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Building information modeling for Public Private Partnership Projects A literature review and future research directions

Ali Al-Shamayleh[1], Sharifah Zakaria[2], Nur Rahim[3], Doa'a Al Totanji[4]

[1]PhD Student, USM, Malaysia
[2]Associate Professor, USM, Malaysia
[3]Lecturer, UniMap, Malaysia
[4]PhD Student, USM, Malaysia

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Abstract—*The main focus of the Public Private Partnership (PPP) is to maximise the projects' profitability. Building Information Modeling (BIM) can help decision-makers make educated decisions throughout the project's life cycle. However, despite the number of studies on BIM for PPP projects, many challenges, inconveniencies, and hurdles still face the successful and feasible implementation of BIM in PPP projects. The study presents a systematic review based on an in-depth review of 56 journal articles published from 2012 to 2022 of the status of Building Information Modeling (BIM) adoption in Public Private Partnerships (PPP) projects, highlights current trends and patterns, and systematically outlines future research agenda. Finally, it is hoped that this research will argue for the future development of a smoother BIM adoption in PPP projects to overcome hurdles and improve overall project outcomes. The results of this study clarify the current research areas and future research agenda in the field of BIM for PPP projects. Defining current and future research on the topic will help the smooth implementation of BIM in PPP projects to reap the benefits, overcome the challenges and provide key decision-makers with the ability to make educated decisions across the project life cycle.*

***Keywords*— Building Information Modeling (BIM), Public-Private Partnerships (PPP), Literature Review, Content Analysis, Bibliometric analysis, Performance Management**

I. INTRODUCTION

Public-Private Partnership (PPP) Projects are operationally complex and involve many fields, such as law, finance, engineering, and management, and stakeholders from the public and private sectors with conflicting interests(Chen et al., 2021). Effective performance management in PPP projects is essential to recognise the Value for Money (VfM), which makes an in-depth understanding of PPP projects' performance problems critical (Yuan et al., 2020); for example, it is estimated that 60% to 90% of construction change orders occur due to poor design documentation (Regan et al., 2015) Value for Money (VfM) can be considered the procurement justification assessment approach in PPP project feasibility analysis. However, this performance measurement lacks automation and an information exchange scheme (Ren et al., 2019).

The main focus of PPPs is to maximise the projects' profitability. Building information modelling can digitally represent the assets' physical and functional characteristics and help decision-makers make educated decisions throughout the project's life cycle (Love et al., 2015). BIM also allow for fast testing, high flexibility in design changes and adjustments, and critical feedback in construction projects, reducing the political stakeholders' demand for significant design changes before and during construction (Rothengatter, 2019). BIM adoption also seems to ease communication due to the greater clarity for all stakeholders across the project's lifecycle (Patil & Laishram, 2016). However, using BIM alters the traditional work practices for organisations, initiates changes to the government's procurement policies[8], and exposes users to additional risks regarding reducing sharing information barriers (Habib et al., 2020).

This paper addresses the following objectives: first, to assess academic journals' literature by mapping trends according to the reviewed articles' content and contribution regarding BIM adoption in PPP projects. Second, to identify research and organise research into relevant domain topics. Third, to present future research agenda for each domain based on the literature.

II. RESEARCH METHODOLOGY

This study utilises a quantitative and qualitative research method to analyse and categorise existing BIM for PPP from 2012 to 2022. The bibliometric analysis provides statistical methods to analyse trends in academic publications and citations to assess the current research performance and future research patterns. The analysis consists of six steps, as shown in Fig.1: (1) Scopus database keywords search; (2) selecting filters for target BIM for PPP projects, English language, and Journal articles (3)selecting journals with CiteScore greater than one (4) Searching journal databases (5) Removing any duplicates (6) categorising articles based on their topics.

keyword research in the Scopus database was searched using different keywords: (1) “BIM”; (2) “Building Information Modeling”; (3) “Building Information Modelling” (4) "PPP" (5) "PPP Projects" (6) "Public Private Partnership" (7) "3P" (8) "triple P" (9) "BOT" (10) "BOOT" (11) "DBFO" (12) "DBFM" (13) "DBMFO" (14) "DCMF". The search yielded 430 articles; then, we filtered articles to all journals related to BIM in the PPP projects published in English, which resulted in 80 articles. Journals are then filtered with a CiteScore higher than one (CiteScore: citations received by a journal in a year to documents published in three previous years, all divided by the number of documents indexed in Scopus published in these three years). Individual selected journals' databases were searched in the previous step to overcome any limitations of the Scopus database. The final step was combining search results from Scopus and individual selected journals and removing duplicated articles. The final number of relevant research articles that passed the selection criteria is 56. The study adopted content analysis to generate a qualitative analysis of 56 articles' patterns and derive a future research agenda for each proposed section.

III. BIBLIOMETRIC ANALYSIS RESULTS

The bibliometric analysis shows a noticeable growth in the total number of publications per year on BIM for PPP projects from 2012 to 2022. however, because this research was ready before the end of 2022, it does not represent the year. More than 50% of publications were done in the past 3 years, which indicates that the subject is gaining interest. Table 1 and Fig. 2 shows the number of publication over the last decade.

The largest publications based on the selection criteria over the past ten years in the field of BIM for PPP projects were published in "Automation in Construction", totalling 8 articles. They were followed by "Engineering, Construction and Architectural Management" with 4 articles. Table 1 and Fig. 3 show each journal's annual publication for the past ten years.

The bibliometric analysis shows that the largest number of publications over the last decade were from (1) China (2) the United Kingdom (3) Australia (4) Malaysia, as shown in Fig. 4. China is expected to have the largest proportion of publications in BIM for PPP projects since PPP projects are a widely used procurement method in China. Furthermore, three of the top ten most cited articles were published in “Automation and Construction”. Table 2 shows the top ten cited articles using the Scopus citation metric. Fig. 5 demonstrates keyword clustering for the most frequent keywords, as found in the literature review.

1. *Content analysis*

selected articles were analysed and reviewed to generate qualitative analysis and to propose future research agendas. Articles were categorised into twelve categories based on their contribution, as shown in Fig. 6.

1. *Research Gap and Future agenda*

The following section presents research trends regarding Building Information Modeling (BIM) applications in Public-Private Partnership (PPP) projects and suggests future research in each pattern's scope.

Category 1: Stakeholders Management

Building information modelling implementation in public-private partnership projects is reforming the traditional building mode, which requires stakeholders to cooperate actively. BIM has become a meaningful way to solve the cross-organization information collaboration of PPP projects effectively. Promoting BIM implementation in PPP projects has become a challenge to be solved urgently. However, when governments promote the reduction of BIM costs or are punished by superior management authorities, they will choose the active promotion strategy, and the behaviour gradually converges (Jia et al., 2021). Critical success factors for BIM implementation, stakeholder management, and BIM project performance were identified and tested. Structural equation modelling was used to analyse the data. It found that the effective use of BIM can directly improve project performance (Zhang et al., 2022) and introduce a new tool to integrate stakeholder information for stakeholder collaboration improvement(Xue et al., 2020). Due to the essential role of stakeholders, another research developed an integrated project delivery IPD-inspired framework to measure the integration of stakeholder integration in PPP projects(Malaeb & Hamzeh, 2021). A different research direction analysed the procurement process sustainability in PPP projects and found that adopting a building information modelling (BIM) system can improve stakeholder communication can promote decision-making participation (Patil & Laishram, 2016) (Patil et al., 2021).

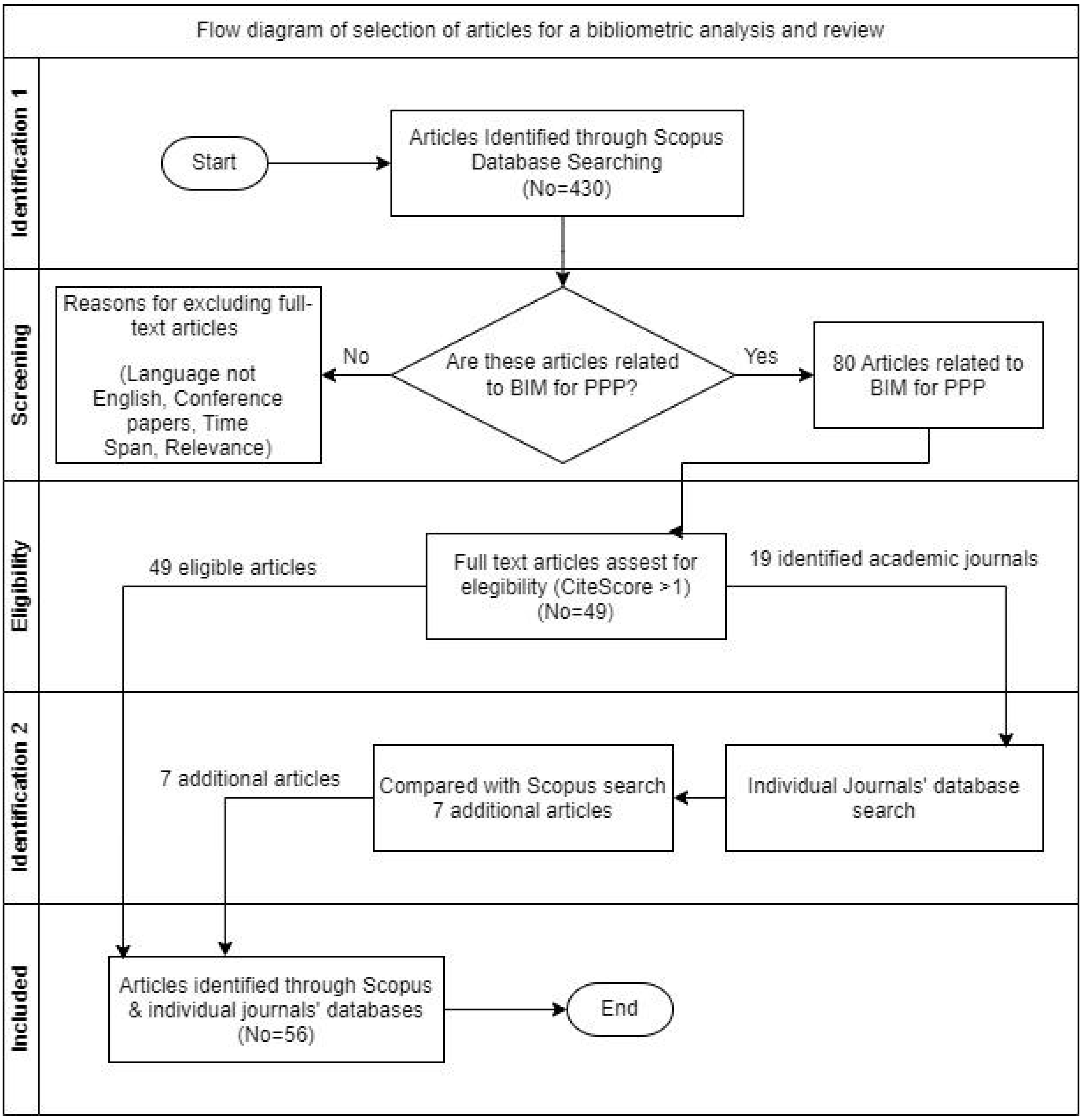

Fig. 1. Flow diagram of selection of articles for bibliometric analysis on BIM for PPP.

Public-private partnership projects are complex, have a long-life cycle, and involve many fields like engineering, management, finance, and law. PPP projects include conflicting interest stakeholders from the government and private sector. Therefore, the reasonable selection of sustainable building materials can reduce costs significantly. The new (BIM) technology has become a hot research area in sustainability(Chen et al., 2021). BIM allows for fast testing, high flexibility in design changes and adjustments, and critical feedback in construction projects, reducing the political stakeholders' demand for significant design changes before and during construction(Rothengatter, 2019). Future research agenda could involve: exploring the impact of stakeholders' variety and complexity according to various contractual arrangements and types of BIM-enabled projects (Zhang et al., 2022), identifying additional collaboration metrics, factors rating based on the respondents' background, and investing in other case studies (Malaeb & Hamzeh, 2021), address feedback mechanism when the consistency level is low in decision experts(Chen et al., 2021), and improve the accountability of mega projects in terms of evaluation that leads sustainability goals (Rothengatter, 2019).

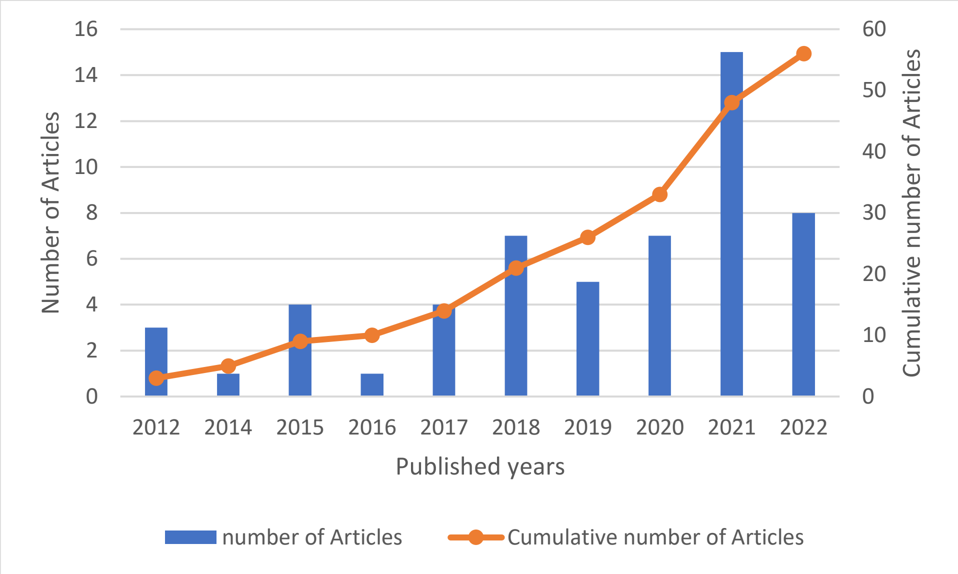

Fig. 2. BIM for PPP articles published over the last decade.

Category 2: Value for Money (VfM)

Value for Money (VfM) for PPP projects is mainly the overall procurement justification performance assessment that still lacks automation and an information exchange scheme (Ren et al., 2019) (Ren et al., 2021). This study tries to address this issue by developing an information exchange scheme concerning Value for Money assessment in Public-Private Partnerships utilising the potential of the emerging BIM technology (Ren et al., 2019) (Yuan et al., 2020). However, a different approach is used to automate the evaluation by aligning BIM goals for information support with ontology for knowledge process enhancement (Ren et al., 2021). Another study tries to shed light on issues concerning performance management in PPP and provides an experimental BIM system to improve PPP performance(Ren et al., 2020). The future research agenda addresses comprehensive performance assessment for PPP projects (Ren et al., 2019). Development of an information exchange scheme for VfM, creating a Vfm knowledge base, creating a VfM database that includes project externalities(Ren et al., 2021) (Ren et al., 2020), and finally, performance improvement by engaging designers in PPP PM, real-time performance monitoring and measurement (Yuan et al., 2020).

Category 3: Performance Evaluation

Effective performance measurement and evaluation are critical to successfully implementing PPP projects (Love et al., 2015) (Xu et al., 2020). However, the traditional ex-post evaluation only focuses on the budget and predetermined timeline. Building Information Modelling (BIM) can enable coordination and integration, as it not only provides a digital representation of the physical and functional characteristics of an asset but also provides key decision-makers with the ability to make educated decisions across a project's life cycle. This study reviews and proposes performance measurement, and a life-cycle PPP project evaluation approach is suggested (Love et al., 2015). That is the reason that a conceptual framework of life-cycle performance measurement can help ensure resilience(Liu et al., 2019). On the other hand, other researchers studied the impact and relationship between contractual flexibility and BIM-enabled PPP project performance, especially during construction. The results reveal that both content flexibility and executing flexibility significantly positively impact the performance of BIM-enabled PPP projects during the construction phase(Xu et al., 2022) and performance evaluation utilising IFC extension and the enhanced matter-element method to evaluate PPP project performance accurately and efficiently. (Xu et al., 2020). Other research took a different approach by combining empirical with experimental study, starting with semi-structured interviews to build BIM Based Performance Management System(BPMS) by combining it with Web and Cloud technology(Yuan et al., 2020). Another approach is identifying and prioritising 63 stage-based performance indicators (KPIs) for build-operate-transfer (BOT) projects. An integrated project delivery system with BIM implementation can be used throughout the BOT project's lifecycle. To meet emerging information and sharing project requirements(Budayan et al., 2020).

Two studies targeted the cost performance of infrastructure rail projects. The studies show that BIM enables visualisation that assists in defining the requirements of the public sector and identifying the 'best' route for an LRT system(Love, Ahiaga-Dagbui, et al., 2017) and improves cost certainty during the construction of rail projects(Love, Zhou, et al., 2017). Researchers integrated different dimensions of behavioural responses, and different levels of contextual factors quantify the multidimensionality of behavioural responses to BIM implementation in construction projects throughout the post-adoption period. Data was collected from BIM-based construction projects in China(Cao et al., 2021). Other research studied the role of mediating stakeholder management in the relationship between BIM implementation and project performance and found that effective stakeholder dynamics and stakeholder engagement or empowerment positively affect BIM implementation and project performance(Zhang et al., 2022). Scope changes, inability to adapt and respond to risk and uncertainty, ineffectual project management and governance, and optimism bias, impact hospital projects' performance adversely. Because of hospital projects' complexity, it may be argued that if BIM had not been used, their costs would have been much higher than those incurred(Love & Ika, 2022). Nevertheless, Exploring information exchange and the role of a cloud-Based BIM in calculating the life-cycle building performance under the PPP procurement process(Redmond et al., 2012). However, a different study tries to predict completion risk in PPP projects using Big Data Analytics, including oracle financials, BIM models, and Primavera(Owolabi et al., 2018).

The future research agenda involves the use of BIM for managing asset performance(Love et al., 2015), the impact and usage of BIM on various payment methods, more potential variables, the impact of contract flexibility(Xu et al., 2022), creating a PPP project performance evaluation case database(Xu et al., 2020) and cost overrun in historical PPP projects(Owolabi et al., 2018), performance improvement by engaging designers in PPP PM, real-time performance monitoring and measurement(Yuan et al., 2020), investigate the complex behavioural responses from a dynamic standpoint(Cao et al., 2021), better determine construction cost contingencies in the lights of BIM and SIM(Love, Zhou, et al., 2017), Explore the impact of stakeholders' variety and complexity according to various contractual arrangements and types of BIM-enabled projects(Zhang et al., 2022) how to measure Key Performance Indicators(Budayan et al., 2020), and examine the feasibility of the developed performance measurement framework(Liu et al., 2019).

Category 4: Sustainability

The sustainability of public-private partnership (PPP) projects is influenced by project life cycle characteristics, automation, and robotic technologies; this study investigates the role of automation and robotics in the sustainability of PPP infrastructure projects. The results demonstrate that collaboration actions, experimentation, and automation platforms promote sustainability throughout the project life cycle (Hoeft et al., 2021). Another research deals with BIM and energy simulations to help make better decisions and enhance sustainability. The progressive BIM methodology advises providing appropriate information to match the objective of an ongoing restoration design process, emphasising energy performance(Stegnar & Cerovšek, 2019). Another research investigating BIM for a better selection of sustainable building materials could improve buildings' sustainability and reduce costs significantly (Chen et al., 2021). A different research direction analysed the procurement process sustainability in PPP projects and found that adopting a building information modelling (BIM) system can improve stakeholder communication, facilitate the integration of the strategies, and can promote decision-making participation (Patil & Laishram, 2016) (Patil et al., 2021). Another research studied emerging construction practices such as BIM, prefabrication construction, green building, and integrated project delivery in the big chinse construction market. The results provide insights for industry practitioners and government officials on the latest sustainable practices of China's construction industry (Ma et al., 2018).

Future research agenda can involve: investigating Multi-disciplinary research designs linked to infrastructure projects and the impact of automation and robotics (Hoeft et al., 2021), addressing feedback mechanisms when the consistency level is low in decision experts (Chen et al., 2021), monitoring various interaction activities among the stakeholders (Patil & Laishram, 2016), reanalyse the system dynamics model to comprehend the new structure of the system (Patil et al., 2021), and finally, more case studies to evaluate the impact of BIM on the performance of different types of projects (Ma et al., 2018).

Category 5: Infrastructure

Infrastructure projects, in many cases, are large complex projects. They can cause many challenges for planners, constructors, managers and policymakers because of their volume, complexity and expected sublimes. BIM allows for greater flexibility for necessary changes and adjustments, which improves efficiency (Rothengatter, 2019). Studying the current issues affecting the Value for Money (VfM) is essential. Adopting BIM throughout the PPP lifecycle could support decision-making and determine whether the provided value is sufficient (Ren et al., 2020). Justifying and identifying the cost performance for Light Rail Transit (LRT) projects is essential for effective project delivery (Love, Ahiaga-Dagbui, et al., 2017), the cost performance of rail infrastructure projects has gotten much attention because they are rarely completed on time (Love, Zhou, et al., 2017). The studies show that BIM enables visualisation that assists in defining the requirements of the public sector and identifying the 'best' route for an LRT system(Love, Ahiaga-Dagbui, et al., 2017) and improves cost certainty during the construction of rail projects(Love, Zhou, et al., 2017). Another research used a case study to study BIM implementation in handover management for an underground rail transit project (Wang & Zhang, 2021). Performance measurement is prominent in ensuring transport infrastructure functions optimally and is resilient to external changes. This research focuses on a conceptual framework of lifecycle performance measurement that will help ensure the resilience of transport infrastructure assets(Liu et al., 2019).

It has been estimated that 60% to 90% of change orders in Australian construction projects result from poor design documentation, which is where BIM technology adoption can readily address. One research direction focuses on public infrastructure procurement, differentiating adversarial and non-adversarial contracting methods(Regan et al., 2015). On the other hand, another research is trying to bridge the gap of future-proofing large-scale transport infrastructure assets utilising a procurement policy-making pathway(Love et al., 2021). Another research direction is the role of digital practices in Civil Integrated Management (CIM) in infrastructure asset management, particularly in highway projects. The study statistically analysed three alternative delivery methods that showed similarities between CIM and BIM(Sankaran et al., 2018). Another study identifies how project life cycle characteristics, automation, and robotic technologies influence the sustainability of public-private partnership (PPP) infrastructure projects (Hoeft et al., 2021). Future research agenda can involve: improving the accountability of mega projects in terms of evaluation that leads to sustainability goals (Rothengatter, 2019), development of an information exchange scheme for VfM, creating a Vfm knowledge base, creating a VfM database that includes project externalities(Ren et al., 2020), to better determine construction cost contingencies (Love, Zhou, et al., 2017), examine the feasibility of the developed performance measurement framework (Liu et al., 2019), developing new forms of contract and insurances (Love et al., 2021), future case studies needs to facilitate deep industry-academic cooperation (Wang & Zhang, 2021), Multi-disciplinary research designs linked to infrastructure projects and the impact of automation and robotics (Hoeft et al., 2021), and finally, developing guidance for STAs for the selection of CIM technologies and anticipated performance benefits (Sankaran et al., 2018).

Category 6: Contractual Flexibility

Public-Private partnership (PPP) projects are complex procurement method that usually takes a long time to execute. Therefore, an effective and flexible contract of BIM-enabled PPP procurement is still unresolved. The study results demonstrate that content flexibility and executing flexibility assuredly impact the performance of BIM-enabled PPP projects(Xu et al., 2022). Another research direction identified positive and negative interactions of 28 legal and contractual issues with BIM-based construction projects(Abd Jamil & Fathi, 2018). One research direction focuses on public infrastructure procurement, differentiating adversarial and non-adversarial contracting methods. BIM technology adoption can readily address change orders related to poor design documentation(Regan et al., 2015). A different research approach deals with the similarities and differences between project partnering, project alliancing and integrated project delivery. Early involvement of key parties, transparent financials, shared risk and reward are critical features incorporated in all the arrangements(Lahdenperä, 2012). The future research agenda can be summarised as the impact and usage of BIM on various payment methods, more potential variables, the effect of contract flexibility (Xu et al., 2022), and creating framework analyses of BIM implementation throughout the whole life cycle of projects (Abd Jamil & Fathi, 2018).

Category 7: Risks and Challenges

Building Information Modelling (BIM) is a mechanism to improve collaboration and integration in PPP projects. However, BIM also exposes its users to additional risks when reducing information sharing-barriers. That is the driving motive to investigate the BIM risk factors significantly impacting PPP projects implementing BIM (Habib et al., 2020). An information management method was developed to cope with the risk problems involved in dealing with the increasing complexity of public-private partnership (PPP) projects. PPP failure cases and an extensive literature review establish a domain framework for risk knowledge(Jiang et al., 2022). The risk of accurate prediction of potential delays is another valuable information relevant to planning and mitigating the completion of PPP projects. a Big Data Analytics predictive modelling technique for completion risk prediction is suggested (Owolabi et al., 2018). Organisational and people-centred issues pose the most significant challenge for BIM implementation; However, the maturity and adoption of BIM depend mainly on the client or the owner in construction projects. BIM partnering-based public procurement framework is proposed to ensure the best value in construction projects(Porwal & Hewage, 2013). Another challenge facing BIM is legal and contractual issues, which represent positive and negative interactions. This study critically identifies the possible interactions between the legal and contractual aspects of BIM project procurement and the practical aspects of BIM project delivery(Abd Jamil & Fathi, 2018).

Another study deals with BIM implementation's collaboration and change management perspectives in construction to help manage PPP risks and share and reuse risk knowledge(Matthews et al., 2018). Government pressure and cultural factors are the main drivers for BIM adoption in the public sector, while competitor pressure and communication behaviour are in the private sector(Belay et al., 2021). The last research direction is to analyse the motivation, definition, and implications of servitisation in construction and its transformation pathway (Liu et al., 2021). The future research agenda is summarised as addressing technical competencies, social and legal impacting PPP projects(Habib et al., 2020), promoting interoperability between ontologies, and combining ontology technologies with BIM(Jiang et al., 2022), extensive data analysis investigation of historical overruns in PPP projects (Owolabi et al., 2018), national guidelines to scale BIM implementation in the construction industry (Porwal & Hewage, 2013), creating framework analyses of BIM implementation throughout the whole life cycle of projects (Abd Jamil & Fathi, 2018) (Belay et al., 2021), and finally, overcoming limitation to promote servitisation in construction(Liu et al., 2021).

Category 8: Energy Management

Building Information Modeling (BIM) and energy simulations are commonly utilised to help make better decisions. The progressive BIM methodology advises providing appropriate information to match the objective of an ongoing restoration design process, emphasising energy performance(Stegnar & Cerovšek, 2019)**.** A different approach suggests efficiently considering BIM techniques can reduce and lessen construction waste using a case study of a waste-to-energy project(Ajayi et al., 2017). Future studies should consider key design strategies critical to designing out construction waste and preventing waste-inducing activities(Ajayi et al., 2017).

Category 9: Facility Management

Facility management is potentially the area that can benefit the most from BIM adoption, yet it is still the least developed regarding implementation. Furthermore, even though there are an increasing number of publications about BIM-FM, the publication is unequal between public and private, and research regarding BIM for facility management for public organisations lacks standardisation(Pinti et al., 2022). However, the wide use of BIM and learning and innovation culture are significant opportunities for facility management development(Meng, 2015). Integration of FM in the development process is essential. Therefore, another research direction aims to establish the critical success factors for the facility management development process (FM-DP) framework. The study also found that BIM can help facility management adapt to PPP projects (Tucker & Masuri, 2018). Furthermore, another research direction aims to develop a strategic information taxonomy framework for facility management for healthcare facilities(Demirdöğen et al., 2021). Another research direction studied the cross-sectional fields of urban heritage conservation and urban facility management and found a potential application of BIM in urban heritage facility management that can be adapted to reuse in PPP projects (Prabowo et al., 2021). Future research agenda for this category could involve: Test the framework on different scenarios, building types and other FM software solutions, and Big Data Analytics implementation to enable efficient and faster queries(Demirdöğen et al., 2021), and further studies to understand how FM could be better integrated into the urban heritage management field (Prabowo et al., 2021).

Category 10: Healthcare

Healthcare facilities must ensure that patients receive safer services without interruption, and management requires precise and rapid information to facilitate decision-making processes. Therefore, the first research direction in this category aims to develop a strategic information taxonomy framework for facility management for healthcare facilities (Demirdöğen et al., 2021). Am automated portfolio-based strategic asset management based on deep neural image classification was investigated to accommodate the needs of operation and maintenance inspection-repair processes (Fang et al., 2022). Furthermore, a different research approach examines the hospital building project misperformance and finds that risk associated with procurement method choice is one of the main reasons for some hospital projects' misperformance (Love & Ika, 2022). Another research proposes recommendations for adopting an automated compliance system to check the design of healthcare buildings due to the complexity and extensive requirement for healthcare building design (Soliman-Junior et al., 2021). As an example of a successful BIM adoption in healthcare buildings, this research clarifies that a hospital design plan to combat Covid-19 in China was completed within 24 hours, and the construction of the hospital finished in only 60 hours (Abbas et al., 2021). The research agenda for this category could involve: Test the framework on different scenarios, building types and other FM software solutions, and Big Data Analytics implementation to enable efficient and faster queries (Demirdöğen et al., 2021), a hybrid solution for the automation application system should be further explored (Soliman-Junior et al., 2021), and finally to test and exploit the performance of the image classification system should be investigated (Fang et al., 2022).

Category 11: Critical Success Factors

BIM-enabled Project success factors cost, time and quality management, safety management, resource utilisation, conflict management, facility management, and interface management in PPP projects are the most critical to success(McArthur & Sun, 2015), starting by presenting a modern method for selecting up-to-date multi-attribute procurement for procurement methods in construction is essential (Naoum & Egbu, 2016). Key performance indicators (KPIs) of build-operate-transfer (BOT) projects were identified and analysed to study successful automated collaboration in construction (Budayan et al., 2020). Variables with active relations and cooperative working in design meetings were analysed to find the requirements for successful automated cooperation in the construction industry(Van Gassel et al., 2014). Furthermore, issues around project development stage integration must be tackled to achieve building lifecycle integration concerning the interface between the client and project organisations (Kamara, 2012). However, to improve the integration of projects, another study analysed the requirements for cloud-based BIM governance solutions to facilitate team collaboration in socio-organisational, legal, and technical requirements (Alreshidi et al., 2018). Another aspect of success factors indicates that effective use of BIM can directly improve project performance, and stakeholder management has a critical and positive role in BIM implementation (Zhang et al., 2022). Because rework negatively impacts project performance, addressing and mitigating rework occurrence in the construction industry is essential (Love et al., 2022).

Expanding BIM usage in construction can build a more promising future for proactive management utilising online cooperative possibilities. The BIM model enables contractors to be involved early in design decision-making (Meng, 2020). A different area of research deals with organisational conditions for BIM's role in rational and enriching the information flows among contractually bound supply chain partnerships (Papadonikolaki & Wamelink, 2017). A different research approach deals with the similarities and differences between project partnering, project alliancing and integrated project delivery. Early involvement of key parties, transparent financials, shared risk and reward are critical features incorporated in all the arrangements (Lahdenperä, 2012). The last research direction in this category deals with the influential role of BIM implementation in survey investment analysis in PPP projects(Boniotti, 2019). Future research agenda in this category can be described as the manner in which Key Performance Indicators could be measured (Budayan et al., 2020). To objectively develop and measure the level of success of recently completed projects based on an expert-based system (Naoum & Egbu, 2016), ensure effective integration and exchange of information from project development to project and from project to FM (Kamara, 2012), implement a prototype to produce a cloud-based BIM governance platform (Alreshidi et al., 2018), Explore stakeholders' impact and relationships under various contractual arrangements and contrasting BIM-enabled projects (Zhang et al., 2022), and supply chain collaboration performance with or without BIM implementation (Papadonikolaki & Wamelink, 2017).

Category 12: Information Exchange & Cloud-BIM

Public-Private Partnership is one of the most used procurement methods in government construction projects; PPP projects typically involve multidisciplinary and multi-actor collaborations that generate massive amounts of data over their lifecycle. Therefore, cloud-based governance solutions are suggested (Alreshidi et al., 2018). However, to analyse the requirements for cloud-based BIM governance solutions to facilitate team collaboration in socio-organisational, legal, and technical requirements and improve the integration of projects. The information exchange mechanism for Cloud BIM reflects the results of the semi-structured interviews. The concept's core is based on developing a cloud platform that hosts web-based BIM applications (Redmond et al., 2012). Another study deals with BIM progressive methodology to support energy renovation. Therefore, the proposed method suggests specifying adequate information to match the purpose of the progressive renovation design process (Stegnar & Cerovšek, 2019). Since Value for Money (VfM) is an essential assessment approach in PPP projects, developing an information exchange scheme using Building Information Modeling (BIM) can provide an appropriate way to address this challenge.(Ren et al., 2019), while a different approach aligned using BIM with ontology for information exchange and retrieval. Future research agenda can involve implementing a prototype to produce a cloud-based BIM governance platform (Alreshidi et al., 2018) and exploring addressing comprehensive performance assessment for PPP projects (Ren et al., 2019).

Table 1 Review sources of 34 academic journals and the identified articles during 2012–2022

Journal	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	total
Automation in Construction	1	1	1	1	0	0	1	0	0	2	1	8
Engineering, Construction and Architectural Management	0	0	0	0	0	0	0	0	2	1	1	4
applied sciences	0	0	0	0	0	0	0	0	1	1	1	3
J. of Building Engineering	0	0	0	0	0	0	1	1	0	1	0	3
Engineering	0	0	0	0	0	0	0	0	0	1	2	3
Sustainability	0	0	0	0	0	0	1	0	0	1	0	2
Built Environment Project and Asset Management	0	0	0	0	1	0	1	0	0	0	0	2
construction innovation	0	0	0	0	0	0	0	0	0	1	1	2
Production Planning & Control	0	0	0	0	0	0	1	0	1	0	0	2
J. of public procurement	0	0	0	1	0	0	0	0	0	1	0	2
Transportation Research Part A	0	0	0	0	0	2	0	0	0	0	0	2
International J. of Managing Projects in Business	0	0	0	0	0	0	0	0	1	0	1	2
Complexity	0	0	0	0	0	0	0	0	0	1	0	1
J. of Infrastructure Systems	0	0	0	0	0	0	0	0	0	0	1	1
Planning Malaysia	0	0	0	0	0	0	0	0	1	0	0	1
Advances in Civil Engineering	0	0	0	0	0	0	0	0	0	1	0	1
IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT	0	0	0	0	0	0	1	0	0	0	0	1
Energy	0	0	0	0	0	0	0	1	0	0	0	1
Research in Transportation Economics	0	0	0	0	0	0	0	0	0	1	0	1
International J. of Project Management	0	0	0	0	0	0	0	0	1	0	0	1
Renewable and Sustainable Energy Reviews	0	0	0	0	0	1	0	0	0	0	0	1
Transport Policy	0	0	0	0	0	0	0	1	0	0	0	1
Transportation Research Part D	0	0	0	0	0	0	0	1	0	0	0	1
Applied Soft Computing	0	0	0	0	0	0	0	0	0	1	0	1
Built Environment	0	0	0	1	0	0	0	0	0	0	0	1
J. of Management and Governance	0	0	0	0	0	0	0	0	0	1	0	1
BUILDING RESEARCH & INFORMATION	0	0	0	0	0	1	0	0	0	0	0	1
International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences	0	0	0	0	0	0	0	1	0	0	0	1
Tunnelling and Underground Space Technology	0	0	0	0	0	0	0	0	0	1	0	1

Architectural Engineering and Design Management	**1**	0	0	0	0	0	0	0	0	0	0	**1**
Property Management	0	0	0	**1**	0	0	0	0	0	0	0	**1**
Requirements engineering	0	0	0	0	0	0	**1**	0	0	0	0	**1**
Construction management and economics	**1**	0	0	0	0	0	0	0	0	0	0	**1**
Total Per Year	**3**	**1**	**1**	**4**	**1**	**4**	**7**	**5**	**7**	**15**	**8**	**56**

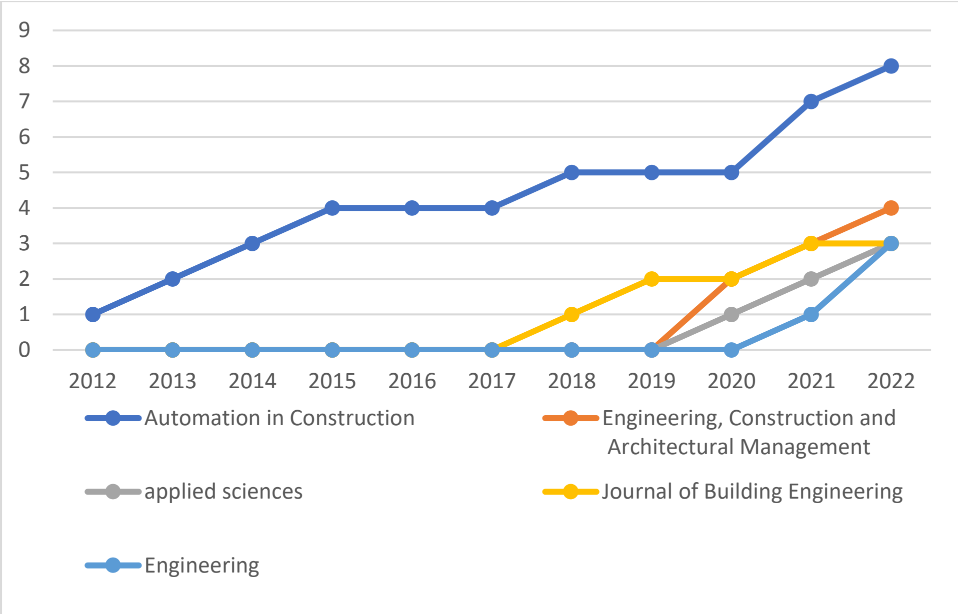

Fig.3. Articles per year per source (Top 5 journals).

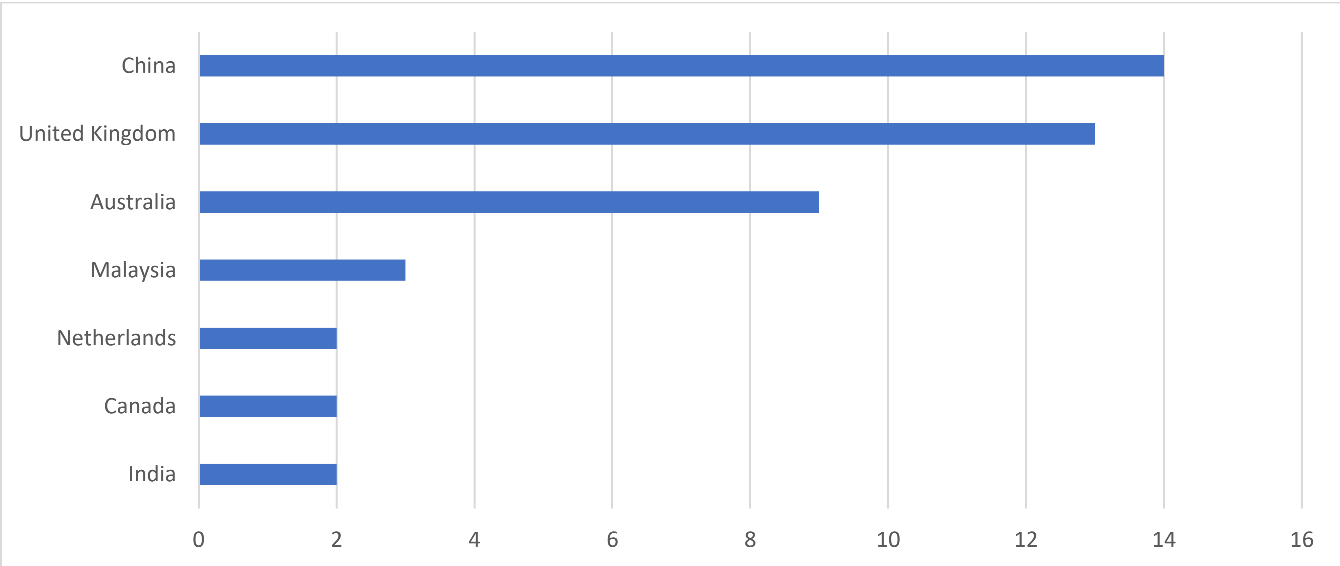

Fig. 4. Articles by country or territory (Top 7 countries)

Table 2 The top ten cited articles according to the Google Scholar citation metric

Citat-ion	Author	Title	Journal	Year
600	(Porwal & Hewage, 2013)	Building Information Modeling (BIM) partnering framework for public construction projects	Automation in construction	2013
522	(Lahdenperä, 2012)	Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery	Construction management and economics	2012
356	(Redmond et al., 2012)	Exploring how information exchanges can be enhanced through Cloud BIM	Automation in Construction	2012
133	(Love et al., 2015)	Future proofing PPPs: Life-cycle performance measurement and building information modelling	Automation in Construction	2015
98	(Alreshidi et al., 2018)	Requirements for cloud-based BIM governance solutions to facilitate team collaboration in construction projects	Requirements engineering	2018
98	(Matthews et al., 2018)	Building information modelling in construction: insights from collaboration and change management perspectives	Production Planning & Control	2018
94	(Papadonikolaki & Wamelink, 2017)	Inter- and intra-organizational conditions for supply chain integration with BIM	BUILDING RESEARCH & INFORMATION	2017
57	(Love, Zhou, et al., 2017)	Off the rails: The cost performance of infrastructure rail projects	Transportation Research Part A	2017
57	(Ajayi et al., 2017)	Attributes of design for construction waste minimization: A case study of waste-to-energy project	Renewable and Sustainable Energy Reviews	2017
41	(Abd Jamil & Fathi, 2018)	Contractual challenges for BIM-based construction projects: a systematic review	Built Environment Project and Asset Management	2018

IV. FINDINGS DISCUSSION

The study of reviewing Building Information Modeling (BIM) and its applications in Public Private Partnership (PPP) projects encompass a wide range of categories. The content analysis results (Fig. 6.) of this study identified 12 main key themes of research, which are: stakeholders management, value for money, performance evaluation, sustainability, infrastructure, contractual flexibility, risks and challenges, energy management, facility management, healthcare, critical success factors, and information exchange & cloud-BIM. Each key theme highlights an essential aspect of BIM for PPP in a holistic approach.

Several Keywords were used to explore the literature on the topic. However, keyword clustering shows the most commonly used keywords for the issues related to BIM for PPP, as shown in (Fig. 5.) is It was found that "architectural design," "building information modeling," "project management," "public-private partnership," "performance assessment," "performance measuring," and "value for money" were the most frequently used keywords. Keyword clustering shows the critical and relevant application of BIM in PPP construction projects and highlights the importance of evaluating, assessing, and measuring their success.

Many studies were conducted, and many publications were published on BIM related to PPP projects. However, the top publications in various academic journals are shown in Table 1 and Figure 3 from 2012 and 2022. The most ranked journals were Automation in Construction, Engineering Construction and Architectural Management, and Applied Sciences, each with 8, 4, and 3 publications, respectively. The findings highlight the importance and relevance of this topic which increases in publication, indicating that further research can and should be done to understand better and cover the research gaps.

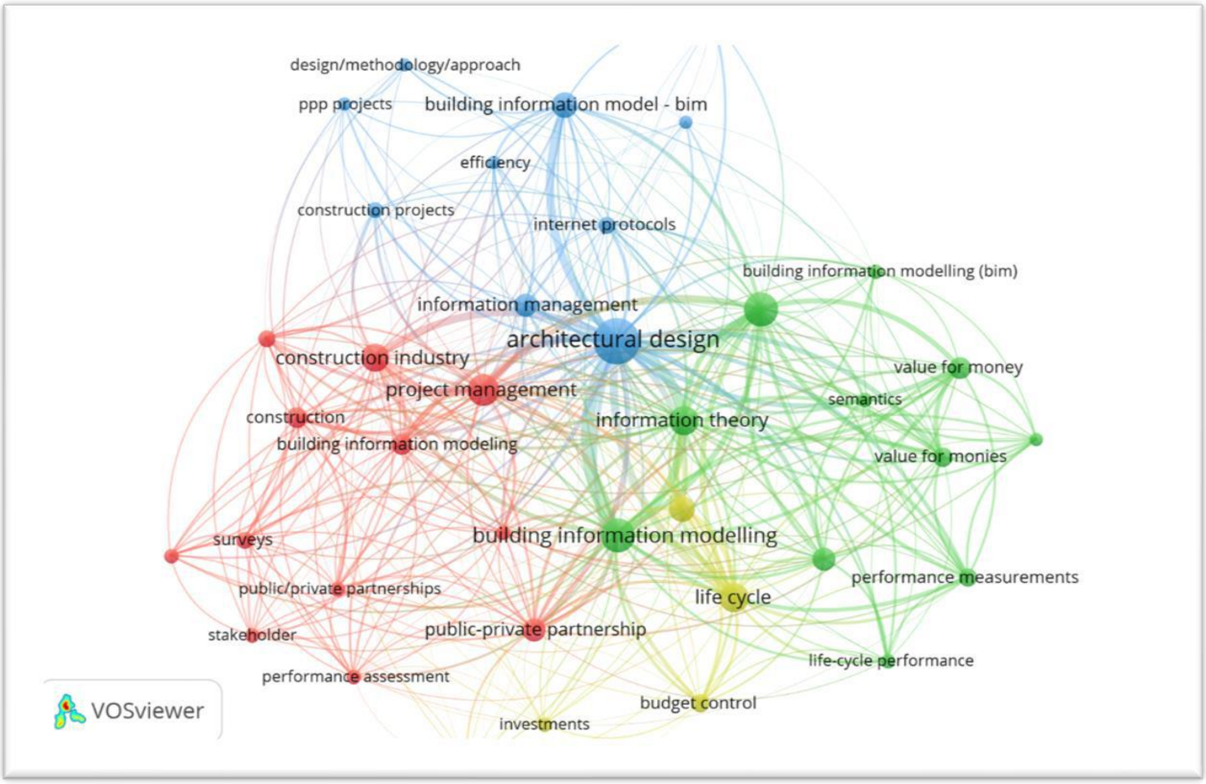

Fig. 5. Keyword Clustering.

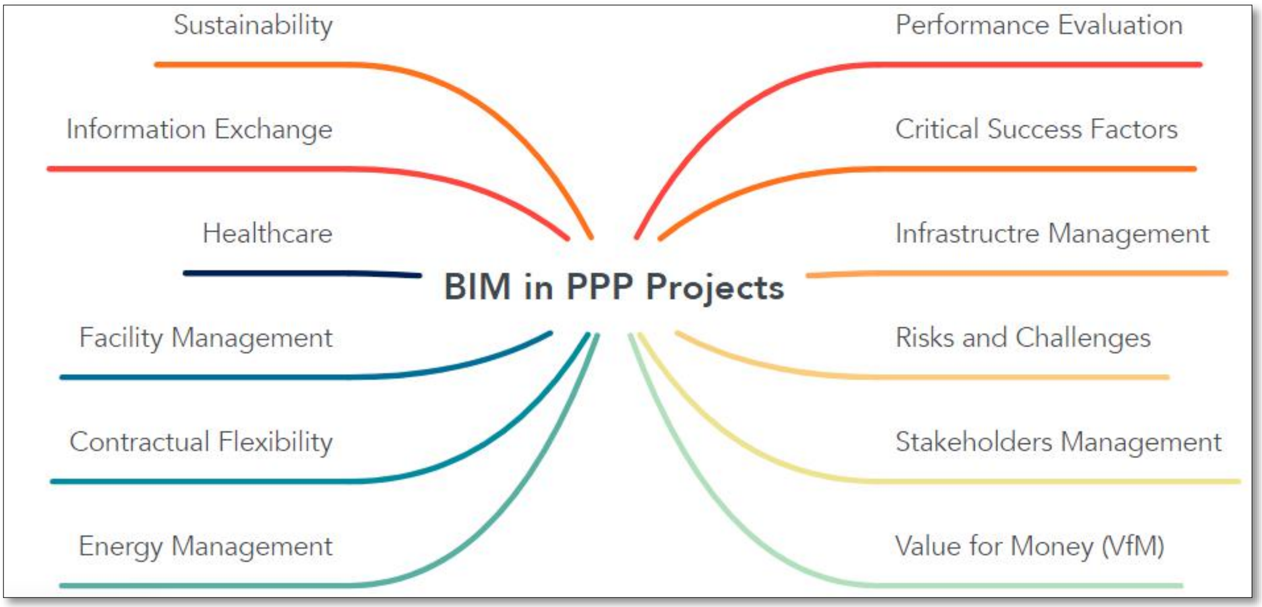

Fig. 6. Content analysis results.

The top cited articles within the 56 articles selected in this review, as shown in Table 2, were "Building Information Modeling (BIM) partnering framework for public construction projects" by Porwal and Hewage, published in 2013, with 600 citations. Lahdenperä's article "Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery" from 2012 is the second most cited article with 522 citations. The third most cited article is "Exploring how information exchanges can be enhanced through Cloud

BIM" by Redmond et al., published in 2012 with 356 citations. The number of citations for these publications suggests that BIM for PPP is still a relatively new topic that many studies still investigate to understand further the collaboration and performance enhancement this new technology can provide for the construction industry.

From a country point of view, as elaborated in Figure 3, China has the highest publication at 14, followed closely by the United Kingdom at 13. The third and fourth places were Australia, then Malaysia at 9 and 3 publications. The results suggest that the previously mentioned countries are the most active in studying this field and have invested more resources into research in this area.

Overall the implication of this study suggests that BIM implementation for PPP projects can enhance stakeholder management, improve the value for money, enhance performance evaluation and sustainability, and help better manage risk for PPP. Furthermore, this study highlights the importance of analyzing critical success factors to overcome challenges related to BIM for PPP projects. This review analysis can provide valuable insights for practitioners and policymakers dealing with PPP projects.

V. CONCLUSION

This paper provided an overview of BIM adoption in PPP projects, shedding light on research areas, future research agenda, and current risks and challenges in different types of PPP projects. Fifty-six articles published between 2012 and 2022 were recalled and systematically reviewed, where existing literature gaps and future research opportunities were traced. Implementation of BIM in PPP projects can be successfully achieved based on this analysis through: More case studies from the real world to investigate the current state of BIM implementation in PPP projects, addressing technical competencies, social and legal impacting PPP projects, developing national guidelines to scale BIM implementation in the construction industry, creating framework analyses of BIM implementation throughout the whole life cycle of projects, and ensuring a standardised process for feedback loops between operations and design phases.

Eventually, it is hoped that this paper will clarify the current research areas and future research agenda, which will help the smooth implementation of BIM in PPP projects to reap the benefits and overcome the challenges. Despite this study's strengths, further review studies should consider different types of PPP projects and explore their challenges, risks, and future developments throughout the whole building life cycle. BIM implementation in PPP projects will be a growing research area for many years. To overcome the current challenges, developments in this area necessitate the collaboration of academics and practitioners from the industry.

REFERENCES

[1] Abbas, H. S. M., Xu, X., Sun, C., Gillani, S., & Raza, M. A. A. (2021). Role of Chinese government and Public–Private Partnership in combating COVID-19 in China. *Journal of Management and Governance*, 1-22.

[2] Abd Jamil, A. H., & Fathi, M. S. (2018). Contractual challenges for BIM-based construction projects: a systematic review. *Built Environment Project and Asset Management*.

[3] Ajayi, S. O., Oyedele, L. O., Akinade, O. O., Bilal, M., Alaka, H. A., Owolabi, H. A., & Kadiri, K. O. (2017). Attributes of design for construction waste minimization: A case study of waste-to-energy project. *Renewable and Sustainable Energy Reviews*, *73*, 1333-1341.

[4] Alreshidi, E., Mourshed, M., & Rezgui, Y. (2018). Requirements for cloud-based BIM governance solutions to facilitate team collaboration in construction projects. *Requirements engineering*, *23*(1), 1-31.

[5] Belay, S., Goedert, J., Woldesenbet, A., & Rokooei, S. (2021). Comparison of BIM adoption models between public and private sectors through empirical investigation. *Advances in Civil Engineering*, *2021*.

[6] Boniotti, C. (2019). THE BENEFICIAL ROLE OF SURVEYS IN THE INVESTMENT ANALYSIS FOR PUBLIC BUILT CULTURAL HERITAGE CONCESSIONS. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*.

[7] Budayan, C., Okudan, O., & Dikmen, I. (2020). Identification and prioritization of stage-level KPIs for BOT projects–evidence from Turkey. *International Journal of Managing Projects in Business*.

[8] Cao, D., Shao, S., Huang, B., & Wang, G. (2021). Multidimensional behavioral responses to the implementation of BIM in construction projects: an empirical study in China. *Engineering, Construction and Architectural Management*.

[9] Chen, Z.-S., Yang, L.-L., Chin, K.-S., Yang, Y., Pedrycz, W., Chang, J.-P., Martínez, L., & Skibniewski, M. J. (2021). Sustainable building material selection: An integrated multi-criteria large group decision making framework. *Applied Soft Computing*, *113*, 107903.

[10] Demirdöğen, G., Işık, Z., & Arayici, Y. (2021). Facility management information taxonomy framework for queries in healthcare buildings. *Journal of Building Engineering*, *44*, 102510.

[11] Fang, Z., Tan, T., Yan, J., Lu, Q., Pitt, M., & Hanna, S. (2022). Automated portfolio-based strategic asset management based on deep neural image classification. *Automation in Construction*, *142*, 104481.

[12] Habib, S. N. H. A., Ismail, S., & Khuzzan, S. M. S. (2020). RISK FACTORS TOWARDS PUBLIC-PRIVATE PARTNERSHIPS (PPP) PROJECTS IMPLEMENTING BUILDING INFORMATION MODELLING (BIM) IN THE

UNITED KINGDOM (UK): A LESSON LEARNT FOR MALAYSIA. *Planning Malaysia*, *18*.
[13] Hoeft, M., Pieper, M., Eriksson, K., & Bargstädt, H.-J. (2021). Toward life cycle sustainability in infrastructure: the role of automation and robotics in PPP projects. *Sustainability*, *13*(7), 3779.
[14] Jia, C., Zhang, R., & Wang, D. (2021). Evolutionary game analysis of BIM adoption among stakeholders in PPP projects. *Complexity*, *2021*.
[15] Jiang, X., Wang, S., Liu, Y., Xia, B., Skitmore, M., Nepal, M., & Ghanbaripour, A. N. (2022). A method for the ontology-based risk management of PPP construction projects. *Construction Innovation*(ahead-of-print).
[16] Kamara, J. M. (2012). Integration in the project development process of a Private Finance Initiative (PFI) project. *Architectural Engineering and Design Management*, *8*(4), 228-245.
[17] Lahdenperä, P. (2012). Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. *Construction management and economics*, *30*(1), 57-79.
[18] Liu, D., Wang, H.-W., Zhong, B.-T., & Ding, L.-Y. (2021). Servitization in Construction and its Transformation Pathway: A Value-Adding Perspective. *Engineering*.
[19] Liu, H. J., Love, P. E., Sing, M. C., Niu, B., & Zhao, J. (2019). Conceptual framework of life-cycle performance measurement: Ensuring the resilience of transport infrastructure assets. *Transportation Research Part D: Transport and Environment*, *77*, 615-626.
[20] Love, P. E., Ahiaga-Dagbui, D., Welde, M., & Odeck, J. (2017). Light rail transit cost performance: Opportunities for future-proofing. *Transportation Research Part A: Policy and Practice*, *100*, 27-39.
[21] Love, P. E., & Ika, L. A. (2022). Making Sense of Hospital Project MisPerformance: Over Budget, Late, Time and Time Again—Why? And What Can Be Done About It? *Engineering*, *12*, 183-201.
[22] Love, P. E., Ika, L. A., Matthews, J., Li, X., & Fang, W. (2021). A procurement policy-making pathway to future-proof large-scale transport infrastructure assets. *Research in Transportation Economics*, *90*, 101069.
[23] Love, P. E., Liu, J., Matthews, J., Sing, C.-P., & Smith, J. (2015). Future proofing PPPs: Life-cycle performance measurement and building information modelling. *Automation in Construction*, *56*, 26-35.
[24] Love, P. E., Matthews, J., Sing, M. C., Porter, S. R., & Fang, W. (2022). State of science: Why does rework occur in construction? What are its consequences? And what can be done to mitigate its occurrence? *Engineering*.
[25] Love, P. E., Zhou, J., Edwards, D. J., Irani, Z., & Sing, C.-P. (2017). Off the rails: The cost performance of infrastructure rail projects. *Transportation Research Part A: Policy and Practice*, *99*, 14-29.
[26] Ma, L., Le, Y., Li, H., Jin, R., Piroozfar, P., & Liu, M. (2018). Regional comparisons of contemporary construction industry sustainable concepts in the Chinese context. *Sustainability*, *10*(11), 3831.
[27] Malaeb, Z., & Hamzeh, F. R. (2021). IPD-inspired framework for measuring stakeholder integration in public-private partnerships. *Construction Innovation*.
[28] Matthews, J., Love, P. E., Mewburn, J., Stobaus, C., & Ramanayaka, C. (2018). Building information modelling in construction: insights from collaboration and change management perspectives. *Production Planning & Control*, *29*(3), 202-216.
[29] McArthur, J., & Sun, X. (2015). Best practices for BIM execution plan development for a public–private partnership design-build-finance-operate-maintain project. *Built Environ*, *149*, 119-130.
[30] Meng, X. (2015). Facilities management: tracing its development trajectory. *Property Management*.
[31] Meng, X. (2020). Proactive management in the context of construction supply chains. *Production Planning & Control*, *31*(7), 527-539.
[32] Naoum, S. G., & Egbu, C. (2016). Modern selection criteria for procurement methods in construction: A state-of-the-art literature review and a survey. *International Journal of Managing Projects in Business*.
[33] Owolabi, H. A., Bilal, M., Oyedele, L. O., Alaka, H. A., Ajayi, S. O., & Akinade, O. O. (2018). Predicting completion risk in PPP projects using big data analytics. *IEEE Transactions on Engineering Management*, *67*(2), 430-453.
[34] Papadonikolaki, E., & Wamelink, H. (2017). Inter-and intra-organizational conditions for supply chain integration with BIM. *Building research & information*, *45*(6), 649-664.
[35] Patil, N. A., & Laishram, B. S. (2016). Sustainability of Indian PPP procurement process: development of strategies for enhancement. *Built Environment Project and Asset Management*.
[36] Patil, N. A., Thounaojam, N., & Laishram, B. (2021). Enhancing sustainability of Indian PPP procurement process using system dynamics model. *Journal of Public Procurement*.
[37] Pinti, L., Codinhoto, R., & Bonelli, S. (2022). A Review of Building Information Modelling (BIM) for Facility Management (FM): Implementation in Public Organisations. *Applied Sciences*, *12*(3), 1540.
[38] Porwal, A., & Hewage, K. N. (2013). Building Information Modeling (BIM) partnering framework for public construction projects. *Automation in Construction*, *31*, 204-214.
[39] Prabowo, B. N., Salaj, A. T., & Lohne, J. (2021). Urban Heritage Facility Management: A Scoping Review. *Applied Sciences*, *11*(20), 9443.
[40] Redmond, A., Hore, A., Alshawi, M., & West, R. (2012). Exploring how information exchanges can be enhanced through Cloud BIM. *Automation in Construction*, *24*, 175-183.
[41] Regan, M., Love, P. E., & Jim, J. (2015). Public infrastructure procurement: a review of adversarial and non-adversarial contracting methods. *Journal of Public Procurement*, *15*(4), 405-438.
[42] Ren, G., Li, H., Ding, R., Zhang, J., Boje, C., & Zhang, W. (2019). Developing an information exchange scheme

concerning value for money assessment in Public-Private Partnerships. *Journal of Building Engineering*, *25*, 100828.

[43] Ren, G., Li, H., Liu, S., Goonetillake, J., Khudhair, A., & Arthur, S. (2021). Aligning BIM and ontology for information retrieve and reasoning in value for money assessment. *Automation in Construction*, *124*, 103565.

[44] Ren, G., Li, H., & Zhang, J. (2020). A BIM-based value for money assessment in public-private partnership: an overall review. *Applied Sciences*, *10*(18), 6483.

[45] Rothengatter, W. (2019). Megaprojects in transportation networks. *Transport Policy*, *75*, A1-A15.

[46] Sankaran, B., Nevett, G., O'Brien, W. J., Goodrum, P. M., & Johnson, J. (2018). Civil Integrated Management: Empirical study of digital practices in highway project delivery and asset management. *Automation in Construction*, *87*, 84-95.

[47] Soliman-Junior, J., Tzortzopoulos, P., Baldauf, J. P., Pedo, B., Kagioglou, M., Formoso, C. T., & Humphreys, J. (2021). Automated compliance checking in healthcare building design. *Automation in Construction*, *129*, 103822.

[48] Stegnar, G., & Cerovšek, T. (2019). Information needs for progressive BIM methodology supporting the holistic energy renovation of office buildings. *Energy*, *173*, 317-331.

[49] Tucker, M., & Masuri, M. R. A. (2018). The development of facilities management-development process (FM-DP) integration framework. *Journal of Building Engineering*, *18*, 377-385.

[50] Van Gassel, F., Láscaris-Comneno, T., & Maas, G. J. (2014). The conditions for successful automated collaboration in construction. *Automation in Construction*, *39*, 85-92.

[51] Wang, G., & Zhang, Z. (2021). BIM implementation in handover management for underground rail transit project: A case study approach. *Tunnelling and Underground Space Technology*, *108*, 103684.

[52] Xu, Y., Chong, H.-Y., & Chi, M. (2022). Impact of Contractual Flexibility on BIM-Enabled PPP Project Performance during the Construction Phase. *Journal of Infrastructure Systems*, *28*(1), 04021057.

[53] Xu, Z., Wang, X., Xiao, Y., & Yuan, J. (2020). Modeling and performance evaluation of PPP projects utilizing IFC extension and enhanced matter-element method. *Engineering, Construction and Architectural Management, 27*(8), 1763-1794.

[54] Xue, J., Shen, G. Q., Yang, R. J., Wu, H., Li, X., Lin, X., & Xue, F. (2020). Mapping the knowledge domain of stakeholder perspective studies in construction projects: A bibliometric approach. *International Journal of Project Management*, *38*(6), 313-326.

[55] Yuan, J., Li, X., Ke, Y., Xu, W., Xu, Z., & Skibnewski, M. (2020). Developing a building information modeling–based performance management system for public–private partnerships. *Engineering, Construction and Architectural Management*.

[56] Zhang, H. M., Chong, H.-Y., Zeng, Y., & Zhang, W. (2022). The effective mediating role of stakeholder management in the relationship between BIM implementation and project performance. *Engineering, Construction and Architectural Management*.

