons for homeowners, facility managers, contractors, and fabricators to utilize BIM (Ramaji, Messner, and Leicht 2016).

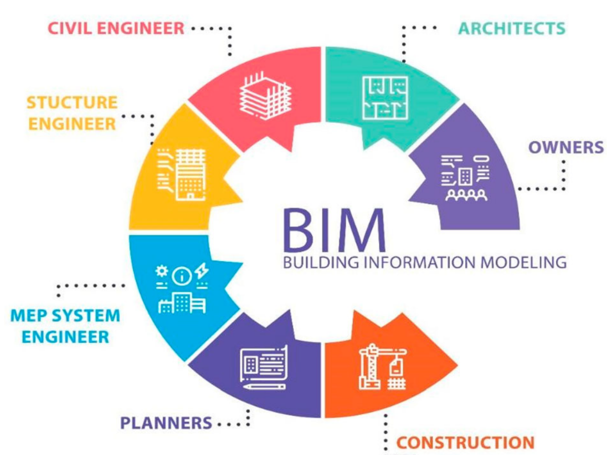

Figure 5. BIM collaborative platform.

The co-occurrence analysis of the research paper indicates that the majority of the key factors when applying BIM in a building layout are focused on automating the modeling process, improving the accuracy of building documents and the construction process, and the automatic reflection of changes. A relatively comprehensive literature review on BIM and its applications shows that most resources are mainly focused on planning, design, construction, operation, and management. Researchers from different countries have expressed that although building firms are using simulation tools, there is a gap in BIM interoperability with other tools. This gap can help avoid re-entering all available data in other models for the project.

The following objectives indicate the high-frequency core keywords in BIM research:

Objectives	Description
Visualization	3D renderings with minimal extra effort.
Construction/shop drawings	Generating building plans for diverse applications and systems with ease.
Code reviews	Used by officials like the fire department to review building design.
Cost estimating	Automatic updates of material quantity for cost evaluation as changes occur.
Construction sequence	Organizing the process of ordering materials, construction, and schedules of delivery for all building ingredients.
Contradiction and interposition	Automatically checks all interferences in 3D area.
Legal analysis	Adjusted to display possible defeats, leakages, discharge programs, etc. in a graphic format.
Facilities management	Used for renovations, space planning, and maintenance operations.
Objectives	Description
Visualization	3D renderings with minimal extra effort.

Source: (Utkucu and Sözer 2020).

3.2.2. AI and Construction

The Boolean operators for this cluster are as follows: (AI OR 'artificial intelligence') AND construction AND 'building management'. The search process using the mentioned Boolean operator and 'title/abstract/keyword' has provided 8374 articles from listed journals in the engineering domain. Hence, the most relevant articles were taken into account for further investigation in the filtering stage. In total, 985 research papers on the AI domain were imported to VOSviewer and CiteSpace software

Table 3. Different types of BIM software.

Num.	Software	Developer	File extension	Operating System	Main Use
1	Revit	Autodesk	.rvt	Windows, Mac, Linux	Arc, Design, Electrical, and Mech.
2	Micro Station	Bentley	.dng	Windows, Mac, Linux	Arc, Design, Electrical, and Mech.
3	ArchiCAD	Graphi soft	.pln	Windows, Mac, Linux	Arc, Design, and Mech.
4	Vector works	Nemetschek	.wmx	Windows, Mac, Linux	Arc, Design
5	Digital Projects	Gehry	.CATProduct	Windows, Mac, Linux	Arc, Design, Electrical, and Mech.
6	All Plan	Nemetschek	.ndw	Windows, Mac, Linux	Arc, Design, Electrical, and Mech.
7	SketchUp Pro	Trimble Navigation	.skp	Windows, Mac, Linux	Arc, Design, Electrical, and Mech.
8	IDEA Architecture	4M	.dwg	Windows, Mac, Linux	Arc, Design
9	Tekla Structures	Tekla Corporation	.tsc	Windows, Mac, Linux	Arc, Design, Electrical, and Mech.
10	Rhino BIM	Robert McNeel	.3dm	Windows, Mac, Linux	Arc, Design, Electrical, and Mech.

Source: www.autodesk.com and 'Different types of Building Information Modeling (BIM) used in construction' PDF, n.d.

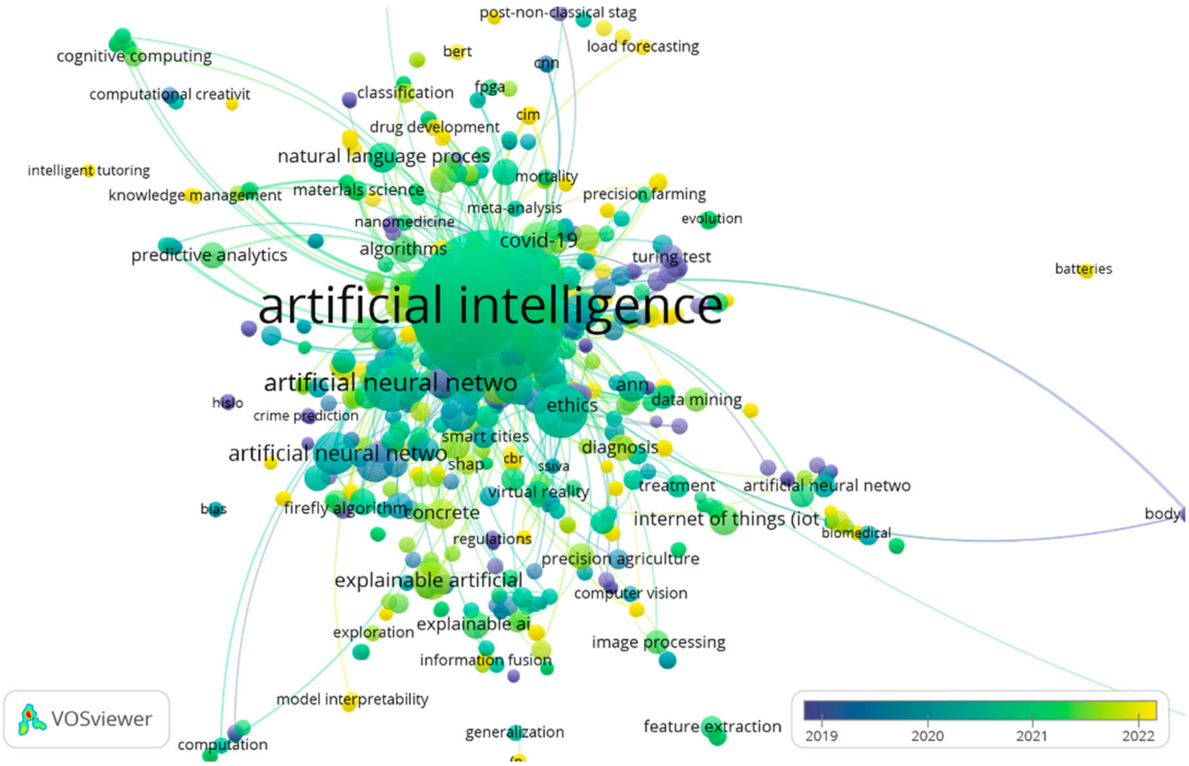

Figure 6. Keywords co-occurrence analysis in the AI domain using VOSviewer.

to perform the keywords co-occurrence analysis. The minimum number of keywords was set to 12, and normalization was done to reduce errors. The threshold was reached by 380 authors out of 27,727. The analysis indicates 108 nodes among the keywords and 786 connected lines. Figure 6 illustrates the combination of AI and construction in various subcategories and indicates the applications of AI and its supporting methods in construction engineering, including AI types and techniques.

According to the literature, 'artificial intelligence technology' refers to the combination of software and hardware that can automatically solve complex problems without the need for human intervention. In the context of launching real digital strategies in construction engineering and management (CEM), artificial intelligence (AI) serves as the backbone for changing the way construction projects are executed. AI is considered part of computer science and allows computers to perceive and understand input data like humans do for sensing, learning representation, cognition, problem-solving, and planning. This enables them to deal with complex and ill-defined obstacles in a conscious, intelligent, and adaptive way (Farzaneh et al. 2021).

Within the construction industry, various computational models have been employed for different purposes, such as cost estimation (Ahn et al. 2020), occupational risk prediction (Tsoukalas and Fragiadakis 2016), time estimation (Pujitha and Venkatesh 2020), constructability analysis (Manoj Philip and Ramesh Kannan 2020), and insolvency prediction (Alaka et al. 2017; Jackson and Wood 2013). After reviewing the extant literature, it was discovered that AI intelligent model development methods commonly used in the construction industry could be categorized into four groups: (a) machine learning techniques, (b) knowledge-based techniques, (c) evolutionary techniques, and (d) hybrid systems. Each of these groups was explored to identify its strengths and weaknesses. A comparison of the four categories is presented in Table 4. Table 5 presents the AI techniques used in construction studies.

3.2.3. BIM and AI

The Boolean operators for AI and BIM integration are as follows: (BIM OR 'Building Modeling Information') AND construction AND 'building management' AND (AI OR 'artificial intelligence') AND construction AND 'building management'. The total number of obtained articles in the scope of BIM and AI is about 19,742. In total, 453 research papers on BIM and AI integration were imported to VOSviewer and CiteSpace software for the purpose of performing keyword co-occurrence analysis. Figure 7 displays the various subfields of the integration of BIM and AI, with different colors used to visualize the keyword map in a sequential order. The purpose of this analysis is to collect data for research direction in integrating building information models and artificial intelligence. The approach to BIM and AI integration and analysis of construction and building engineering databases involve the knowledge base (original and empirical), reasoning machine, and interpretation mechanism.

BIM software companies have already started using artificial intelligence to enhance the efficiency and potential of their programs. BIM software can leverage machine learning (ML) to learn from data and figure out templates, which can help it make independent decisions on the method of automation and improving the construction procedure model. BIM software accumulates a large amount of data that AI can use to investigate the probabilities of each feature of a building project and detect the optimal solution faster than a human mind. This not only speeds up the process but also reduces the risk of human error, making construction sites safer. We can expect to see more AI-assisted BIM

Table 4. Comparison of AI techniques.

AI techniques	Description	Key strengths	Key limitations	Example
Machine Learning Techniques	Learn from data	Handle uncertainty and incomplete data efficiently	Lack technical justification for results and decisions	Artificial Neural Network (ANN), Fuzzy Logic (FL), Support Vector Machines (SVM), Rule-based Learning (RBL), Association Rule Learning (ARL)
Knowledge Based systems	Mimic human domain experts in finding solutions to complex problems	Strong explanation abilities	Poor learning and knowledge discovery abilities	Expert Systems (ES), Rule-Based Reasoning (RBS), Case-Based Reasoning (CBR), Semantic Networks (SN), Ontologies
Evolutionary algorithms	Bioinspired techniques that use heuristics to find solutions to complex problems	Require little domain-specific information and easy to implement	Heuristics are difficult to generalize	Genetic Algorithm (GA), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Particle Swarm Optimization (PSO), Differential Evolution (DE), Evolutionary Programming (EP)
Hybrid systems	Integrate multiple AI techniques to provide a synergetic solution	Overcome specific limitations of individual techniques and combine their strengths	Could be complex to design and implement	Neuro-Fuzzy Systems (NN + FIS), Genetic Fuzzy Systems (EC + FS), Fuzzy Expert Systems (FISES), Evolutionary Neural Networks (EC + NN)

Source: (McKinsey Global Institute 2018).

Table 5. Artificial intelligence techniques in construction studies.

AI Techniques	Area of Study and Source	Techniques
Machine Learning Techniques	Time and Cost estimation	ANN-SVM
	Prediction of cost performance	SVM
	Interval cost estimation	SVM
	Building energy performance assessment	FS
Knowledge Based systems	Construction bid decision making	CBR
	Overcoming problems in pavements	ES
	Checking of models and schedules	DSS
	Construction and public road planning Cost estimation	CBR- Ontology
Evolutionary algorithms	Cost estimation	CBR
	Cost optimization	GA
	Construction time-cost optimization	ACO
	Optimization of composite structures	ABC
	Optimizing building thermal design / supply locations / Time-cost-resource	GA
	Water resource management	ACO
Hybrid systems	Estimating Construction Waste	ANN + ACO
	Optimization for building retrofit	GA + ANN
	Time-cost-quality trade-off in construction	FS + PS
	Prediction of cost and schedule	ANN + SVM
	Construction cost estimation	ANN + GA + FS/LS + SVM

Source: (Konstantinidis 2018).

tools in the industry over the next decade. AI has the potential to take BIM to the next level and drive further advancements in the industry.

One of the main challenges in the building and construction industry is productivity, which has hindered its growth. Artificial intelligence appears to be a solution to the obstacles that the industry has faced in the past. In BIM, AI plays a significant role in identifying potential barriers that may arise in the future. Since infrastructure development projects are large-scale and mistakes can be costly, AI helps to create a long-term vision and the ability to anticipate future challenges. A BIM platform can accumulate and process diverse data, and AI helps to understand and analyze this data to predict and generate models for future progress. AI applies the collected data by BIM software to evaluate opportunities, explore effective solutions, and even create executable programs that reduce the risk of failure (see Figure 8). According to the literature, AI has recently been used in BIM to strengthen its parametric analysis for the following purposes:

- optimizing BIM-based construction planning and scheduling;
- optimizing BIM models based on different variables;
- optimizing a schedule for building energy management systems (BEMS).

3.3. Co-authorship relations

Author-based citation analysis was conducted to identify common references on specific topics. The minimum number of documents was set at 4, while the minimum number of citations for authors was set at 3. This threshold was met by 56 authors out of 586. Figure 9 illustrates the clustering techniques used in VOSviewer.

3.4. Co-citation analysis

To visualize patterns and trends in the scientific literature on the integration of BIM and AI and generate citation relations maps, CiteSpace software was used to conduct the analysis. Citation data from popular sources such as the Web of Science and Scopus were processed in CiteSpace. Figure 10 illustrates the article clusters analyzed by CiteSpace, using the Log-Likelihood Ratio (LLR) algorithm. CiteSpace was applied repeatedly to track the development of the integration of BIM and AI closely and extensively. Citation clusters were created as the common way of

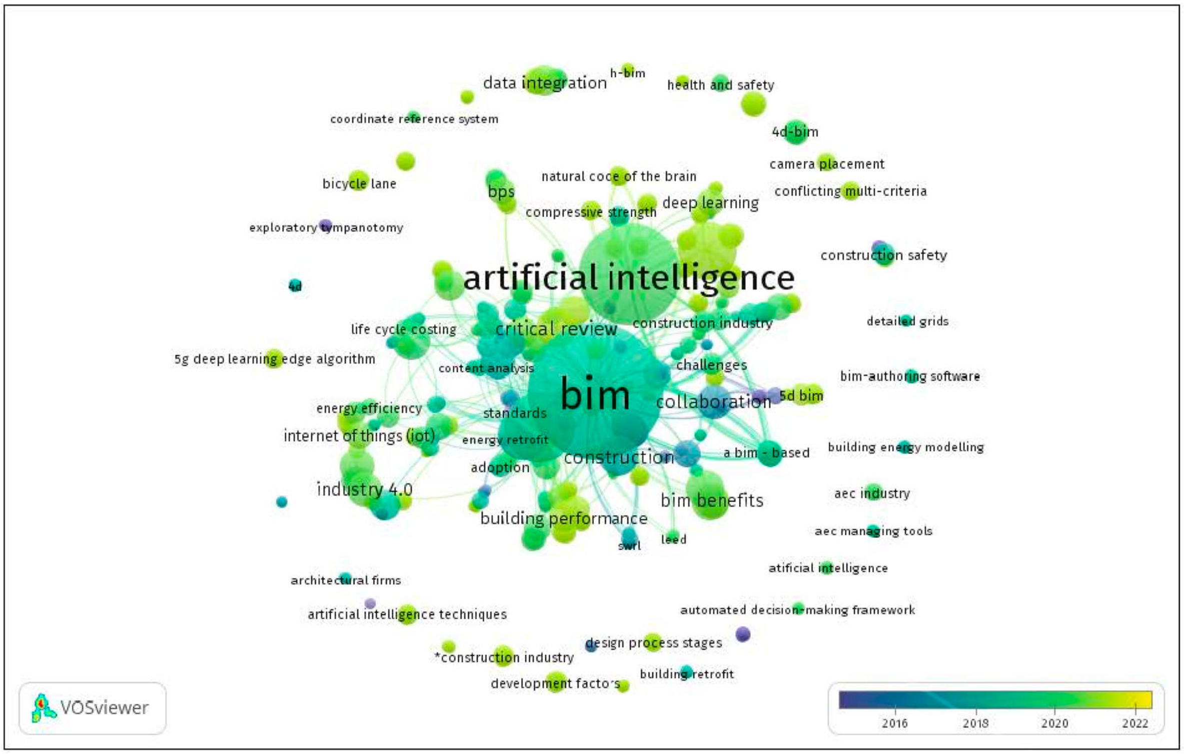

Figure 7. Keywords overlay visualization by VOS viewer in AI & BIM integration.

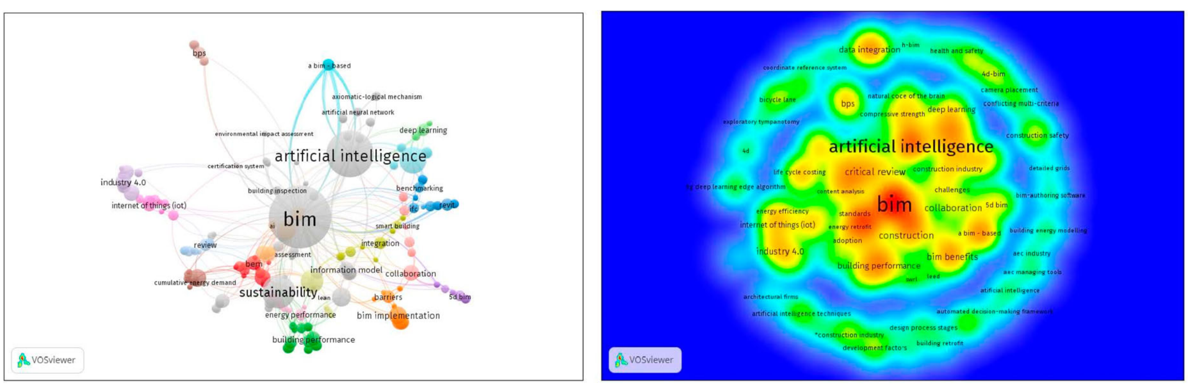

Figure 8. Keywords network & density visualization by VOSviewer in AI & BIM integration.

network co-citation analysis. By filtering out small clusters, eight clusters (out of 78) were selected as the basic research domains. The fewer clusters, the more relevant the research topic. Therefore, cluster 0 is the largest one, demonstrating more articles and publications than cluster 8. Due to the concentration of CiteSpace on cluster generation, the software suggests different labels. To assess cluster performance, CiteSpace's calculation tool evaluates measures like Modularity (Q) and Mean Silhouette (MS) ($Q = 0.7$, $MS = 0.6$). Modularity is a metric for assessing the division strength of a network into clusters. The independence of networks and clusters is indicated in the Modularity criteria. The value of this metric is between $0 < Q < 1$, which indicates the quality of a network's structure:

- If the modularity is close to 1, it represents a well-structured network;
- while if it is close to 0, it indicates uncertain cluster borders.

'Validation of consistency within clusters of data' was assessed using the Mean Silhouette method. The silhouette value measures the cohesion and separation of the individual and compared clusters. The criteria range from -1 to $+1$, where a high value indicates that the cluster's object is well-matched to its own and separated from neighboring clusters, and a low value indicates that the cluster is poorly matched to its own (indicating heterogeneity). The characteristics of the clusters are listed in Table 6, which was generated using data from the CiteSpace software.

The Mean Silhouette evaluation reveals the concentration of research domains and subdomains within the BIM and AI integration field from 2015 to 2021. The co-citation analysis highlights the latest focus of articles on Artificial Intelligence and smart systems, as well as the use of AI techniques in Construction Engineering Management. Other core research areas are listed in Table 6. The citation analysis shows a limited focus on

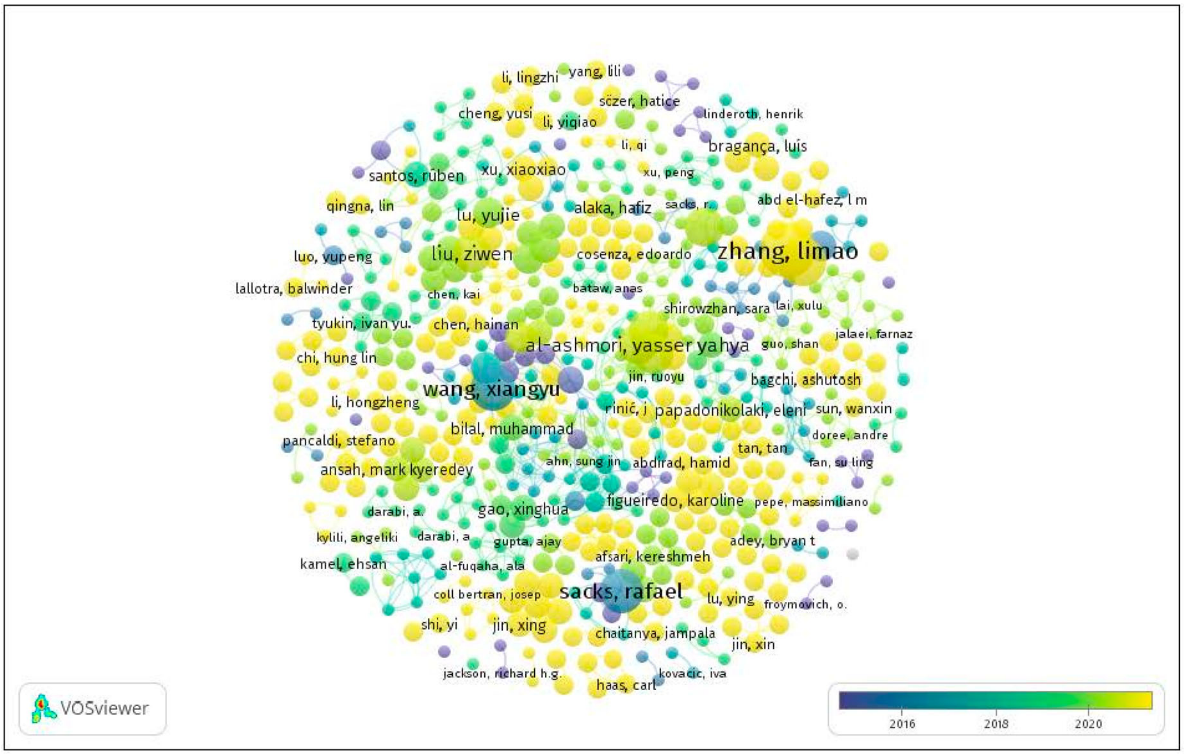

Figure 9. Co-Authorship overlay visualization by VOS Viewer in BIM & AI Articles and Publications.

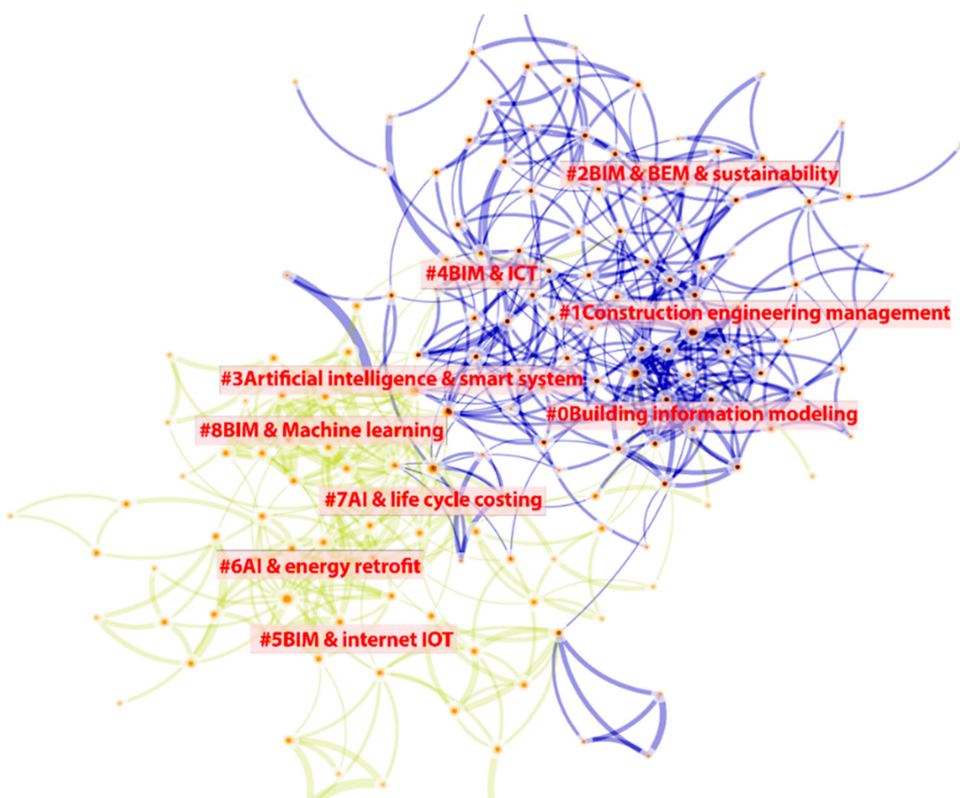

Figure 10. Clustering structure of BIM and AI integration in CiteSpace software.

Table 6. Co-citation analysis of BIM & AI selected clusters between 2015 and 2021.

Cluster ID	Size	Modularity	Mean Silhouette	Focus of cluster
0	94	0.9	0.902	Building information modeling
1	49	0.8	0.813	Construction engineering management
2	49	0.7	0.954	BIM & BEM & sustainability
3	39	0.9	0.840	Artificial intelligence & smart system
4	35	0.7	0.810	BIM & ICT
5	28	0.7	0.945	BIM & internet of things (IOT)
6	25	0.7	0.870	AI & energy efficiency retrofit
7	20	0.7	0.915	AI & life cycle costing
8	17	0.7	0.875	BIM & Machine Learning

BIM and AI interoperability in construction, indicating the need for further research. The visualized clusters are well-structured and connected, indicating a promising future for the integration field.

The given networks and clusters were analyzed in Gephi using different statistical tests. The distribution of hubs and authorities in the HITS (Hyperlink-Induced Topic Search) algorithm and size distribution in modularity were calculated and tested. The 'Authority' evaluation in Gephi provides a score to each journal to indicate the value of the node's content. Gephi's statistics estimation gives each node a 'hub' value to indicate the value of external links of nodes and edges. Various metrics were analyzed in the 'Data Laboratory' and illustrated in the overview in Figure 11. The layout of Gephi was set to Yifan Hu and Yifan Hu's properties, with a convergence threshold of 1.0E−4 and Quadtree max level of 10. The analysis was based on the ranking and position of nodes. Figure 12 visualizes the Gephi analysis and data distribution by 5354 nodes and 7950 edges.

In order to manage the attraction and repulsion of nodes and edges in the visualized graph, layout algorithms have been applied. The ForceAtlas2 algorithm has been selected to illustrate the linkage of nodes. If the nodes have a connection, the network demonstrates attraction, while if the nodes have no connection or linkage, the network pushes apart and shows sprawl.

This dataset visualization depicts the strong relationship between the main nodes and keywords (BIM and AI) in the analysis. The compactness and interweaving of 'nodes and edges' in the center of the network diagram illustrate the connection and alliance between BIM and AI attributes. The spatialization of nodes and edges demonstrates the high level of centralization in the visualized network. The 'nodes and edges' in Figure 12 are evenly distributed throughout the graph without any structural holes in the visualized networks and clusters distribution. The core of the visualized network encompasses almost all the nodes and edges. The denser zone of the network represents the integrated clusters of BIM and AI.

4. Interoperability of BIM and AI

Although BIM technology has been established as a building design module, many of its fundamental properties have not yet been fully utilized. Despite its powerful foundation, BIM is a collaborative tool that requires integration with smart software or models to improve collaboration and fully demonstrate its capabilities beyond the design scope, such as building optimization.

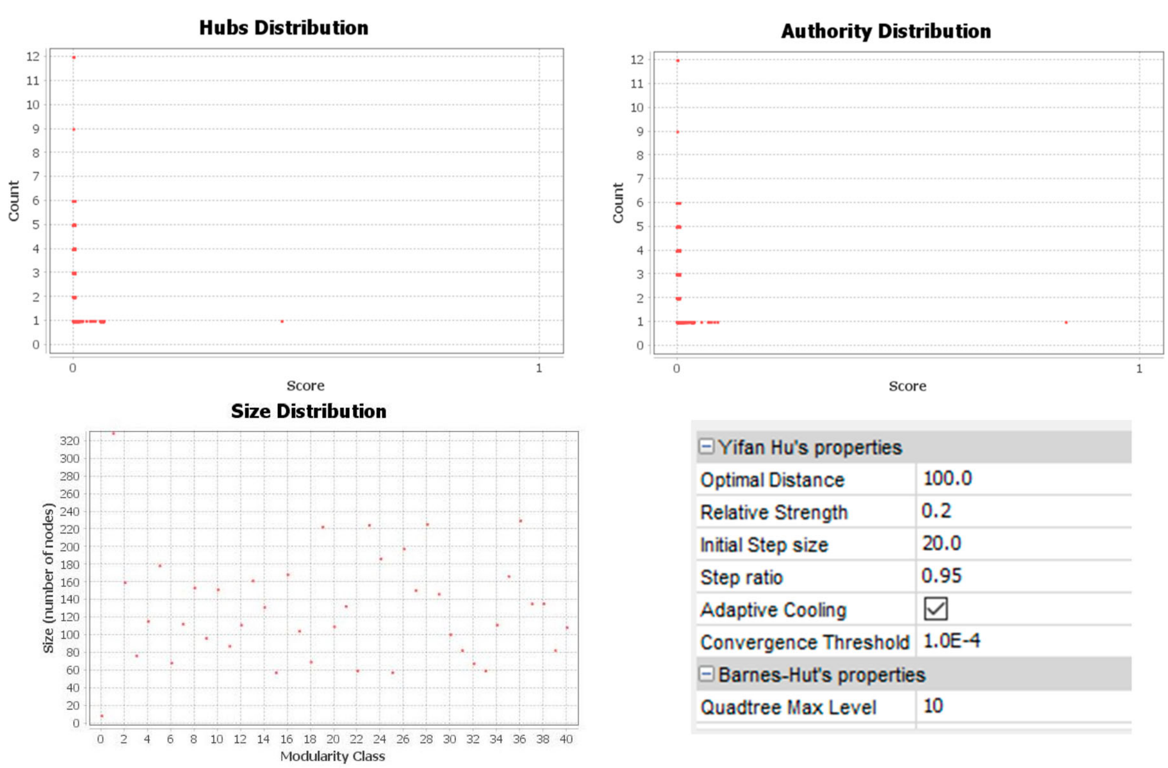

Figure 11. Modularity & HITS of BIM and AI integration in Gephi software.

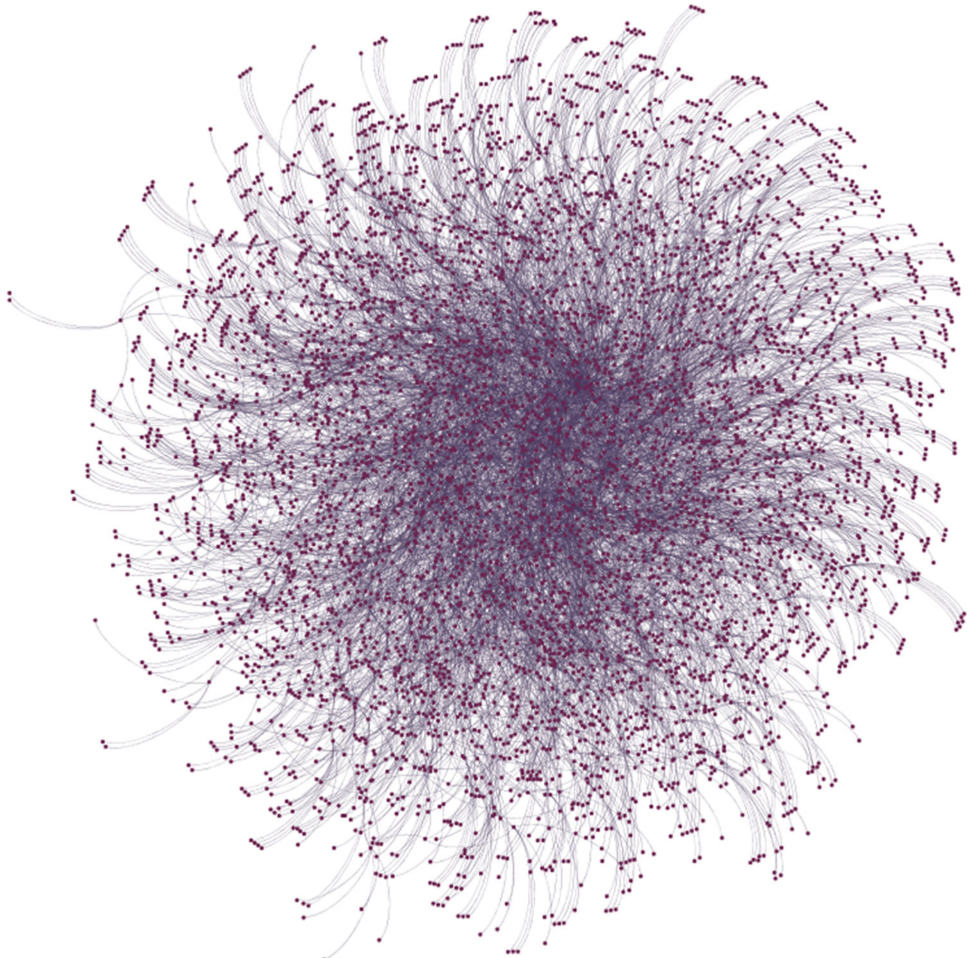

Figure 12. Visualized networks & clusters distribution of BIM and AI integration in Gephi software.

In fact, to achieve smart construction, it is necessary to ensure the interoperability and compatibility of all smart devices, engineering services, and software. The development of BIM as an internal optimizer, which mainly focuses on design, requires its integration with other technologies to automate the construction lifecycle. These mergeable models and technologies could be AI, VR/AR, and others.

The BIM software has the ability to gather and work with different types of information and data. The AI technology utilizes the data collected by BIM software to understand, analyze, and create a final model. It also provides opportunities and solutions to reduce mistakes and risks caused by human errors.

The main purpose of this section is to emphasize the need for integrating BIM and AI in construction. To achieve this purpose, the paradigms and technologies associated with BIM and AI are initially presented. Then, various methods to make BIM systems more efficient through AI are discussed.

4.1. Paradigms and technologies associated with BIM & AI

Building Information Modeling (BIM) and Artificial Intelligence (AI) are two powerful technologies that are transforming the construction industry. BIM is a 3D modeling software that allows construction professionals to visualize and simulate building designs before they are built, enabling them to detect and resolve potential issues before construction begins. AI, on the other hand, refers to the simulation of human intelligence in machines that are programed to think and act like humans.

When BIM and AI are integrated, they create a powerful combination that can bring about many benefits to the construction industry. This integration allows the use of advanced technologies like machine learning, natural language processing, and computer vision, which can help automate many construction processes and improve decision-making.

There are several paradigms and technologies associated with BIM and AI, including:

- Internet of Things (IoT): IoT is a network of interconnected devices that are embedded with sensors and software, which allows them to communicate and exchange data with each other. In the construction industry, IoT devices can be used to monitor the performance of equipment, track materials, and provide real-time data on construction site conditions.
- Big Data: Big data refers to the large volume of data that is generated on construction projects, including data on materials, labor, and equipment. When combined with AI, big data can help construction professionals analyze and understand complex data sets, identify patterns, and make more informed decisions.

- Cloud Computing (CC): CC refers to the delivery of computing services over the internet, including software, storage, and processing power. CC can provide construction professionals with access to powerful computing resources without the need for expensive hardware.
- Mobile Computing (MC): MC refers to the use of mobile devices like smartphones and tablets to access and share data on construction projects. MC can provide construction professionals with real-time access to project data, enabling them to make more informed decisions.
- Geographic Information Systems (GIS): GIS is a technology that uses location-based data to analyze and visualize information. In the construction industry, GIS can be used to map construction sites, track equipment, and analyze site conditions.
- Augmented Reality (AR): AR refers to the use of digital technology to overlay computer-generated images onto the real world. In the construction industry, AR can be used to visualize building designs in real-world settings, allowing construction professionals to see how designs will look and function before construction begins.

The hierarchical linkage of different smart devices in the construction industry that can provide real-time data and analysis to improve decision-making, optimize processes, and increase efficiency is illustrated in Figure 13. Each of these smart devices plays a vital role in the construction industry, and they work together to provide a comprehensive solution to the challenges faced in the industry.

Qualitative and bibliometric analysis and evaluation of BIM and AI in various software such as VOSviewer, Gephi, and CiteSpace indicate a lack of research on the integration of AI-BIM as a new generation of smart devices. However, there is a varied range of studies on the integration of IoT, GIS, and AR with BIM.

Literature suggests that a smart city utilizes IT to make more efficient use of physical infrastructure through the use of artificial intelligence and data analytics to support strong and healthy

Table 7. Benefits of BIM and AI interoperability.

Benefits	Focus of integration
Security and risk mitigation	Building construction is a hazardous industry, but BIM has improved site safety and implemented safety tools. With AI, BIM can predict incidents before they occur. Using machine learning, BIM can analyze images and identify risks like workers' fall hazards.
Building design	AI enables users to import project criteria or regulations to create a permanent output based on requirements. This can be applied in site analysis and plan drawing, with correlated building components that adjust automatically for accuracy.
Continuous updating	AI devices rely on experimental knowledge and learning from previous and current projects, which means AI-assisted BIM machines can provide useful data to building workers through their updating features.
Increase productivity	Investment in the construction industry has led to progress in AI-assisted BIM, resulting in a more efficient construction process that reduces inefficiencies and improves project speed.
Justification of cost changes	AI-BIM integration can manage construction projects in terms of budget and complexity of building tasks, as well as reduce the rate of volatility in budget and time schedule.

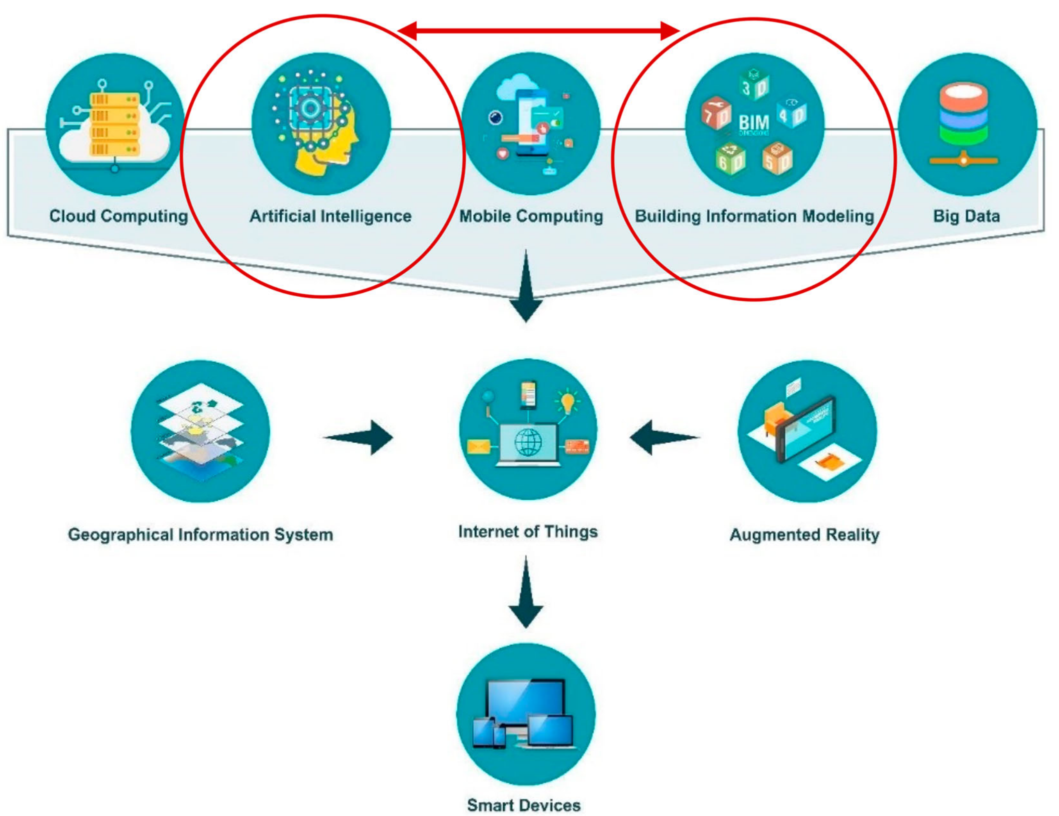

Figure 13. Paradigms and technologies associated with BIM & AI.

Table 8. Future research trends & insights.

Trend	Definition	Benefits and Impact on the Future of Construction
Smart Robotics	Any machine that can perform human tasks faster and with fewer errors. According to the Robot Institute of America, a 'robot' is a multifunctional, reprogramable manipulator designed to move material, parts, tools, or specialized devices through variable programed motions for the performance of various tasks.	Presented in all stages of a construction project Preferred in case of dangerous tasks. Cost-effective solution leading to budgets and cost optimization. Reduces workforce requirements. Enhances efficiency, accuracy, productivity, and time efficiency. Reduces wasted materials. Autonomous robots could revolutionize the construction industry during pandemics, such as COVID-19, and other disasters by using artificial intelligence.
Cloud VR/AR	AR/VR allows architects to take their plans to a whole new level, opening up new opportunities for the construction industry. Virtual Reality (VR) in the construction industry is the ability to view, walk around, and interact with a computer-generated 3D model before any construction takes place using headsets or a 'BIM Cave' (a virtual reality room). Augmented Reality (AR) in construction merges digital elements, sounds, and sensory stimuli in real-time using professional camera and sensor technologies. AR refers to the technology that brings computer-generated items into a real physical environment, such as AR glasses for construction.	Displays details and components on the building plan. Provides a deep understanding of the project. Allows for virtual tours of the building before construction, providing a clear idea of what the building would look like. Enables the composition of documentation and digital data. Monitors the construction process by those involved, such as employes, architects, engineers, and customers. Visualizes construction project data in the real world. Improves teamwork, problem-solving, error correction, and minimizes reworking. Enhances accuracy and efficiency in construction.
AIOT (Artificial Internet of Things)	'AIoT is a new paradigm of distributed sensor networks' 'Artificial intelligence of things (AIoT) is the combination of artificial intelligence (AI) technologies and the internet of things (IoT) infrastructure'. AIoT aims to make IoT functions more effective, enhance human-machine relations, and improve information management. Usage of AIoT: Robotics – Traffic Monitoring and Management – Retail Analytics – Smart Buildings, Cities, and Industries.	Increases operation efficiency by analyzing data. Increases ability to manage, produce, and analyze data in real-time. Provides professional risk management. Requires fewer workforces for data monitoring. Reduces time and costs due to AI. Increases the scale of connected devices to optimize the process. Enables the possibility of having 5G for fast transfer of large-scale data. Sequential steps of AIoT: Data collection → Data transmission → Data processing → Data prediction → Actionable insights
Digital Twins	A digital twin combines real information from physical built elements (e.g. a building or railroad network) with its digital visualization to provide insights during the project lifecycle. The data collected in a digital twin for a high-rise office building includes information on lift products, servicing schedules, and access to security protocols. The database in a digital twin for the railroad network could include train locations and accessibility.	Implementing Supreme Projects. Optimizing operations. Reducing costs. Increasing operational efficiency. Creating successful experiences. Reflecting reality in 2D or 3D models. Collecting spatial data for all businesses, including architecture, etc. Preventing rework. Increasing cooperation. Creating the 'Single Source of Truth (SSOT)', which supports all construction operations and tracks the process status through BIM.
4D printing	4D printing, also known as smart printing, is a novel science and technology that applies the properties of self-activation to 3D-printed elements, which are time-dependent. This method allows for the programming of elements to have additional attributes that enable them to temporally transform and modify performance during the time. The programed features of self-repair, self-change, and self-adjustment perform on objects autonomously based on environmental stimuli like heat, water, light, wind, or electricity. 4D printing is performed without human or mechanical intervention. 4D printing needs further investigation and improvement, and would not be accessible to everyone'. 4D printing is a combination of smart materials, a 3D printer, and a programed self-administered plan.	Compressing larger objects than the printer allows. 'Size-changing' capabilities. The possibility of using smart and new materials with innovative features. A 'self-repairing system'. 'Self-assembling furniture': Transforming a flat board into a chair by adding water or light. Optimizing energy consumption. Possibility of using active structures in construction. Possibility of 'self-repair'. Possibility of 'self-adaptability'. Possibility of 'self-construction'. Having origami-like structures.
Blockchain	'Blockchain technology' is a type of digital ledger technology (DLT) that has various features, including decentralization, distribution, and immutability. This technology is used to record transactions and track finances on different computers, with the recorded data on the blocks linked together like a chain. Blockchain networks can be public, private, or built by an organization.	Creating a unique source of truth for all parts of a building project. Simplifying construction project management. Simplifying long-term maintenance systems. Greater trust and security through coding. Improving productivity and sustainability. Ensuring data accuracy and achieving more efficiencies. Facilitating immediate collaboration through blockchain connection with BIM. Scalability and improving project transparency. Saving time by eliminating data recording. Using smart contracts to speed up transactions, reduce costs, manage risks, and mitigate complexity. Recording unsafe conditions. Speeding up the payment process.

economic, social, and cultural development in the construction industry. AI and BIM are used together as tools for evaluating large datasets.

Although the future of the construction industry is promising, there are a number of basic problems and issues that need to be solved. The integration of AI and BIM in construction is being used to present effective methods to solve these problems and reduce the risk taxonomy in construction, such as human errors. This integration can focus on an optimal combination of topological data, building information, Internet of Things (IoT) sensors, and machine learning. According to systematic analysis and various surveys, there is a limited range of studies and publications focusing on developing a novel approach that combines these two smart devices to help the construction industry. Due to little research on AI in BIM, this topic is hot and new in construction literature. A survey and evaluation suggest that China and the United States are the two leading countries in these domains, with other countries following suit.

Overall, the integration of BIM and smart devices like AI can bring significant benefits to the construction industry, and future research in this area should focus on further exploring the potential of these technologies and identifying new opportunities for innovation and improvement (see Table 7).

5. Future research trends and insights

The authors arrived at the 'Future Research Trends and Insights' through a comprehensive review of the literature on BIM and AI in the construction industry. They examined the current status quo of BIM and AI in the construction industry and identified the challenges facing the industry, such as low productivity, overbudget, and unqualified workforces. They also reviewed the potential solutions offered by digital fabrication, smart devices, and automation. The authors then conducted a systematic literature review of over 19,742 research papers published between 2015 and 2022 to identify the latest trends and insights in the field.

The authors analyzed the literature using scientometric and bibliometric methods and performed qualitative analyzes of the BIM and AI domains through the co-occurrence method, science mapping, and network visualization. Based on their analysis, they suggest that the integration of AI and BIM will be a great paradigm in the construction industry, especially in the operation and management of construction and design.

To address the risk and complexity in the construction industry, the authors suggest six domains of insights and future trends, including smart robotics, cloud VR/AR, AIoT (Artificial Intelligence of Things), digital twins, 4D printing, and blockchain. These six domains of insights and future trends are described in detail in Table 8 of to provide readers with more information.

6. Conclusions

Based on the systematic review of the current state of BIM and AI in the construction industry, it is evident that integrating these two technologies has the potential to bring significant benefits, such as improved decision-making, process optimization, and increased efficiency. The construction industry faces various challenges such as low productivity, cost overruns, and unskilled labor forces, and digital fabrication, smart devices, and automation are seen as potential solutions to these issues. Although integrating BIM and AI is challenging, it could be a significant paradigm shift in the construction industry.

The study evaluated over 19,742 research papers between 2015 and 2022 using scientometric and bibliometric analysis. Qualitative analyzes were conducted to evaluate BIM and AI domains using the co-occurrence method, science mapping, and network visualization. The SLR was conducted in five stages: programming, organizing, categorizing, describing, and reporting, and both quantitative and qualitative analyzes were considered using VOSviewer, CiteSpace, and Gephi software.

The analysis indicates that there are various smart devices that can be integrated with BIM, and one type of smart device alone cannot solve the challenges faced by the construction industry. Integrating AI or ML with BIM could be a great chance to level up the construction industry and building lifecycle and solve the limitations of BIM software.

Machine learning has become far more efficient and widely accessible, and in the construction domain, AI has a transformative effect compared with traditional and multi-purpose techniques. The bottleneck now is in architecture and building construction, competitive advantage, innovation, implementation, and the building's future imagination.

Integrating BIM and AI requires careful consideration of various factors, such as data integration, software compatibility, and project objectives. AI can be integrated into BIM through the use of machine learning algorithms. Machine learning algorithms use statistical techniques to enable the computer system to learn from data, identify patterns, and make predictions. In BIM, machine learning algorithms can be used to predict the performance of building systems, identify potential design issues, and optimize building performance.

Overall, integrating BIM and AI can provide numerous benefits for the construction industry, including improved decision-making, increased efficiency, and enhanced building performance. By standardizing data, using machine learning algorithms, implementing natural language processing, using virtual assistants, utilizing optimization algorithms, and leveraging cloud computing, the integration of BIM and AI can transform the construction industry and lead to significant advancements in building design and construction.

The study highlights the need for further research on the interoperability of BIM and AI and their potential benefits, such as energy consumption, time and cost estimation, long-term vision, and integration of data using BIM. It is evident that AI and machine learning should be integrated into BIM for building and construction estimation purposes. The paper provides insights into future research trends and their interoperability with digital devices and can serve as a guide for researchers and practitioners in the construction industry.

At first glance, the idea that AI and machine learning could and should be integrated into BIM for building and construction estimation purposes may seem almost far-fetched. In order to establish the link from the upstream to downstream of the theoretical background of this research, the relevant drivers of BIM and AI and their mutual interactions, such as applications, types, and usages, were briefly reviewed as the state of the art.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data available on request from the authors. The data that support the findings of this study are available from the corresponding author, [author initials], upon reasonable request. All software files used in the systematic literature review are available.

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Appendix

Nomenclature

Abbreviations: IRM: Integration Research Method, LS: Library Study, CS: Case Study, FS: Field Survey, SA: Simulation Analysis, LM: Laboratory Measurements, DA: Descriptive Analytics, NA: Numerical Analysis; EA: Experimental Analysis, HA: Holistic Analysis, DM: Data Mining, DAP: Data Acquisition and Preprocessing; PE: Performance Evaluation, LR: Literature Review, SR: Systematic Review, SA: Scientometric Analysis, QA: Qualitative Analysis, TA: Theoretical Review, IR: Inductive Reasoning, BM: Bibliometrics Method, KA: keywords Analysis, PA: Parametric Analyzes, AP: Application Analyzes, CA: Content Analysis, HS: Holistic Simulation, PRO: Peer-Review Outlets, SE: Synthesize Evidence, DE: Data Evaluation, MAT: Medial Axis Transform, TDVRP: Time-Dependent Vehicle Routing Problem, C: Comparing, PS: Pattern Selection, I: Identification, O: Organization, C: Categorize, DMADV: Six Sigma's

Define-Measure Analyze-Design-Verify, SOA: State Of the Art, TF: TensorFlow, P: Python, AR: Autodesk Revit, NS: Numerical Simulation, SA: Statistic App, OS: Open Studio, GBS: Green Building Studio, IES: Integrated Environmental Solutions, DB: Design Builder, SAT: Static Analytical Tool, PLC: Product Life Cycle, EMB: Energy Management Based, DES: Discrete Event Simulation, PSO: Particle Swarm Optimization, EPSE: Energy Plus Simulation Engine, CEM: Construction Engineering And Management, L: Logs, LCE-B: Life Cycle Energy Of Buildings, GD: Geographical Distributions, CM: Conceptual Model, C/S: Clint/Server, B/S: Browser/Server, LEED: Leadership In Energy And Environmental Design, BREEAM: 'Building Research Establishment Environmental Assessment Method', SOA: Service-Oriented Architecture, BS: Energy Simulation, CF: Creation Of a Framework, LOD: Level Of Development, MVD: Model View Definition, OF: Objective Function, EST: Energy- Simulation Tool, CBF: Construction Business Function, IE: Information Exchange, DR: Design Review, ERQC: Energy-Related Quality Control, LCC: Life-Cycle Commissioning, RTO: Real-Time Operation, MM: Maintenance Management, PF: Path Finding, EIA: Emergency Information Access, RA: Residential Apartments, EA: Evacuation Assessment, ERP: Escape Route Planning, SE: Safety Education, EM: Equipment Maintenance, E: Energy, KRR: Knowledge Representation And Reasoning, IF: Information Fusion, CV: Computer Vision, NLP: Natural Language Processing, IO: Intelligence Optimization, PM: Process Mining, HP: Hyper Parameters, CT: Construction Tech, RDP: Representing Design And Planning, BF: BIM to-Field, FB: Field-to-BIM, LCA: Life Cycle Assessment, LCEA: Life Cycle Energy Analysis, LCCA: Life Cycle Cost Analysis, CE: Circular Economy, BE: Building Energy, BIM: Building Information Modeling, BCNC: Based Construction Networks Collaboration, AE: Architectural Engineering, AI: Artificial Intelligence, DB: Database, DO: Design Optimization, GBAS: Green Building Assessment Schemes, IoT: Internet of Things, SB: Smart Building, SC: Smart City, SBE: Smart Built Environment, EP: Energy Plus, DP: Design Process, MPS: Manufacturing Process Simulation, EU: Energy Use. S: Sustainability, DC: Developing Countries, IS: Implementation Strategy. IFC: Industry Foundation Class, O&M: Operation & Management, IESM: Indoor Emergency Spatial Model, MACA: Modal Assurance Criteria Algorithms. FM: Facilities Management, UBEM: Urban Building Energy Modeling. Techniques: ANN: Artificial Neural Networks, SVM: Support Vector Machines, FS: Fuzzy System, CBR: Case Based Reasoning, ES: Expert Systems, DSS: Decision Support Systems, GA: Genetic Algorithm, ACO: Ant Colony Optimization, ABC: Artificial Bee Colony, PS: Particle Swarm, LS: Least Square.