A BIM-based Collaboration Implementation on Construction Projects: A Bibliometric Analysis and Systematic Literature Review

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Abstract: Implementing collaboration-based on building information modelling (BIM) in construction projects can improve project effectiveness and efficiency. Nevertheless, its impact is often less significant than anticipated, with additional responsibilities on stakeholders. To ensure the successful implementation of BIM-based collaboration, it is crucial to have a well-defined strategic direction. This study conducted a literature review to evaluate the possible improvements in collaboration that BIM could offer to various aspects of construction project management. The Scopus database was used to collect previous studies. The studies were then analysed quantitatively using the bibliometric method. A qualitative assessment was conducted using systematic review procedures, involving careful data cleaning and thorough manual selection. Biblioshiny and VOSviewer applications were used to aid with descriptive analysis and data visualisation. The review found that utilising BIM-based collaboration in construction projects could enhance four key aspects: design process collaboration, stakeholders' workflow integration, project management strategies and digital technologies for data and information management. These findings suggest creating BIM implementation strategies that prioritise these aspects to ensure seamless adaptation across stakeholders. Furthermore, it is advisable for future policy initiatives to focus on the specific implementation of BIM-based collaboration, adapting standards to fit local circumstances. This study could contribute to the body of knowledge of BIM and provide a reference for academics and practitioners to improve the implementation of BIM-based collaboration on construction projects.

Keywords: Building information modelling (BIM), Collaboration, Construction project, Bibliometric analysis, Systematic literature review

INTRODUCTION

Building information modelling (BIM) integrates technological advancements into the management process of construction projects, which is essential to promoting its adoption in all project activities. This involves adeptly managing complexity, coordinating multidisciplinary teams and ensuring compliance with contractual requirements concerning time, quality and cost. However, despite its essentials, several challenges emerge during its implementation, such as technical issues, ambiguity regarding responsibilities, inadequate

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communication strategies for adopting BIM in traditional organisational structures and a lack of trust in the environment (Liu, Van Nederveen and Hertogh, 2017). As a result, BIM often fails to achieve optimal effectiveness and efficiency.

Collaboration should be enhanced as one decisive factor in BIM implementation. Hence, it is crucial to carefully examine the implementation of BIM collaboration to determine its natural and beneficial influence on the development of construction projects, challenging the view that BIM simply adds extra tasks to the workload. Consequently, there is a clear need for research into the practical application of BIM-based collaboration within construction project activities, particularly in identifying areas where collaboration can be improved. Nonetheless, various research studies have been conducted to review topics related to collaboration in BIM. For example, research investigating the use of digital collaboration tools in infrastructure projects found that the adoption and progress of this technology were characterised by visualisation, coordination, automation, integration and transformation (Ibrahim, 2013). A separate study examined research on collaboration in BIM-enabled construction projects and concluded that existing studies were sporadic, isolated and focused on narrow, limited and discontinuous areas of collaboration (Oraee et al., 2017b). Another study that focused on BIM-based collaboration showed that most research focused on the role of technology in collaboration, whereas project and managerial aspects were not given enough attention (Oraee et al., 2017a).

A recent study suggested that articles in the research field of BIM can be classified into five categories: collaboration and sustainability-based, BIM adoption, BIM implementation at the process level, BIM implementation in-country and at the industry level and BIM integration (Ozturk, 2020). On the other hand, a study has identified a theme that indicates the collaboration of BIM, IPD and lean construction in existing maturity models, including customer satisfaction, waste minimisation, lean practices and cultural and legal aspects (Rashidian et al., 2024). Additionally, a study identified key research areas in BIM and found that technological development may enhance collaboration among stakeholders, thereby mitigating the risk of uncertain information (Ali, Alhajlah and Kassem, 2022). Another study focused on social collaboration among BIM actors in construction projects, which is directly influenced by human behaviours and directly influenced by contractual, policy, strategy, management support and process (Noor, Ibrahim and Belayutham, 2023). Furthermore, a different study documented BIM functionality in the architecture, engineering and construction industry, which highlighted not only enhancing communication and collaboration but also simulating construction stages, virtually presenting buildings and sites, visualising progress, improving safety, generating accurate cost estimates quickly and serving as a platform for various technological tools during construction (Toyin and Mewomo, 2023).

In general, prior studies have not addressed the practical implementation of BIM-based collaboration in ongoing construction projects, nor have they identified the specific areas of construction management that could be enhanced through the application of BIM-based collaboration. These areas are crucial for establishing the objectives of utilising BIM-based collaboration in building projects and guaranteeing its effective implementation.

Researchers utilised diverse methodologies in literature reviews to attain various purposes. In one study, document analysis was used to gather information and data necessary to support the development of a research topic (Omar, Mahdjoubi and Khosrowshahi, 2014). This method can be extended to critical literature reviews, which are conducted to provide a clear picture of related research, explore specific issues and fill knowledge gaps (Elghaish, Abrishami and Hosseini, 2021). Another method to develop a thorough literature investigation is scientometric analysis by mapping published works to obtain objective insights into current and future research trends (Ozturk, 2020). However, semi-systematic literature reviews, which are performed by collecting relevant literature using specified keywords and examining and categorising current research issues, can map the current knowledge development and investigate potential future research (Handayani et al., 2021). Furthermore, systematic reviews have been utilised to distil scientific information into easily digestible content, allowing researchers to assess consistency and adequacy and identify gaps in the literature on a topic (Oraee et al., 2017b). Meanwhile, bibliometric analysis is used to map and visualise scientific data, analyse the intellectual landscape and achieve research goals (Oraee et al., 2017a). Some researchers have even employed mixed-methods, which combine quantitative and qualitative methodologies, to leverage both strengths and mitigate weaknesses, thereby providing an in-depth understanding of the topic being studied (Yin et al., 2019).

The present study aimed to explore the elements of construction projects that could be improved through BIM-based collaboration. A bibliometric approach and a systematic literature review were employed, as they are proven reliable and have been widely used in previous research. The findings of this study would further increase the existing knowledge of BIM and help construction professionals or specialists improve the use of BIM-based collaboration in construction projects.

METHODOLOGY

This section examines techniques for compiling and executing bibliometric analyses and systematic literature reviews. Previous studies have enhanced these two methods when conducting literature reviews. Bibliometric analysis has been used to map and visualise scientific data, analyse the intellectual landscape and achieve research goals (Oraee et al., 2017a). Meanwhile, systematic reviews have been utilised to distil scientific information into easily digestible content, allowing researchers to assess consistency and adequacy and identify gaps in the literature on a topic (Oraee et al., 2017b). Some researchers even combined these methods as a mixed-methods design to leverage both strengths and mitigate weaknesses, providing an in-depth understanding of the topic being studied (Yin et al., 2019). Given the complementary nature of these methods and the combined strengths of both quantitative and qualitative analysis (Johnson and Onwuegbuzie, 2004), a mixed-methods approach was adopted in this study. This approach, which involves validating qualitative research findings or vice versa, is also known as triangulation (Zou, Sunindijo and Dainty, 2014). The mixed-methods approach is particularly well-suited for this research, where understanding both the quantitative scope and qualitative depth of existing studies was important to address research gaps and refine future directions.

Bibliometric analysis has been recognised as a valuable technique for decoding and mapping bodies of scientific knowledge by illustrating the nuances of the evolution of fields by comprehending enormous amounts of unstructured data rigorously (Donthu et al., 2021). This approach helped identify the knowledge domain and research trend (Yin et al., 2019) regarding the implementation of BIM-based collaboration on construction projects. However, bibliometric analysis alone does not provide detailed insights into the context, methodologies and underlying principles of research findings. Consequently, a systematic literature review that focuses on synthesising the research questions, methodologies, main findings and defining gaps in existing studies provides a qualitative examination of the literature (Linnenluecke, Marrone and Singh, 2020). However, systematic reviews are susceptible to researcher bias due to their reliance on subjective interpretation. Such an approach contrasts with bibliometric analysis, which relies on quantitative techniques to avoid or reduce these biases (Donthu et al., 2021).

Data Retrieval and Filtering

Various methodologies were explored to gather and analyse bibliographic data and comprehensively review existing literature, as illustrated in Figure 1. The data source was taken from the Scopus dataset, which is recognised for (1) its broad range, covering nearly 16,000 publications that surpass other international databases, (2) open access (no subscription) for individual scientists and scientific journals (Guz and Rushchitsky, 2009) and (3) prominent journal coverage in the fields of life sciences, physical sciences and technology (Singh et al., 2021).

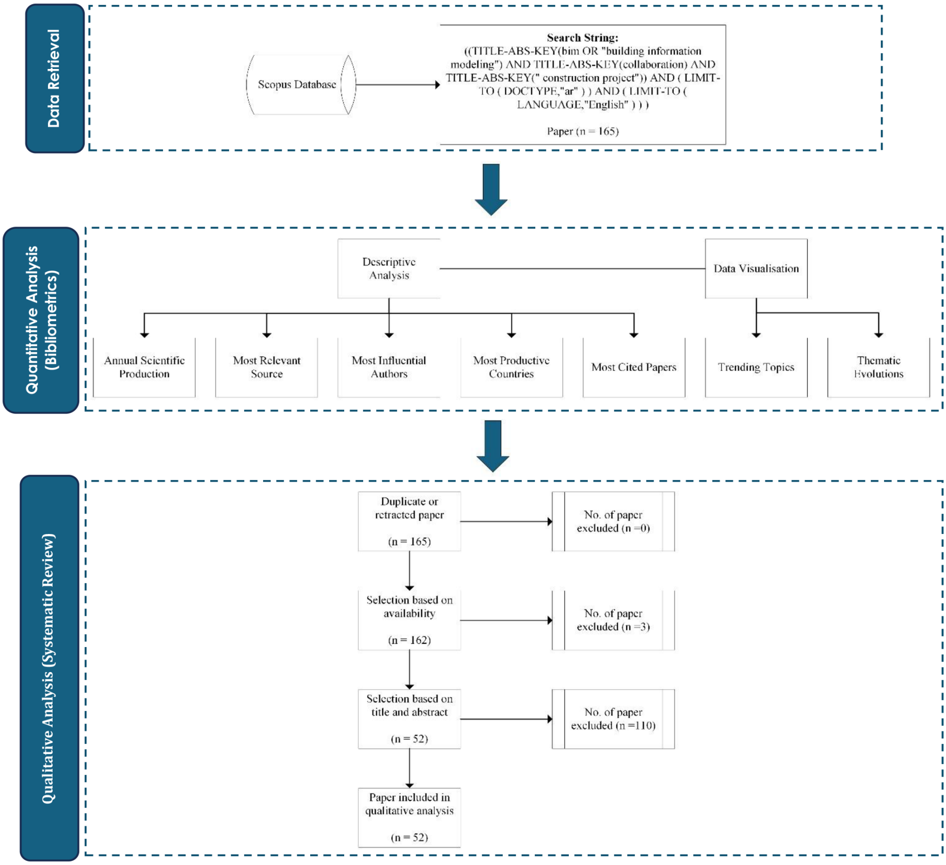

Figure 1. Three-steps research framework

Table 1 displays the steps involved in this study. The steps began with identifying specific terms or phrases that aligned with the predefined criteria to be used to search. Several keywords were selected to filter out articles that matched the criteria on Scopus. To illustrate, for document type, keywords "Articles" and language "English" shaped the structure of the search string ((TITLE-ABS-KEY(bim OR "building information modelling") AND TITLE-ABS-KEY(collaboration) AND TITLE-ABS-KEY ("construction project"))AND(LIMIT-TO(DOCTYPE,"ar"))AND(LIMIT-TO(LANGUAGE,"English"))). This query resulted in 165 articles, which were subsequently analysed.

Table 1. Inclusion criteria of the article selection

Criteria	Inclusion
Publication type	Primary research articles, peer-reviewed
Availability	Available online as full text
Language	English
Period	2010 to 2023

Following the completion of quantitative analysis, the research proceeded with qualitative analysis. Initially, data cleaning was performed using a manual selection method to exclude articles that did not meet the inclusion criteria. Articles involving non-primary research (e.g., literature review, survey, identification and investigation) and those unavailable online in full text were excluded. This screening process, executed on Microsoft Excel and Zotero software, resulted in 52 articles meeting the criteria out of the initial 165.

Bibliometric Analysis

The dataset was subjected to analysis using one of the bibliometric software applications, namely "Biblioshiny". Biblioshiny, which is included in the Bibliometrix package, is a free, web-based interface integrated with the R operating system, where R is free, open-source software. It is a unique open-source tool designed to conduct comprehensive science mapping analysis and support the recommended workflow for bibliometric analysis (Aria and Cuccurullo, 2017). The utilisation of Biblioshiny for bibliometric analysis involved several actions. Firstly, descriptive analysis was performed on the bibliographic data framework, which presented data on annual scientific production, the most relevant sources, the most influential authors, the most productive countries and the most cited articles. Secondly, data visualisation displayed trending topics and conceptual structure mapping, specifically depicting the thematic evolution throughout the dataset (Aria and Cuccurullo, 2017).

Systematic Literature Review

The data underwent a manual cleansing process where the titles and abstracts of each article were selected. Articles that did not meet the inclusion criteria, such as non-primary research articles (including literature reviews, investigations, identifications and factor analyses) and those not accessible online in full text, were excluded. The use of Microsoft Excel and Zotero, a free and open-source software designed specifically for managing bibliographic information and related research resources, aided in this process. Through this approach, 52 articles were identified that aligned with the criteria for further discussion based on their relevance to the topic title and the cluster keywords linked to each article. These results were later discussed in the results section, highlighting future research needs in BIM-based collaboration within construction projects.

The subsequent step involved a systematic literature review. Initially, the co-occurrence network of article keywords was mapped using VOSviewer. VOSviewer is a computer programme that is freely available for creating and viewing bibliometric maps and it focuses on the graphical representation of these maps compared to other programmes such as SPSS and Pajek (Van Eck and Waltman, 2010). In addition to its effective visualisations, VOSviewer can also load and import data from various sources (Moral-Muñoz et al., 2020). VOSviewer generated keyword maps using a co-occurrence matrix, involving three distinct processes. Firstly, the similarity matrix was calculated. Secondly, the VOS mapping technique was applied. Thirdly, transformations (translation, rotation and reflection) were applied to ensure that VOSviewer yielded consistent results (Van Eck and Waltman, 2010). The mapping results generated by VOSviewer depicted the connections between keywords found in the article dataset, with clusters distinguished by assorted colours. The subsequent step involved interpreting the data by assigning general topic names to each cluster.

RESULTS AND FINDINGS

This section provides insights into how quantitative and qualitative data are analysed and highlights noteworthy findings uncovered during the research process.

Descriptive Analysis: Scientific Production and Countries

Selecting the “Article” category within the Scopus filter indicated the preference only to examine journal publications. This decision was influenced by the understanding that journal articles typically offer greater comprehensiveness, detail and depth compared to conference articles and they undergo a rigorous peer-review process to ensure the research’s quality, validity and impact (Saini, 2023). A total of 165 articles relating to the keyword “BIM collaboration on construction projects” were identified during the data collection process.

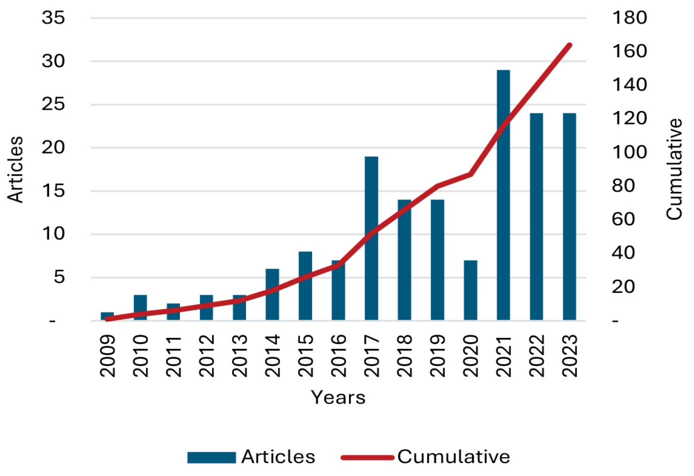

Figure 2. Annual scientific production output

Figure 2 illustrates annual scientific production data addressing BIM collaboration in construction projects. The publications showed a general upward trend from 2009 onwards. However, there was a noticeable decline from 2019 to 2020. The decline was attributed to the COVID-19 outbreak. The outbreak affected the construction business sector by causing a shift in organisational work patterns, delaying construction projects and reducing workforce capacity (Iqbal et al., 2021). The most significant increase in scientific research was in 2021, following the declaration that the COVID-19 outbreak was over. The number of publications surpassed 20 for the first time, indicating a positive trend up to the present.

The study found 43 recognised countries as producers of articles on BIM-based collaboration in construction projects (as shown in Figure 3). Europe and Asia were the dominant continents, with 17 and 16 countries, respectively. In North America, two countries (i.e., the USA and Canada) contributed, while three countries in the South did (i.e., Peru, Brazil and Chile). In Africa, four countries contributed (i.e., South Africa, Cameroon, Nigeria and Ethiopia), while in Oceania, only one country (i.e., Australia) contributed an article. China produced the most articles, with 108 articles, significantly surpassing other nations. Such occurrences were due to China's significant adoption of BIM policies, particularly between 2016 and 2018, resulting in 138 policies produced (Yang, Shao and Cao, 2024). These policies played a crucial role in fostering the progression of BIM and associated technologies as innovative solutions within the construction industry. Malaysia recorded 84 articles, the UK with 72 articles, the USA with 57 articles and Australia with 47 articles, while the rest have fewer than 20 research articles.

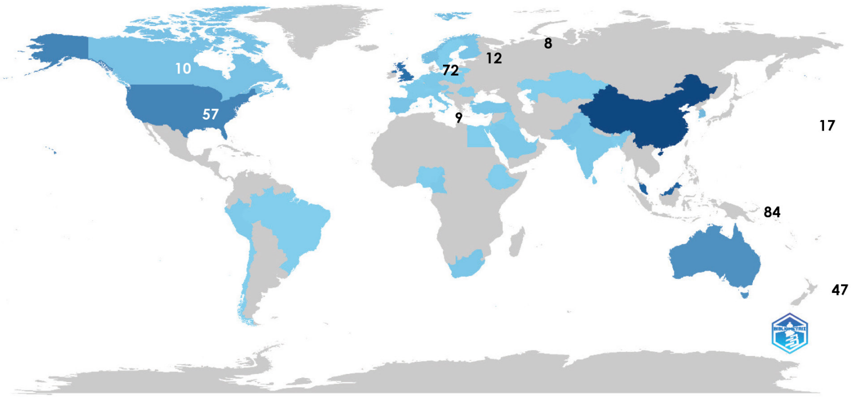

Figure 3. The most productive countries' output

China and Malaysia initiated their production beginning in 2013. In contrast, Australia, the UK and the USA had earlier engaged in research on BIM collaboration in construction projects with four, seven and eight articles, respectively. The data reflected the rapid development of research on this topic in China and Malaysia over the last decade.

Data Visualisation: Trend and Evolution of the Topics

Researching the evolving trend of BIM-based collaboration in construction projects has been intriguing. The analysis was conducted using the Biblioshiny software, which produced graphical data outputs as shown in Figure 4.

The investigation into "building information modelling" as a research subject began in 2012 to support the construction industry. By 2017, research focused on BIM's capabilities, particularly collaboration and interoperability in structural design. This period saw discussions on methods to accelerate the process of design coordination between architects and structural design software. From 2018 to 2019, research shifted towards technology utilisation, such as digital storage, as a centralised management hub for information exchange among project stakeholders. The focus was on enhancing the efficiency of construction project management processes. In the 2020 to 2022 period, research concentrated on evaluating BIM's impact on construction project effectiveness, efficiency and integration across life cycles. Discussions extended to lean concepts, supply chain enhancement and utilisation of blockchain technology in decision-making support. In more recent years, post-2022, researchers have focused on the impacts of BIM-based collaboration on sustainable development in construction projects. It suggests ongoing research and development that focuses on tackling current industry difficulties and promoting sustainable practices.

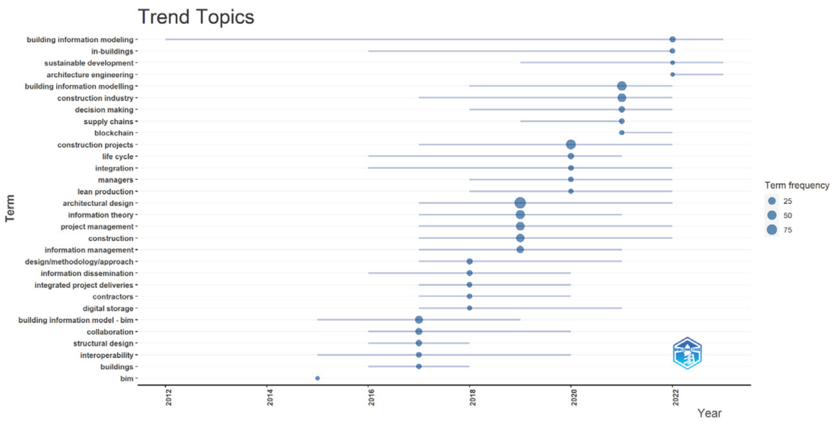

Figure 4. Trending topics in research development's output

The trend topic graph, a scatter plot with time on the x-axis and topics on the y-axis, illustrated the progression of research interests. Each bubble represented a topic, with its size reflecting the frequency of occurrence and grey lines delineating the quartiles of occurrence distribution.

In addition, by utilising a clustering method on the keyword network, various themes within a specific domain were highlighted. Each cluster/theme was depicted on a dedicated plot, known as a thematic map, as shown in Figure 5. Centrality functioned as a measure of the theme's relevance, while density assessed the theme's level of development. Each bubble in the diagram represents a network cluster and the names of the bubbles consist of terms from the cluster with higher occurrence values. The size of each bubble was directly proportional to the frequency of words within the cluster (*Bibliometrix.org*, 2023).

By dividing the period into different intervals, one could examine and map the evolution of topics over time to represent them as a trajectory. This approach is called longitudinal thematic map analysis, alternatively termed thematic evolution (*Bibliometrix.org*, 2023). Based on the publication distribution graph per year, time was divided into three sections with two cut points, specifically 2015 and 2020. From Biblioshiny, there were two views: the thematic evolution of all time slices and the thematic map of each time slice. From 2009 to 2024, developments related to BIM-based collaboration on construction projects could be observed.

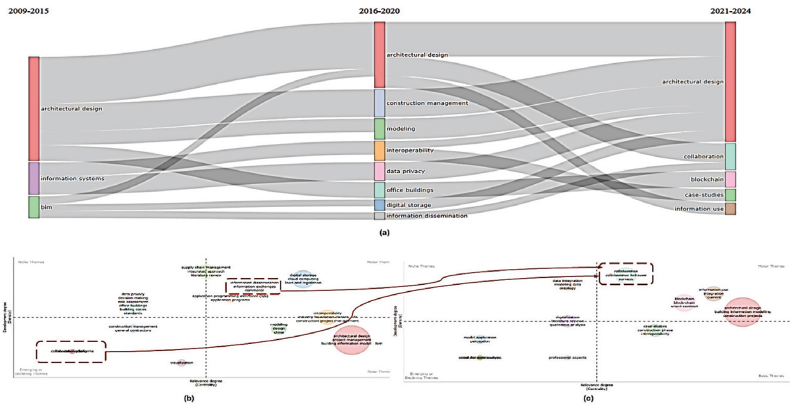

Figure 5. (a) Thematic evolution in research development's output, (b) Thematic map for time slice 2 (from 2016 to 2020) and (c) Thematic map for time slice 3 (from 2021 to 2024)

Figure 5(a) depicts the thematic evolution of articles on BIM-based collaboration in construction projects. This evolution was divided into three time slices: the first from 2009 to 2015, the second from 2016 to 2020 and the third from 2021 to 2024. During the initial time slice, three primary sets of keywords emerged: (1) architectural design, (2) information systems and (3) BIM. The thematic evolution map was detailed by a thematic map as depicted in Figures 5(b) and 5(c). Upon an early examination of the thematic map in the first time slice, these keyword groups aligned with the basic theme, motor theme and niche theme consecutively. Moving to the second time slice, these keyword groups showed a tendency to either converge (e.g., architectural design and BIM merging into architectural design) or diverge (e.g., information systems branching into interoperability and data privacy). This pattern persisted in subsequent time slices, demonstrating the phenomenon referred to as the theme evolution over time.

The reading technique adopted aided the emergence of a collaboration theme. In the second time slice, the BIM theme diverged to include digital storage, information dissemination and architectural design. This evolution led to the formation of the collaboration theme in the third time slice. It was clear that the implementation of BIM-based collaboration only became widespread from 2021 onwards, establishing itself as a motor theme, despite initial discussions beginning in 2017. However, these early discussions did not gain much traction. It was observed that the architectural design theme had become overly dominant in BIM-related research until it became the origin of the collaboration theme, which started gaining interest and was subsequently explored by researchers.

Co-occurrence Network Mapping

Co-occurrence network mapping was conducted on VOSviewer. The technique involved drawing a map using bibliographic data, extracting data from bibliographic database files (e.g., the Scopus file in CSV format), selecting the co-occurrence analysis type with the analysis unit set to all keywords and employing the complete counting method. A threshold was set at a minimum keyword occurrence of 3. A total of 48 keywords, out of the initial 583 keywords, met the threshold criteria. These keywords were used to generate a network visualisation displaying the interconnected keywords, as presented in Figure 6.

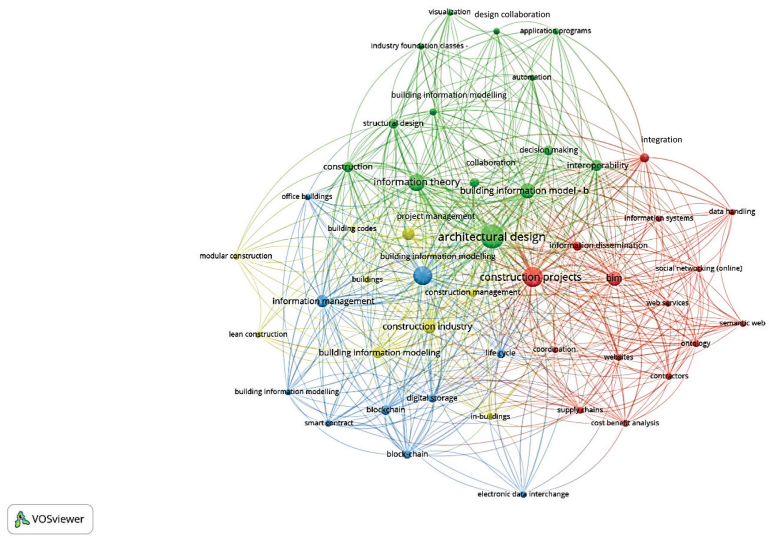

Figure 6. Co-occurrence map and network of keywords' output

The VOSviewer map was constructed based on several principles, including circles, labels, distances, lines and colours. A circle visually represented each term and specific terms were additionally labelled. The scale of a term reflected the frequency of its occurrence in publications, while the distance between two terms provided an approximate measure of their relationship. The interrelation of terms was established through their co-occurrence in publications. In other words, a higher frequency of co-occurrence in publications indicated a stronger relationship between the two terms (Van Eck and Waltman, 2017). The most robust relationships were visually depicted using curved lines. Furthermore, colours were employed to denote groups of terms that had significant associations with each other (Van Eck and Waltman, 2017).

The existing body of research on BIM collaboration in construction projects primarily focuses on the phrase “Architectural design”. Other keywords that were strongly associated with this topic were BIM, construction projects, construction industry, construction, project management, information theory and collaboration. There were four notable main clusters, each characterised by distinct colours (green, blue, red and yellow). Each cluster and corresponding keyword provides significant opportunities for further analysis.

Systematic Literature Review: Cluster Analysis

As an initial qualitative analysis, data cleaning was performed using a manual selection method to exclude articles that did not meet the inclusion criteria. Articles involving non-primary research (e.g., literature review, survey, identification and investigation) and those unavailable online in full text were excluded. This screening process was executed using Microsoft Excel and Zotero software by reading the article title and abstract, which resulted in 52 articles meeting the criteria out of the initial 165 articles. The 52 articles were then used to draw co-occurrence mapping before further analysis was done by clustering keywords based on colours. The green represented the design process collaboration cluster, the red represented the stakeholders' workflow integration, the yellow represented the project management strategies cluster and the blue represented the digital technologies for the data and information management cluster.

Cluster 1: BIM-based for the design process collaboration

The activities involved in this field included ensuring interoperability with industry foundation classes (IFC), utilising cloud-based technologies for design, adopting design automation, interdisciplinary design integration and other areas of design collaboration.

Numerous studies have aimed to optimise design collaboration processes. They were considered a reliable solution for handling complex and extensive information models and for integrating software with standard formats, such as IFC, which often led to data loss and redundancy (Steel, Drogemuller and Toth, 2012). Similarly, a study was conducted by transforming architectural models into structural design tools by establishing an IFC-based integrated information model and algorithms to ensure consistent data representation across different structural analysis applications (Hu et al., 2016). On the other hand, a study explored a new restructuring algorithm and a bulk-loading method to import IFC data into the server, which could improve the import speed process (Cho, Won and Ham, 2018). So, design process collaboration could utilise the IFC format to reduce data loss and redundancy, ensuring accurate integration across different software applications.

With the advancement of BIM technology, collaboration in the design process has become increasingly complex, requiring the participation of design experts in the collaborative design process through cloud-based technologies. Cloud-based technologies offer solutions for improving real-time design process collaboration by enabling synchronised data sharing and efficient management of information, reviews and design changes. A study that researched real-time collaborative design processes facilitated by cloud computing enabled synchronised data sharing among multiple computers (Kim, Ji and Jun, 2017). Another study developed a design integration system that consisted of three modules: BIM Modeller, BIM Checker and BIM Server, which helped in modelling, documentation, reviews, information management, collaboration and design changes (Oh et al., 2015).

Moreover, with the growing complexity of construction projects, the industry faces increasing pressure to improve integration, particularly during the design phase, leading to increased adoption of design automation concepts. A study was conducted that explored generative design concepts using BIM software, integrating genetic algorithms to optimise design solutions (Abrishami, Goulding and Rahimian, 2021). Furthermore, a study concentrated on automated design collaboration that integrates BIM with wind engineering and developed a system to generate 3D models and computational domains for use in fluid dynamics simulations (Delavar et al., 2020). Adoption of design automation could enhance the efficiency and optimisation of design solutions even across disciplines. Also, interoperability among BIM tools used by different organisations emerged as another crucial aspect of design process collaboration. Interdisciplinary design integrations are essential for improving the interoperability among BIM tools, which improves collaboration and efficiency in construction projects. Standard formats, such as IFC, facilitate information exchange between stakeholders, supporting the integration of architectural design and structural analysis (Hu et al., 2016), as well as architectural design and MEP system design (Oh et al., 2015). Other formats, besides IFC, can facilitate integration between design software, in which the SBIM format serves as a medium of communication between architectural design and structural analysis software plugins (Habte and Guyo, 2021).

Other areas of design collaboration were the integration of BIM with artificial intelligence (AI), fuzzy logic, design for safety, design for complex buildings and model versioning control. A study conducted a successful integration of an AI model with BIM, which proved high accuracy and performance and helped optimise space utilisation and enhance safety measures, thereby benefiting engineers (Wang, Ismail and Basher, 2023). Further, in construction projects, IFC formats were employed to enhance HVAC design and conduct safety risk assessments (Torregrosa-Jaime et al., 2019). These efforts were often complemented using fuzzy logic (Xun, Zhang and Yuan, 2022). The utilisation of BIM in collaborative activities has been discovered to optimise the process of construction design development and improve project performance for complex buildings (Wang et al., 2014). Noteworthy studies have applied a graph-based version control methodology to analyse interdisciplinary dependencies across partial models, facilitating the more efficient resolution of conflicting model versions (Esser, Vilgertshofer and Borrmann, 2023). These advanced design collaboration methods lead to more efficient and safer construction projects. They can optimise space, streamline processes and improve performance, which makes complex building projects easier to manage and more successful.

Future research on design process collaboration should focus on developing standardised BIM modelling guidelines to ensure consistency and interoperability across projects, which would help reduce errors. Meanwhile, the use of ontologies and model checkers can enhance design reliability by identifying flaws early in the process, minimising costly rework. Additionally, improving cloud-based information management standards would streamline data tracking and improve transparency in design changes. Furthermore, exploring code compliance-based design optimisation can ensure regulatory alignment, promote sustainability and prevent delays. Finally, utilising AI to support decision-making would allow for more informed and balanced design choices by considering factors such as cost, durability and sustainability. These advancements would significantly improve collaboration, reduce inefficiencies and promote more sustainable and compliant design outcomes.

Cluster 2: BIM-based for stakeholder's workflow integration

This cluster concentrated on establishing a robust framework for integrating and collaborating among stakeholders in construction projects facilitated by BIM technology. It involved coordinating activities among parties, disseminating information to all project stakeholders and integrating various information systems.

The nature of complex construction projects faced the issue of efficiently coordinating processes among parties. This highlighted the need for efficient collaboration and coordination of workflow internally within contractors and externally with other project stakeholders. A study developed a platform for conducting e-procurement activities that is seamlessly integrated through web service connections for collaboration during tendering, contract awarding and ordering (Grilo and Jardim-Goncalves, 2011). Similarly, another study proposed a concept to accommodate precast supply chain management activities, utilising cloud computing, context awareness (CA) and BIM via private cloud and software as a service (SaaS) (Abedi et al., 2016). This system supported deliveries, monitoring and improved communication among stakeholders.

Meanwhile, the optimisation of the 4D BIM model was used to automate progress tracking and visualise project status, which enhances decision-making and collaboration among project participants (Park et al., 2017). Additionally, supply chain activity can be enhanced through the use of a heuristic algorithm for scheduling fluctuations and material ordering decisions, thereby improving collaboration between suppliers and contractors (Chen, De Soto and Adey, 2021). Furthermore, coordination between stakeholders in BIM model development was explored by introducing a BIM collaboration management framework to enhance BIM model quality through inspection, confirmation and tracking during collaborative work (Lin and Yang, 2018). This concept was implemented in subsequent research, creating a collaboration-based BIM model development management system to improve sharing and tracking information efficiency (Lin et al., 2020). Construction projects can achieve greater efficiency, improved quality and enhanced effective communication among parties by utilising BIM collaboration tools.

Also, the complexity of construction projects could produce a large volume of information, requiring effective information dissemination between stakeholders. A study implemented an automation system for managing information exchange in multidisciplinary construction projects, offering a suite of verification tools and a common data environment (Benghi, 2019). Another study developed a system that provides the necessary information for cost estimation, utilising Resource Description Framework, semantic web services and ontologies (Niknam and Karshenas, 2015). The construction project activities produce a large amount of data across distinct stages that require effective data management for informed decision-making. Among the research approaches were process mining (Pan and Zhang, 2021) and data mapping techniques (Herrera-Martín et al., 2022). These advancements in implementing BIM technologies for information dissemination to all project stakeholders underline the importance of effective data management in improving decision-making and project outcomes in the construction industry.

The process of expanding BIM-based collaboration involved integrating with diverse information systems, as explored through studies that integrated BIM with geographic information systems (GIS) for pre-construction operations and geotechnical parameter modelling (Karan and Irizarry, 2015; Khan, Park and Seo, 2021; Zhao, Mbachu and Liu, 2022). Augmented reality (AR) (Lin et al., 2015) and game engine (Buhammood et al., 2022) integration were explored for enhancing the visualisation capabilities. Maximising BIM capacity in collaboration to facilitate data exchange and integration with other information systems and distributed information sources for estimating construction costs was pursued through a management information system (Scherer and Schapke, 2011; Tchouanguem et al., 2021). The integration of BIM with various information systems and technologies opens up opportunities for improved collaboration, data exchange and interoperability, leading to more efficient and informed decision-making throughout the construction project lifecycle.

Future research on stakeholder workflow integration should focus on implementing e-procurement systems for both the execution and maintenance phases to streamline purchasing and resource allocation, thereby reducing delays. A robust system for managing the precast supply chain would improve material tracking and delivery coordination, thereby reducing errors and enhancing communication among stakeholders. Meanwhile, creating cost-minimisation models for demand fluctuations can optimise resource management, reduce waste and improve financial outcomes. In addition, integrating BIM with visual dashboard technologies for real-time insights would enable faster decision-making, improving project oversight and efficiency. Finally, standardising material ontologies to extend BIM knowledge bases can enhance materials data integration, data sharing and support informed decision-making. These advancements would significantly improve collaboration, communication and decision-making, leading to more efficient and successful project delivery.

Cluster 3: BIM-based for project management strategies

In the dynamic construction sector, adopting BIM collaboration in project management strategies became a focal point. One of the main clusters in this field was centred on regulatory compliance and effective project management strategies. Discussions within this cluster encompassed diverse topics, ranging from compliance with building codes, an effort to achieve project goals and implementation of lean construction methodologies and modular construction techniques.

When discussing regulatory compliance, the importance of code compliance inspection was highlighted. This process was described to assess designs without modifying them but ensuring that they complied with applicable regulations (Ismail, Ali and Iahad, 2017). A study developed a web services framework based on BIM for green building codes (Katranuschkov, Cheng and Das, 2014), while another suggested an integrated framework to evaluate retrofit strategies by considering their simultaneous impact on structural, architectural and MEP aspects according to regulations (Caterino et al., 2021). Utilising BIM-based collaboration gives flexibility to adopt code or regulatory compliance by providing a unified platform for seamless communication, real-time updates and coordinated efforts among all stakeholders, which leads to more efficient and compliant project outcomes.

BIM-based techniques were considered essential for optimising collaboration in achieving project goals. For instance, a study developed an information system that combined BIM with indoor positioning to manage construction quality (Ma et al., 2018). Additionally, BIM was utilised to detect conflicts between as-built and design documentation to address conflict detection through the project life cycle (Abd and Khamees, 2017), control project progress and scheduling tasks (Jiang et al., 2022) and serve as a knowledge base to reduce waste of steel materials to achieve cost efficiency (Chidambaram, 2019). Employing BIM techniques for construction project management practices could enhance coordination, improve accuracy and streamline processes, which leads to more efficient, cost-effective and higher-quality project outcomes. Lean construction principles also began to be applied to reduce material waste in construction projects. A study developed a BIM-enabled system for aiding production planning and control (Sacks, Radosavljevic and Barak, 2010), while in other research, BIM was used alongside lean principles to enhance team communication platforms, coordination, productivity and safety (Zhang et al., 2017b). Integrating lean principles and BIM could foster improved efficiency, minimise waste and promote a safer, more productive construction environment through enhanced communication and coordination.

In efforts to create more efficient and sustainable construction methods, there was an increased emphasis on modular construction. Research studies focused on developing a digital platform for collaboration in modular construction (Ezzeddine and De Soto, 2021) and an expanded model view definition standard for seamless information exchange in modular projects (Ramaji and Memari, 2018). These provided tangible evidence of how construction continues to evolve towards more efficient and sustainable practices. Utilising BIM in modular construction techniques can enhance coordination, streamline workflows and ensure precision in the assembly process, ultimately leading to improved efficiency and sustainability in construction projects. The integration of BIM into modular construction was expected to improve collaboration among stakeholders.

Future research on project management strategies should explore ensuring green building compliance, as aligning construction practices with sustainable methods will not only support sustainability goals but also reduce environmental impacts. Meanwhile, enhancing construction schedules and automating inspector assignments can improve project oversight and timely project completions. Moreover, the integration of advanced technologies, such as AR and voice input, offers significant potential for improving on-site decision-making, enhancing safety and streamlining operations. Furthermore, research on coordinating manufacturers with site schedules, optimising assembly sequences and enhancing transportation logistics is crucial for a smoother workflow. Additionally, studying the impact of BIM on team morale could offer valuable knowledge to enhance collaboration and productivity. These research areas would contribute to more sustainable, efficient and collaborative project management practices.

Cluster 4: BIM-based integration with digital technologies for data and information management

This cluster explored data and information management practices and the application of digital technology within the field of BIM. The discussion addressed topics related to digital storage and information management throughout the lifecycle of buildings, alongside the deployment of smart contracts. Additionally, the research explored how blockchain could enhance data security, transparency and trust in BIM-enabled construction projects.

The rapid growth of BIM technology offered full collaboration between project teams in real-time by integrating digital technologies into the BIM process with mature applications at level three (Eischet and Kaduma, 2023). Various research studies were conducted to further investigate this matter and address implementation challenges. For instance, a study utilised a BIM overlay technique that transparently federates data stored on an individual discipline’s IT infrastructure (Beach et al., 2017). Meanwhile, another one developed a multi-server system within a private cloud, ensuring structured data distribution among stakeholders (Zhang et al., 2017a). Simultaneously, another study developed a federated cloud framework to facilitate seamless collaboration across various organisational levels and project phases by creating a multi-site construction coordination model (Petri et al., 2017). Moreover, research established a cloud-based collaborative system that assists construction partner selection (Ahmed et al., 2020). Another alternative entailed the development of cognitive assistant technologies specifically designed to support the execution of coordination tasks and to improve communication (Mutis and Ramachandran, 2021). The utilisation of digital storage to enhance information management could streamline collaboration, improve decision-making and ensure continuity of project knowledge and efficiency across all phases.

The integration of blockchain and smart contracts with BIM served as a technology-enabled process for multidisciplinary collaboration, with the potential for enhanced collaborative information exchange. To streamline this process, additional digital technologies, such as blockchain and smart contracts, were integrated. Blockchain acted as a data repository for information collected from various software applications used by project participants, while smart contracts, which served as tools for executing transactions on the blockchain, were employed to link specific processes to a BIM model, ensuring clear records of project processes and the as-built condition of structures (Greenwald, 2020). A study demonstrated that an integrated digital twin and blockchain framework enabled safe, traceable and unchangeable data communication between project participants, resulting in faster contract execution, payments and subsequent decision-making (Lee et al., 2021). Other studies have highlighted the ability of BIM-Blockchain to record all design attempts (Dounas, Lombardi and Jabi, 2021), streamline construction data processing, reduce redundant documentation and enhance transparency and communication between stakeholders (Celik, Petri and Barati, 2023). Moreover, the integration of blockchain-based BIM project management platforms can address multiple facets of design technology, construction management, material scheduling and the entire construction lifecycle (Ni, Sun and Wang, 2021). Integrating blockchain with BIM could enhance data integrity, security and transparency throughout the construction lifecycle, ensuring streamlined processes and improved collaboration among stakeholders.

Numerous studies have explored the integration of smart contracts within BIM and blockchain. For instance, a study utilised smart contracts to address challenges in sustainable design within BIM, negotiating editing permissions and maintaining an immutable record of general modifications (Liu et al., 2019). Additionally, smart contracts were employed for secure information sharing, permission execution and historical data retrieval (Tao et al., 2023). Furthermore, research on integrating blockchain, smart contracts and the Internet of Things (IoT) in off-site manufacturing has emphasised activity automation, traceability and data security throughout the supply chain, thereby mitigating time wastage and cost overruns (Brandín and Abrishami, 2021). Integrating smart contracts with BIM can enhance automation, security and accountability in project management processes, ensuring the efficient and transparent execution of contractual agreements and data management tasks.

Future research on digital technologies for data and information management should focus on refining BIM maturity models for BIM integration to improve workflow efficiency. Moreover, exploring the optimisation of digital storage for building specifications will enhance compliance with regulations and ensure easy access to accurate information throughout the project lifecycle.

Meanwhile, investigating the use of cognitive agents for clash detection and conflict resolution can enhance design accuracy by quickly identifying and resolving conflicts in complex models. Furthermore, integrating blockchain with IoT devices could improve operational efficiency by automating data integrity checks and enhancing real-time data updates. Additionally, conducting comprehensive cost-benefit analyses of blockchain and smart contract adoption in BIM systems would enable stakeholders to make informed decisions about their integration, effectively balancing costs and benefits. These advancements will strengthen data security, improve collaboration and enable more efficient decision-making in the construction industry.

The Summary of Technology Methods and Potential Development

The next step in the systematic analysis was to extract the essential information from 52 selected scientific articles. These articles focused on the technological approaches used to carry out BIM-based collaborations and identify potential development. The approach involved reviewing each article and categorising them according to the software tools, data formats, key improvement areas and integration methods of the implementation of BIM-based collaboration, as illustrated in Table 2.

Table 2. Information for implementing BIM-based collaboration

Description	Number of Articles	Source
Software Tools		
Revit	28	Steel, Drogemuller and Toth (2012); Wang et al. (2014); Katranuschkov, Cheng and Das (2014); Oh et al. (2015); Niknam and Karshenas (2015); Karan and Irizarry (2015); Hu et al. (2016); Abedi et al. (2016); Kim, Ji and Jun (2017); Park et al. (2017); Beach et al. (2017); Petri et al. (2017); Abd and Khamees (2017); Ma et al. (2018); Delavar et al. (2020); Buhammood et al. (2022); Ahmed et al. (2020); Lin et al. (2020); Habte and Guyo (2021); Abrishami, Goulding and Rahimian (2021); Chen, De Soto and Adey (2021); Tchouanguem et al. (2021); Caterino et al. (2021); Ezzeddine and De Soto (2021); Jiang et al. (2022); Xun, Zhang and Yuan (2022); Zhao, Mbachu and Liu (2022); Celik, Petri and Barati (2023)
Tekla	4	Steel, Drogemuller and Toth (2012); Hu et al. (2016); Park et al. (2017); Chidambaram (2019)
ArchiCAD	3	Grilo and Jardim-Goncalves (2011); Steel, Drogemuller and Toth (2012); Karan and Irizarry (2015)

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Table 2 *Continued*

Description		Number of Articles	Source
	AutoCAD	2	Park et al. (2017); Jiang et al. (2022)
	Others	5	Steel, Drogemuller and Toth (2012); Abedi et al. (2016); Khan, Park and Seo (2021); Scherer and Schapke (2011); Katranuschkov, Cheng and Das (2014)
Data Formats			
	IFC	30	Grilo and Jardim-Goncalves (2011); Scherer and Schapke (2011); Steel, Drogemuller and Toth (2012); Oh et al. (2015); Karan and Irizarry (2015); Abedi et al. (2016); Hu et al. (2016); Beach et al. (2017); Park et al. (2017); Zhang et al. (2017a); Petri et al. (2017); Cho, Won and Ham (2018); Ma et al. (2018); Ramaji and Memari (2018); Benghi (2019); Chidambaram (2019); Torregrosa-Jaime et al. (2019); Buhammood et al. (2022); Ahmed et al. (2020); Khan, Park and Seo (2021); Pan and Zhang (2021); Habte and Guyo (2021); Tchouanguem et al. (2021); Mutis and Ramachandran (2021); Herrera-Martín et al. (2022); Xun, Zhang and Yuan (2022); Zhao, Mbachu and Liu (2022); Celik, Petri and Barati (2023); Esser, Vilgertshofer and Borrmann (2023); Tao et al. (2023)
	COBie	1	Benghi (2019)
	XML	5	Scherer and Schapke (2011); Katranuschkov, Cheng and Das (2014); Karan and Irizarry (2015); Park et al. (2017); Mutis and Ramachandran (2021)
	JSON	5	Hu et al. (2016); Kim, Ji and Jun (2017); Herrera-Martín et al. (2022); Zhao, Mbachu and Liu (2022); Tao et al. (2023)
	Others	6	Niknam and Karshenas (2015); Karan and Irizarry (2015); Abedi et al. (2016); Pan and Zhang (2021); Khan, Park and Seo (2021); Ezzeddine and De Soto (2021)
Key Improvement Areas			
	Collaborative design	14	Wang et al. (2014); Katranuschkov, Cheng and Das (2014); Oh et al. (2015); Steel, Drogemuller and Toth (2012); Kim, Ji and Jun (2017); Beach et al. (2017); Zhang et al. (2017a); Cho, Won and Ham (2018); Torregrosa-Jaime et al. (2019); Dounas, Lombardi and Jabi (2021); Tchouanguem et al. (2021); Esser, Vilgertshofer and Borrmann (2023); Celik, Petri and Barati (2023); Tao et al. (2023)
	Design analysis	3	Hu et al. (2016); Ramaji and Memari (2018); Habte and Guyo (2021)

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Table 2 *Continued*

Description	Number of Articles	Source
Design automation	2	Abrishami, Goulding and Rahimian (2021); Delavar et al. (2020)
Design simulation	1	Wang, Ismail and Basher (2023)
Design as-built	1	Abd and Khamees (2017)
Procurement	1	Abedi et al. (2016); Ahmed et al. (2020)
Pre-construction planning	5	Karan and Irizarry (2015); Lin and Yang (2018); Lin et al. (2020); Khan, Park and Seo (2021); Zhao, Mbachu and Liu (2022)
Supply chain	2	Park et al. (2017); Chen, De Soto and Adey (2021)
Schedule management	4	Sacks, Radosavljevic and Barak (2010); Caterino et al. (2021); Zhang et al. (2017b); Jiang et al. (2022)
Cost management	1	Niknam and Karshenas (2015)
Quality management	3	Benghi (2019); Pan and Zhang (2021); Ma et al. (2018)
Risk management	1	Xun, Zhang and Yuan (2022)
Project control	5	Grilo and Jardim-Goncalves (2011); Scherer and Schapke (2011); Chidambaram (2019); Lee et al. (2021); Brandín and Abrishami (2021)
On-site coordination	4	Lin et al. (2015); Buhammood et al. (2022); Ezzeddine and De Soto (2021); Mutis and Ramachandran (2021)
Facility management	1	Herrera-Martín et al. (2022)
Lifecycle integration	3	Petri et al. (2017); Liu et al. (2019); Ni, Sun and Wang (2021)
Integration Methods		
Engineering analysis	3	Hu et al. (2016); Delavar et al. (2020); Habte and Guyo (2021)
GIS	3	Karan and Irizarry (2015); Khan, Park and Seo (2021); Zhao, Mbachu and Liu (2022)
Cloud computing	7	Wang et al. (2014); Abedi et al. (2016); Park et al. (2017); Beach et al. (2017); Zhang et al. (2017a); Petri et al. (2017); Ahmed et al. (2020)

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Table 2 *Continued*

Description	Number of Articles	Source
Blockchain	5	Liu et al. (2019); Dounas, Lombardi and Jabi (2021); Ni, Sun and Wang (2021); Celik, Petri and Barati (2023); Tao et al. (2023)
Semantic web	3	Niknam and Karshenas (2015); Tchouanguem et al. (2021); Herrera-Martín et al. (2022)
Database	3	Grilo and Jardim-Goncalves (2011); Cho, Won and Ham (2018); Lin et al. (2020)
Game engine	2	Buhammood et al. (2022), Ezzeddine and De Soto (2021)
AR	1	Lin et al. (2015)
AI	2	Wang, Ismail and Basher (2023); Xun, Zhang and Yuan (2022)
IoT	3	Pan and Zhang (2021); Lee et al. (2021); Brandín and Abrishami (2021)
Positioning	3	Ma et al. (2018); Chidambaram (2019); Chen, De Soto and Adey (2021)
Lean construction	2	Sacks, Radosavljevic and Barak (2010); Zhang et al. (2017b)
Green building	2	Torregrosa-Jaime et al. (2019); Katranuschkov, Cheng and Das (2014)
Others	13	Scherer and Schapke (2011); Steel, Drogemuller and Toth (2012); Oh et al. (2015); Abd and Khamees (2017); Kim, Ji and Jun (2017); Ramaji and Memari (2018); Lin and Yang (2018); Benghi (2019); Chidambaram (2019); Abrishami, Goulding and Rahimian (2021); Caterino et al. (2021); Mutis and Ramachandran (2021); Jiang et al. (2022); Esser, Vilgertshofer and Borrmann (2023)

In BIM-based collaboration, the 3D model serves as the central component, supporting various aspects of design and construction. This aligns with the widespread use of software tools designed to accommodate various aspects of building modelling, such as Revit, ArchiCAD, Bentley, SketchUp and Nemetschek for architectural modelling, Revit and Tekla for structural modelling and Civil 3D for civil infrastructure modelling. Once a model is created, seamless data exchange is crucial for interoperability between platforms. Commonly used formats, such as IFC, COBie, XML and JSON, enable efficient sharing and integration across different systems.

The collaborative nature of 3D model development involves coordination between various platforms and stakeholders. This collaboration supported collaborative design, design analysis, preconstruction planning and project control. Integrating BIM with model reviewers, model checkers, building energy simulations and design quality improvement strategies can ensure the efficient distribution and coordination of design efforts. Furthermore, design analysis can be enhanced by integrating BIM with structural analysis tools, which would improve information flow and minimise inefficiencies. The integration of BIM with GIS enhances planning, safety and information sharing, while blockchain, IoT and databases improve project monitoring. In addition, lean construction methods could optimise schedule management and AR/VR with game engines could enhance on-site coordination. These integrations can streamline workflows, reduce inefficiencies and improve overall project management, demonstrating BIM's vital role in modern construction.

This summary is useful for providing an information overview related to the relationship between the key improvement areas, integration methods, software tools and data formats that are used for the implementation of BIM-based collaboration. For instance, utilising BIM for the supply chain may be effective using integration with technology like cloud computing or positioning. As a result, BIM software like Revit or AutoCAD can be used along with data formats for exchange like XML or IFC.

In addition, BIM-based collaboration offers improvements across design, workflow integration, project management and data management in construction projects. It enhances data interoperability, real-time sharing and interdisciplinary integration, optimising design quality and reducing errors. BIM facilitates better stakeholder coordination, streamlines information dissemination and supports the seamless management of complex workflows. By improving regulatory compliance, scheduling and adopting sustainable practices, BIM ensures cost-effective, efficient and high-quality outcomes. Furthermore, the integration of digital technologies such as blockchain and smart contracts with BIM enhances data security, transparency and process automation, enabling secure and efficient decision-making throughout the project lifecycle. Together, these advancements drive construction projects toward greater efficiency, sustainability and collaboration. These findings can assist academics and practitioners in employing BIM-enabled collaboration in construction projects, tailoring it to their needs and resources for more optimal outcomes.

CONCLUSION

This study explored the development of research on BIM collaboration in construction projects. The analysis of scientific production on BIM collaboration in construction projects highlighted a growing research interest in this field. Although there was a temporary decline during the COVID-19 pandemic, publications rebounded as the industry adapted. Europe and Asia lead in contributions, followed by other regions. China stood out due to its strong support for BIM policy, while other countries showed varying levels of research engagement. This trend highlighted the growing global interest in BIM research, particularly in Asia, where rapid advancements have been made in recent years.

This study revealed that integrating BIM-based collaboration into construction project workflows has evolved to enhance various aspects. The findings, presented chronologically based on the studies that met the analysis criteria, illustrate the progression of BIM-based collaboration from enhancing design process collaboration to focusing on stakeholder workflow integration, project management strategies and finally, leveraging digital technologies for data and information management. These findings were analysed using both quantitative methods (via bibliometric analysis) and qualitative methods (via systematic literature review), as a result offers a comprehensive understanding of the evolution and impact of implementing a BIM-based collaboration in construction projects.

In addition to its theoretical implications, this study provides valuable insights into the evolving role of BIM-based collaboration across various stages of the construction process. From a theoretical perspective, the study enriches existing models of BIM integration from the design phase to the execution phase. From a practical perspective, the study offers insights for academics and practitioners by providing an overview of the current state of BIM collaboration in construction. This overview enables stakeholders to understand the evolution of BIM's role, which facilitates its broader adoption. This work is intended to serve as a reference for future studies aimed at enhancing the technical, organisational and regulatory aspects of BIM-based collaboration in construction projects.

Future research should address the need for standardised BIM modelling guidelines to enhance consistency and interoperability, which will reduce errors in the design process. Stakeholder workflow integration can be improved by implementing e-procurement systems and optimising supply chains to enhance coordination and minimise delays. In project management, exploring the alignment of construction practices with sustainable methods will support sustainability and reduce environmental impact. Additionally, refining BIM maturity models and integrating blockchain with IoT devices could strengthen data security and enhance real-time decision-making in construction projects.

However, it is essential to acknowledge the limitations of this study, notably the exclusive reliance on Scopus as the database source, which may limit the scope of the findings. Future research could benefit from integrating multiple databases, such as Web of Science and Google Scholar, to provide more comprehensive datasets. Additionally, expanding the scope of keywords used could yield a broader range of studies, potentially influencing additional aspects of BIM-based collaboration in construction projects. To enhance the robustness of future studies, it is recommended to validate the findings through consultations with experts in the field, including both academics and practitioners. This would ensure that the findings are grounded in real-world applications. Furthermore, policy suggestions involve delving deeper into the implementation of BIM-based collaboration in construction projects to provide customised implementation guidelines that may be adjusted to different local circumstances. Continuous efforts will focus on conducting pilot trials, closely monitoring BIM implementation and evaluating measurable outcomes to improve decision-making and the adoption of BIM technologies across diverse construction environments.

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