

Optimising Construction Supply Chain Resilience Through Building Information Modelling (BIM) Integration in South Africa

Basit Giwa-Bioku ¹, Clinton Aigbavboa ¹, Opeoluwa Akinradewo ²

¹ *cidb Centre for Excellence and Sustainable Human Settlement and Construction Research Centre, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa*
basitbolakale@gmail.com, caigbavboa@uj.ac.za

² *Department of Quantity Surveying and Construction Management, Faculty of Natural and Agricultural Sciences, University of the Free State, South Africa*
opeakinradewo@gmail.com

Abstract

This study explored integrating Building Information Modelling (BIM) to optimise construction supply chain resilience in South Africa. Through bibliometric analysis embedded in the Scopus database, coupled with the use of keywords such as “construction,” AND “supply,” AND “chain,” AND “building,” AND “information,” AND “modelling,” and the use of Vosviewer to generate occurrence map, 290 papers were exported. The findings showed that integrating BIM from a South African perspective would improve operation. Recommendations emphasized stakeholders' need to invest in BIM technology tools, promote collaboration across the supply chain, and advocate standardized protocols. This study highlights the multifaceted impact of BIM, which includes enhancements in architectural and structural design, the integration of lean principles, and the incorporation of technological innovations such as radio frequency identifiers (RFID) and the Internet of Things (IoT). Furthermore, this research underscores the importance of effective information management, decision-making processes, and knowledge sharing within the construction industry. By embracing these recommendations, the South African construction industry can leverage BIM to enhance efficiency, resilience, and sustainability, thereby positioning itself for continual growth and development.

Keywords: Building Information Modelling (BIM), Supply Chain, Resilience, Construction Sustainability, Technology Adoption.

1. INTRODUCTION

The construction industry in South Africa has notable potential. However, numerous internal and external challenges continue to restrict their capabilities. Unless these obstacles are comprehensively identified, the growth of this industry is anticipated to be impeded (Pillay et al., 2018). Riazi et al. (2020) stated that the construction industry is complicated because of fragmented processes, construction challenges, and numerous stakeholders. Building Information Modelling (BIM) can help address the organizational, operational, and technical complexities in the construction supply chain (SC) (Tezel et al., 2019). Additionally, Supply Chain Management (SCM) has proven effective in managing material, information, cash, and work-crew flows among strategically aligned companies (Papadonikolaki et al., 2017).

Fait et al. (2024) highlight the importance of supply chains in driving innovation and sustaining continuous performance enhancement. Nevertheless, the implementation of

2nd International Conference on Construction Project Management and Construction Engineering, 20-23
Nov 2024, Sydney, Australia

conventional supply chain management practices in the construction industry can be daunting because of its distinctive characteristics. BIM has become a pivotal component in construction supply chain management, offering a transformative approach to project planning, execution, and management throughout the construction lifecycle. In the planning and design phases, BIM acts as a dynamic digital twin for a building or infrastructure project (Qiao et al., 2021). Architects and designers leverage BIM to create a three-dimensional representation that not only captures the physical attributes of the structure, but also integrates valuable data related to materials, costs, and scheduling. This rich information environment enables more accurate and detailed planning, allowing for better decision-making regarding design choices, material selection, and construction methodologies (Sholeh et al., 2020).

Building Information Modelling (BIM) facilitates collaborative design processes because multiple stakeholders can work concurrently on the same digital model (Qiao et al., 2021). Meng (2020) further stated that this collaboration enhances communication and coordination among architects, engineers, and other professionals, reducing the likelihood of errors and discrepancies that may arise from disjointed communication channels. Additionally, BIM enables the simulation of various design scenarios, allowing for informed decision-making regarding energy efficiency, sustainability, and overall project feasibility (Succar, 2009). Hence, this study explores the implementation of BIM technology that explicitly contribute to enhancing the resilience of the construction supply chain in South Africa.

2. BUILDING INFORMATION MODELLING IN CONSTRUCTION SUPPLY CHAIN MANAGEMENT

Building information modelling (BIM) serves as a comprehensive digital representation of a building or infrastructure project, transcending the limitations of traditional 2D drawings by incorporating three-dimensional, dynamic information (Akhavan et al., 2021). This digital model encompasses various facets, including geometry, spatial relationships, geographic data, and quantities, creating a centralized repository that acts as a shared knowledge base for all project stakeholders incorporated into its cycle. BIM has become pivotal in construction supply chain management (Raco et al., 2021). It offers a transformative approach to planning, executing, and managing projects throughout their lifecycle (Samimpay & Saghatforoush, 2020). Integrating BIM in construction supply chain management addresses several challenges inherent in traditional construction processes, providing a holistic and data-driven solution that improves efficiency, collaboration, and decision-making at every stage of the construction project.

2.1 Planning and Design Phase

In the planning and design phase, BIM acts as a dynamic digital twin of the building or infrastructure project (Qiao et al., 2021). Architects and designers leverage BIM to create a three-dimensional representation that not only captures the physical attributes of the structure but also integrates valuable data related to materials, costs, and scheduling. This rich information environment enables more accurate and detailed planning, allowing for better decision-making regarding design choices, material selection, and construction methodologies (Sholeh et al., 2020).

2.2 Construction Phase

During the construction phase, BIM is a powerful tool for project coordination and management (Teicholz et al., 2013). The three-dimensional model created in the planning phase becomes a central repository of information that is accessible to all stakeholders involved in construction. This shared digital environment enhances

communication and coordination between architects, contractors, subcontractors, and suppliers (Sholeh et al., 2020).

2.3 Supply Chain Management

Teicholz et al. (2013) stated that BIM integrates seamlessly with supply chain management and provides a platform for efficient collaboration between construction teams and suppliers. The digital model contains detailed information about materials, quantities, and specifications, enabling accurate procurement planning. Suppliers can access this information in real time, allowing them to align their production and delivery schedules with the construction timeline (Uzairuddin & Jaiswal, 2022).

2.4 Operation and Maintenance

Beyond the construction phase, BIM plays a vital role in the operation and maintenance of built assets. The digital twin created during the planning and design phase evolves into a comprehensive facility management tool (Uzairuddin & Jaiswal, 2022). Facility managers can access information about the building's components, systems, and maintenance schedules, streamlining ongoing operations.

2.5 Collaboration and Communication

Its implementation fosters a culture of collaboration and communication among stakeholders, breaking down the silos that often characterize traditional construction projects, as stated by Whitlock et al. (2021) and Sholeh et al. (2020). Architects, engineers, contractors, and other team members can work simultaneously on the same model, contributing their expertise and insights. This collaborative environment promotes a more holistic understanding of the project, as each discipline can visualize and understand the implications of their decisions on the overall design and construction process. Real-time updates and version control ensure that all stakeholders work with the latest information, reducing the risk of miscommunication and errors (Sholeh et al., 2020).

2.6 Risk Mitigation and Clash Detection

Its advanced clash detection capabilities significantly contribute to risk mitigation during the construction phase (Yevu et al., 2021). The model allows for identifying clashes or conflicts between different building systems, such as electrical, plumbing, and structural elements. Detecting these clashes early in the process enables proactive resolution before construction begins, avoiding costly rework and delays (Zhang et al., 2020). This risk mitigation aspect is crucial for maintaining project timelines and budgets while ensuring the quality and integrity of the final built structure.

2.7 Cost Estimation and Budgeting

Building Information Modelling (BIM) enhances cost estimation and budgeting by providing accurate and detailed information about materials, quantities, and construction processes (Zhang et al., 2020). This enables more precise cost forecasting and budgeting, reducing the likelihood of cost overruns. Additionally, BIM supports evaluating alternative materials and construction methodologies, allowing project managers to make informed decisions that align with budgetary constraints (Chen & Nguyen, 2019). Integrating BIM with cost estimation software further streamlines the budgeting process, creating a more transparent and accountable financial framework for construction projects.

2.8 Sustainability Integration

Regarding sustainability integration, BIM is crucial in promoting sustainability within the construction industry, as stated in the study by Fitriawijaya et al. (2019). Simulating and analyzing different design scenarios allows stakeholders to make informed decisions regarding energy efficiency, resource optimization, and environmental impact (Lu et al., 2017). BIM's data-rich environment facilitates the integration of sustainable practices, such as green building materials and energy-efficient systems, into the design and construction process. This aligns with the global shift towards sustainable construction practices and green building certifications (Fitriawijaya et al., 2019).

2.9 Supply Chain Optimization

In supply chain management, BIM optimizes the procurement process by providing a comprehensive view of materials, specifications, and quantities required for the project (Pryke, 2020). This facilitates efficient collaboration between construction teams and suppliers, enhancing supply chain visibility. Suppliers can access real-time information on project requirements, enabling them to synchronize production and delivery schedules with construction timelines (Han et al., 2022). This level of transparency minimizes the risk of delays, cost fluctuations, and disruptions within the supply chain, contributing to smoother and more predictable construction operations.

2.10 Facility Management and Lifecycle Analysis

BIM's impact extends far beyond the construction phase into facility management. As the project transitions to operation, the digital twin created during the planning and design phase evolves into a valuable tool for facility managers (Deng et al., 2019). BIM for Facilities Management (BIM FM) enables efficient space utilization, maintenance planning, and asset management (Hijazi et al., 2023). Integrating real-time data and historical performance information allows for predictive maintenance, reducing downtime and extending the lifespan of building systems (Han et al., 2022). Furthermore, BIM facilitates lifecycle cost analysis, empowering facility managers to make informed decisions regarding renovations, upgrades, and long-term sustainability initiatives.

3. RESEARCH METHODOLOGY

This study aimed to investigate the utilization of Building Information Modelling (BIM) technology tools in bolstering the resilience of the construction supply chain in South Africa, employing a bibliometric methodology to delineate knowledge domains through the analysis of research trends. The data collection process centered on scrutinizing previously published works within the Scopus database, which is renowned across various scientific disciplines (Guz & Rushchitsky, 2009). Despite the historical predominance of the Web of Science (ISI) in scholarly research, Scopus, established by Elsevier Science in 2004, swiftly emerged as a favoured option for literature exploration, garnering widespread recognition for its comprehensive coverage compared to alternative databases (Chadegani et al., 2013; Hosseini et al., 2018). This study specifically focused on Scopus, a contemporary and rapidly expanding repository highly esteemed among the scientific community (Aghimien et al., 2019). The literature search encompassed terms such as “construction,” “supply,” “chain,” “building,” “information,” and “modelling,” restricted to disciplines including Engineering, Business Management and Accounting, Computer Science, Environmental Science, Social Sciences, Economics, Econometrics, and Finance, with English as the designated language. The search was conducted on March 13, 2024, and yielded 290 papers that met the specified criteria. VOS viewer, a literature review software, was employed for visual representation, selectively displaying nodes in bibliometric networks and

employing distance-based visualizations for effective presentation (Van Eck & Waltman, 2014; Zheng et al., 2016).

4. RESULTS (DISCUSSIONS)

4.1 Publication per document type

Table 1 provides a breakdown of publications based on document types related to Building Information Modelling (BIM) in the construction supply chain in South Africa. Most contributions come from journal articles, with 137 publications emphasising disseminating research findings through scholarly channels. Conference papers and conference reviews contribute significantly, with 93 and 30 publications suggesting a notable presence of BIM-related research in conference settings. Reviews, book chapters, and books represent additional contributions, with 20, 7, and 5 publications showcasing a diversified range of scholarly outputs. This distribution suggests a well-rounded research landscape with in-depth analyses, conference presentations, and comprehensive reviews contributing to the understanding and advancing of BIM technology in the South African construction supply chain.

Table 1. Publication per document type

| Document Type | Number of Publications |
|---------------------|------------------------|
| Journals (articles) | 137 |
| Conference paper | 93 |
| Conference review | 30 |
| Review | 20 |
| Book chapter | 7 |
| Book | 5 |

4.2 Publication per authors' citations

The findings in Table 2 illuminate the collaborative dynamics within the research landscape of Building Information Modelling (BIM) in the South African construction supply chain. Ioan Petri and Yacine Rezgui are significant contributors, each co-authoring five publications, aligning with their recognized roles in BIM research (Aghimien et al., 2019). Eleni Papadonikolaki, Hans Wamelink, and Juns Wang have made substantial contributions, with Papadonikolaki focusing on BIM adoption challenges (Papadonikolaki et al., 2017), Wamelink on BIM and sustainability (Wamelink et al., 2017), and Wang on BIM in project management (Wang et al., 2020). Citations indicate the impact of Petri's work, with 122 citations consistent with his acknowledged influence. Conversely, Abdul-Majeed Mahamadu, Srinath Perera, Debasis Sarkar, and Fan Xue show no citations, suggesting limited visibility or impact. The "Total link strength" metric highlights a robust collaborative network among Petri, Rezgui, Papadonikolaki, Wamelink, and the Wangs (Qiao et al., 2021). This underscores the significance of collaborative efforts and key contributors shaping BIM research in the South African construction supply chain, emphasizing the importance of citation impact as a measure of scholarly influence.

Table 2. Publication per co-authorship

| Author | Document | Citation | Total link strength |
|------------------------|----------|----------|---------------------|
| Petri, Ioan | 5 | 122 | 5 |
| Rezgui, Yacine | 7 | 131 | 5 |
| Papadonikolaki, Eleni | 8 | 181 | 4 |
| Wamelink, Hans | 4 | 163 | 4 |
| Wang, Juns | 4 | 88 | 4 |
| Wang, Xiangyu | 5 | 204 | 4 |
| Mahamadu, Abdul-majeed | 4 | 108 | 0 |
| Perera, Srinath | 4 | 57 | 0 |
| Sarkar, Debasis | 4 | 9 | 0 |
| Xue, Fan | 5 | 421 | 0 |

4.3 Publication per co-occurrence of keywords

With the minimum number of occurrences set at 10 to cover a broad scope, out of the 1860 keywords generated, 41 met the threshold. These thresholds were then organised into five (5) clusters, as shown in Figure 1 below. Even though the researcher is at the liberty of setting the number of occurrences, Aghimien et al. (2020) and Al Husaeni & Al Husaeni (2022) opined that irrespective of the research topic or the choice of the researcher, the generated outcome is perpendicular to the peculiarity of the keywords used.

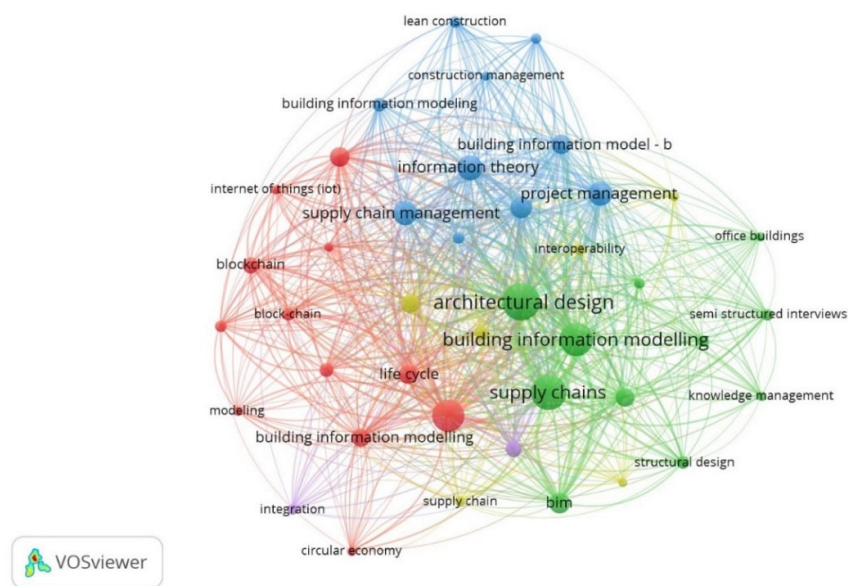


Figure 1. Occurrence network visualisation map

Cluster 1 - **Integrated Sustainability**, represented by red, encapsulates a comprehensive set of variables that collectively contribute to the study's approach. The inclusion of “building information modelling” and “sustainability” aligns with the study's central theme, emphasising the role of BIM in fostering environmentally conscious and economically viable practices within the construction supply chain. The variable “blockchain” suggests a potential exploration of blockchain technology in conjunction with BIM, recognised for enhancing transparency and security in construction processes (Raco et al., 2021). Additionally, the emphasis on “circular economy” underscores the study's commitment to minimising waste and promoting sustainable material practices throughout the construction lifecycle, reflecting contemporary principles in construction management (Dzhengiz et al., 2023). The variables “Internet of Things” and “lifecycle” indicate a focus on integrating real-time monitoring and data exchange, aligning with research that highlights the benefits of IoT technologies in enhancing supply chain efficiency (Sahara & Aamer, 2022). Lastly, “sustainable development” emphasises promoting socially responsible and environmentally sustainable practices in the South African construction industry, aligning with the study's objective to optimise supply chain resilience (Mukhuty et al., 2022).

Cluster 2 - **Construction Integration**, characterised by the green colour, encompasses diverse variables contributing to the study's comprehensive exploration. Including “building information modelling” aligns with the core focus of leveraging BIM technology to enhance efficiency and coordination throughout the construction supply chain. Variables such as “architectural design” and “structural design” suggest a solid examination of BIM's impact on design processes, potentially improving precision and minimising errors in architectural and structural aspects (Eastman et al., 2011). The presence of “construction supply chain” and “contractors” underscores the study's commitment to investigating supply chain dynamics and collaborative relationships among stakeholders, acknowledging their crucial role in achieving resilience (Papadonikolaki et al., 2017). “Knowledge management” signifies an awareness of the organisational learning and information-sharing aspects in the context of BIM adoption, highlighting the need for effective knowledge transfer within the construction industry (Raco et al., 2021). Furthermore, “semi-structured interviews” imply a qualitative research approach, allowing for a nuanced understanding of stakeholders' experiences and perspectives, which is valuable in the South African construction context. Overall, Cluster 2 reflects a thorough examination of BIM integration's multifaceted impact on architectural and structural design, supply chain dynamics, and knowledge management within the construction industry in South Africa.

Cluster 3 - **Construction Efficiency**, denoted by blue, presents a focused set of variables integral to the study's objectives. The inclusion of “building information modelling,” “construction,” and “construction management” aligns with the central theme, emphasising BIM's role in enhancing efficiency and coordination across the construction supply chain. The incorporation of “lean construction” and “lean production” suggests a specific exploration of lean principles within the construction context, emphasising efficiency and waste reduction (Ibrahim et al., 2020). Variables such as “project management” underscore the significance of effective project control and coordination, which are crucial for supply chain optimisation (Yap & Skitmore, 2020). The mention of “radio frequency identifier” signifies a potential investigation into the application of RFID technology, known for its contribution to real-time tracking and inventory management within construction projects (Oke et al., 2021). Lastly, the variable “supply chain management” emphasises a comprehensive approach to understanding and improving the construction supply chain, aligning with the study's overarching goal of resilience enhancement (Singh et al., 2024).

Cluster 4 - **Information Integration**, identified in yellow, encompasses key variables crucial to the study's objectives. The inclusion of “decision-making,” “information management,” and “information systems” underscores the study's focus on examining the role of BIM in enhancing decision-making processes and information management within the construction supply chain (Sadeghi et al., 2023). Variables such as “information technology” and “interoperability” suggest a targeted exploration of technological aspects, emphasising the need for seamless integration and compatibility between various information systems (Hodapp & Hanelt, 2022). Additionally, the variable “supply chain” signifies a broader consideration of supply chain dynamics, emphasising the importance of information flow and technological interoperability in optimising supply chain resilience. Cluster 4 provides insights into how BIM integration can contribute to informed decision-making, effective information management, and technological interoperability within the construction supply chain in the South African context.

Cluster 5 - **Project Integration**, indicated by the purple colour, highlights two critical variables: “construction projects” and “integration”. This cluster suggests a focused exploration of the integration of BIM within construction projects, emphasising its potential impact on enhancing supply chain resilience. The variable “construction projects” focuses explicitly on project-level implementation, suggesting a nuanced examination of how BIM integration influences project outcomes and supply chain dynamics (Samimpay & Saghatforoush, 2020). Additionally, “integration” underscores the importance of seamless integration between BIM technology and existing systems or processes within construction projects, facilitating effective communication and collaboration across project stakeholders (Qiao et al., 2021). Cluster 5 provides insights into the practical implementation of BIM within construction projects and its role in fostering integration among various project elements, contributing to enhanced supply chain resilience in the South African construction industry.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the comprehensive analysis of various clusters within the study, it is evident that Building Information Modelling (BIM) integration offers substantial potential for optimising construction supply chain resilience in South Africa. The diverse range of variables identified across clusters highlights the multifaceted nature of BIM's impact, spanning from architectural and structural design enhancements to the integration of lean principles and technological innovations such as radio frequency identifiers (RFID) and the Internet of Things (IoT). Moreover, the study underscores the importance of effective information management, decision-making processes, and knowledge sharing within the construction industry. Through semi-structured interviews and qualitative methodologies, stakeholders' perspectives were gleaned, providing valuable insights into the practical implementation of BIM within construction projects and its role in fostering integration among various project elements. Overall, the findings emphasise the imperative for South African construction industry stakeholders to embrace BIM integration as a strategic approach to enhance supply chain resilience, improve efficiency, and drive sustainable development initiatives.

Several recommendations are proposed to capitalise on the identified opportunities and address the challenges highlighted in the study. To begin with, stakeholders across the construction supply chain should prioritise investments in BIM technology and related training programs to enhance proficiency and ensure widespread adoption. Furthermore, fostering collaborative relationships among contractors, designers, and supply chain partners is essential to fully leveraging BIM's potential. This collaboration should extend to adopting lean principles, effective project management practices, and integrating emerging technologies such as RFID and IoT. In addition, policymakers and

industry associations should advocate for standardised protocols and interoperability frameworks to facilitate seamless data exchange and integration across BIM platforms. Conclusively, ongoing research efforts and knowledge-sharing initiatives are paramount to continually evolving BIM practices and addressing emerging challenges in the dynamic landscape of the South African construction industry. By embracing these recommendations, stakeholders can harness the transformative power of BIM integration to build a resilient and sustainable construction sector in South Africa.

References

- Aghimien, D. O., Aigbavboa, C. O., Oke, A. E., & Thwala, W. D. (2020). Mapping out research focus for robotics and automation research in construction-related studies: A bibliometric approach. *Journal of Engineering, Design and Technology*, 18(5), 1063-1079.
- Al Husaeni, D. N., & Al Husaeni, D. F. (2022). How to calculate bibliometric using Vos viewer with publish or perish (using Scopus data): Science education keywords. *Indonesian Journal of Educational Research and Technology*, 2(3), 247-274.
- Chadegani, D. A., Salehi, H., Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M.E. brahim, N.A., (2013). A comparison between two main academic literature collections: Web of Science and Scopus. *Asian Social Science*, 5(1): 18-26. <https://doi.org/10.5539/ass.v9n5p18>
- Chen, P. H., & Nguyen, T. C. (2019). A BIM-WMS integrated decision support tool for supply chain management in construction. *Automation in Construction*, 98(3), 289-301.
- Deng, Y., Gan, V. J., Das, M., Cheng, J. C., & Anumba, C. (2019). Integrating 4D BIM and GIS for construction supply chain management. *Journal of Construction Engineering and Management*, 145(4), 04019016.
- Dzhengiz, T., Miller, E. M., Ovaska, J. P., & Patala, S. (2023). Unpacking the circular economy: A problematizing review. *International Journal of Management Reviews*, 25(2), 270-296.
- Fait, M., Palladino, R., Mennini, F. S., Graziano, D., & Manzo, M. (2024). Enhancing knowledge brokerage drivers for dynamic capabilities: the effects on sustainable supply chain ecosystem. *Journal of Knowledge Management*, 28(2), 355-380.
- Fitriawijaya, A., Hsin-Hsuan, T., & Taysheng, J. (2019). A blockchain approach to supply chain management in a BIM-enabled environment. *In intelligent and informed-proceedings of the 24th international conference on computer-aided architectural design research in Asia, CAADRIA 2019*, 3- 5 April, pp. 411-420, Hong Kong, China.
- Guz, A.N., Rushchitsky, J.J., (2009). Scopus: A system for the evaluation of scientific journals. *International Applied Mechanics*, 45(4), 351-362. <https://doi.org/10.1007/S10778-009-0189-4>
- Hamidavi, T., Abrishami, S., & Hosseini, M. R. (2020). Towards intelligent structural design of buildings: A BIM-based solution. *Journal of Building Engineering*, 32, 101685.
- Han, Y., Yan, X., & Piroozfar, P. (2022). An overall review of research on prefabricated construction supply chain management. *Engineering, Construction, and Architectural Management*, 6(4), 0969-9988. doi 10.1108/ECAM-07-2021-0668

Hijazi, A. A., Perera, S., Calheiros, R. N., & Alashwal, A. (2023). A data model for integrating BIM and blockchain to enable a single source of truth for the construction supply chain data delivery. *Engineering, Construction and Architectural Management*, 30(10), 4645-4664.

Hodapp, D., & Hanelt, A. (2022). Interoperability in the era of digital innovation: An information systems research agenda. *Journal of Information Technology*, 37(4), 407-427.

Hodapp, D., & Hanelt, A. (2022). Interoperability in the era of digital innovation: An information systems research agenda. *Journal of Information Technology*, 37(4), 407-427.

Hosseini, M.R., Maghrebi, M., Akbarnezhad, A., Martek, I., Arashpour, M., 2018. Analysis of citation networks in building information modelling. *Research Journal of Construction Engineering Management*, 144(8), 1-13. [https://doi.org/10.1061/\(ASCE\)CO.1943-7862.0001492](https://doi.org/10.1061/(ASCE)CO.1943-7862.0001492)

Ibrahim, A. R., Imtiaz, G., Mujtaba, B., Vinh Vo, X., & Ahmed, Z. U. (2020). Operational excellence through lean manufacturing: Considerations for productivity management in Malaysia's construction industry. *Journal of Transnational Management*, 25(3), 225-256.

Lu, Y., Wu, Z., Chang, R., & Li, Y. (2017). Building information modelling (BIM) for green buildings: A critical review and future directions. *Automation in Construction*, 83(2), 134-148.

Mukhty, S., Upadhyay, A., & Rothwell, H. (2022). Strategic sustainable development of Industry 4.0 through the lens of social responsibility: The role of human resource practices. *Business Strategy and the Environment*, 31(5), 2068-2081.

Oke, A. E., Aigbavboa, C., Stephen, S. S., & Thwala, W. D. (2021). *Sustainable construction in the era of the fourth industrial revolution*. Routledge. Pp. 1-184. <https://doi.org/10.1201/9781003179849>

Papadonikolaki, E., Verbraeck, A., & Wamelink, H. (2017). Formal and informal relations within BIM-enabled supply chain partnerships. *Construction management and economics*, 35(8-9), 531-552.

Pillay, N., Musonda, I. & Makabate, C. (2018). Use of BIM at higher learning institutions: Evaluating the level of implementation and development of BIM at built environment schools in South Africa. Retrieved from: <https://www.ujcontent.uj.ac.za> (Accessed 20 December 2023).

Pryke, S. (2020). *Successful construction supply chain management: Concepts and case studies*. John Wiley & Sons publication, New Jersey, USA.

Qiao, S., Wang, Q., Guo, Z., & Guo, J. (2021). Collaborative innovation activities and BIM application on innovation capability in construction supply chain: Mediating role of explicit and tacit knowledge sharing. *Journal of Construction Engineering and Management*, 147(12), 04021168.

Qiao, S., Wang, Q., Guo, Z., & Guo, J. (2021). Collaborative innovation activities and BIM application on innovation capability in construction supply chain: Mediating role of explicit and tacit knowledge sharing. *Journal of Construction Engineering and Management*, 147(12), 04021168.

Raco, F., Stefani, M., Balzani, M., & Ferrari, L. (2021). Towards effective project documentation, transparency, and data-driven decision-making through BIM-2nd International Conference on Construction Project Management and Construction Engineering, 20-23 Nov 2024, Sydney, Australia

blockchain based applications. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 46, 437-444.

Riazi, S., Zainuddin, M., Nawi, M., Musa, S., & Lee, A. (2020). A critical review of fragmentation issues in the construction industry. *Talent development & excellence (Internet)*, 12(2), 1510-1521.

Sadeghi, M., Carenini, A., Corcho, O., Rossi, M., Santoro, R., & Vogelsang, A. (2023). Interoperability of heterogeneous Systems of Systems: from requirements to a reference architecture. *The Journal of Supercomputing*, 1-34.

Sahara, C. R., & Amer, A. M. (2022). Real-time data integration of an internet-of-things-based smart warehouse: a case study. *International Journal of Pervasive Computing and Communications*, 18(5), 622-644.

Samimpay, R., & Saghatforoush, E. (2020). Benefits of implementing building information modelling (BIM) in infrastructure projects. *Journal of Engineering, Project, and Production Management*, 10(2), 123-140.

Sholeh, M. N., Nurdiana, A., & Setiabudi, B. (2020). Identification of potential uses of building information modelling (BIM) for construction supply chain management: preliminary studies. In *IOP Conference Series: Earth and Environmental Science*, 448(1), p. 012064.

Singh, A., Dwivedi, A., Agrawal, D., & Chauhan, A. (2024). A framework to model the performance indicators of resilient construction supply chain: An effort toward attaining sustainability and circular practices. *Business Strategy and the Environment*, 33(3), 1688-1720.

Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(3), 357-375.

Teicholz, P., Azhar, S., & Venugopal, M. (2013). Why the construction industry needs standards for BIM: A practitioner's perspective. *Automation in Construction*, 35(3), 185-192.

Tezel, A., Papadonikolaki, E., Yitmen, I., & Hilletofth, P. (2020). Preparing construction supply chains for blockchain technology: An investigation of its potential and future directions. *Frontiers of Engineering Management*, 7, 547-563.

Uzairuddin, S., & Jaiswal, M. (2022). Digital monitoring and modelling of construction supply chain management scheme with BIM and GIS: An overview. *Materials Today*, 65(6), 1908-1914.

Van Eck, N.J., Waltman, L., 2014. Visualizing bibliometric networks, in Ding, Y., Rousseau, R. and Wolfram, D. (Eds), *Measuring scholarly impact: Methods and practice*, 2(3): 285-320. https://doi.org/10.1007/978-3-319-10377-8_13

Wang, L., Yan, X., Fan, B., Jin, R., Yang, T., & Kapogiannis, G. (2020). Incorporating BIM in the final semester undergraduate project of construction management—a case study in Fuzhou University. *KSCE Journal of Civil Engineering*, 24(8), 2403-2418.

Whitlock, K., Abanda, F. H., Manjia, M. B., Pettang, C. & Nkeng, G. E. (2021). 4D BIM for construction logistics management. *Civil Engineering Journal*, 2(2), 325-348.

Windapo, A. O., & Cattell, K. (2013). The South African construction industry: Perceptions of key challenges facing its performance, development and growth. *Journal of construction in developing countries*, 18(2), 65-79.

Yap, J. B. H., & Skitmore, M. (2020). Ameliorating time and cost control with project learning and communication management: Leveraging on reusable knowledge assets. *International Journal of Managing Projects in Business*, 13(4), 767-792.

Yevu, S. K., Ann, T. W., & Darko, A. (2021). Digitalization of construction supply chain and procurement in the built environment: Emerging technologies and opportunities for sustainable processes. *Journal of Cleaner Production*, 322(1), 129093.

Zhang, J., Li, H., Golizadeh, H., Zhao, C., Lyu, S., & Jin, R. (2020). Reliability evaluation index for the integrated supply chain utilizing BIM and lean approaches. *Engineering, Construction and Architectural Management*, 27(5), 997-1038.

Zheng, X., Le, Y., Chan, A.P.C., Hu, Y., Li, Y., 2016. Review of the application of social network analysis (SNA) in construction project management research. *International Journal of Project Management*, 34(7), 1214–1225. <https://doi.org/10.1016/j.ijproman.2016.06.005>