INTEGRATED PROJECT CLOUD SERVICE

AND BUILDING INFORMATION MODELING IN EARLY ARCHITECTURAL DESIGN STAGES

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages

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Abstract: In the evolving Architecture, Engineering, and Construction (AEC) industry, the use of Building Information Modeling (BIM) and Integrated Project Cloud Service (IPCS) has become crucial. These tools are particularly essential during the early design stages, as they enable comprehensive management and integration of project information, thus promoting effective decision-making throughout project lifecycles. This combined approach enhances inter-organizational collaborations, improves design and construction practices, and creates a communal data platform for stakeholders. This research explores the effectiveness of the BIM-IPCS system in streamlining data exchange and information flow during early design, suggesting ways to minimize errors, speed up processes, and reduce construction costs through dependable networks. Conclusively, this study underscores the significant impact of the BIM-IPCS system on project management, ensuring well-coordinated and informed construction while advocating for its role in driving innovative and efficient project delivery in the AEC industry.

Keywords: building information modelling; integrated project cloud service; architectural design stages; project management.

VITRUVIO 8 | 2 (2023)
International Journal of Architecture Technology and Sustainability

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

1. Introduction

In the complex landscape of the Architecture, Engineering, Construction (AEC) industry (Chen et al., 2023), collaboration among all stakeholders, including designers, architects, and engineers, is vital throughout a project's lifecycle (Omrany et al., 2023; Li et al., 2020; Hamidavi et al., 2020). Traditional methodologies often see these professionals working separately, particularly in the early design stages (Hamidavi et al., 2020). This compartmentalized approach, reliant on methods like paper printouts (Omrany et al., 2023), can lead to information loss and increased errors during exchanges (Chu et al., 2018). Such disconnects can result in architects creating designs that clash with engineers' structural plans. Building Information Modeling (BIM) emerges as a solution to these challenges. Implementing BIM can enhance collaboration, streamline information transfer, and ensure alignment between architectural designs and structural plans (Omrany et al., 2023; Kubicki et al., 2019; Mehrbod et al., 2019). Moreover, the comprehensive models of BIM offer insights across the project's various phases, aiding teams in preparing efficiently for the construction stage. Research has validated the efficacy of BIM in various planning aspects, ranging from traffic management to ensuring adherence to regulations (Wang & Liu, 2020; Wu et al., 2020; Kincelova et al., 2020).

BIM presents a transformative solution for enhancing communication and coordination within the AEC sector (Sujan et al., 2020; Olofsson Hallén et al., 2023). It is crucial to integrate processes, standards, and methodologies to ensure BIM operates as a well-coordinated organizational subsystem aligning the efforts of all stakeholders with the objective of maximizing value for clients (Olofsson Hallén et al., 2023). While the application of BIM spans the entire project life cycle, from reducing waste in the planning stage to facilitating decisions on refurbishment and demolition (Mellado & Lou, 2020), it is not without challenges. Large-scale projects entail collaboration among various parties, and as data from BIM accumulates across different project stages, the demand for efficient storage and processing solutions intensifies (Zhang et al., 2020). Traditional BIM storage, based on file servers, often falls short in managing complex information exchanges and interdisciplinary collaborations. Additionally, commercial BIM software, predominantly designed for individual users, requires a significant upfront investment, leading to considerable infrastructure expenses (Zhao & Taib, 2022). These challenges, together with issues like potential data inconsistencies and slow model file generation, underscore the AEC industry's need for distributed storage and computing solutions (Liu et al., 2022). Distributed ledger technologies, known for upholding transactional integrity in multi-party scenarios, emerge as a promising solution (Li et al., 2020; Zhang et al., 2023; Chen et al., 2023). Conventional cloud storage for BIM often lacks reliability. Therefore, this research promotes the innovative integration of BIM with the Integrated Project Cloud Service (IPCS), highlighting its potential to establish trusted networks while ensuring transactional consistency.

2. Application of Building Information Modeling (BIM)

BIM tools, equipped with 3D visualization capabilities, support the entire building lifecycle, spanning design to construction (Olofsson Hallén et al., 2023; Chalhoub & Ayer, 2019). This technology stands as a cornerstone in the evolution towards Construction 4.0, transforming the construction industry by emphasizing sustainability (Mellado & Lou, 2020), cost efficiency (Adepoju, 2021), time management (Chalhoub & Ayer, 2019), and safety (Adepoju, 2021; Olofsson Hallén et al., 2023). There is a wealth of research exploring the varied uses of BIM across architectural projects. For instance, studies underscore the pivotal role BIM plays in refining construction management (Omrany et al., 2023; Yang et al., 2021). Notable applications include identifying uncertainties in logistics for modular high-rises (Yang et al., 2021; Manzoor et al., 2021), streamlining material flow (Chen et al., 2021), ensuring precise tracking of construction milestones and planning tasks (Xue & Hou, 2022; Mijwel et al., 2022), and evaluating the structural safety of skyscrapers (Omrany et al., 2023; Atazadeh et al., 2021). Moreover, the potential of BIM to strengthen multi-disciplinary communication during early architectural design is a prominent topic that will be further explored in this section.

2.1 Early Architectural Design Stages

The AEC industry, faced with rising uncertainties and rapidly evolving technologies, contends with the intricacies of design and construction (Shariati et al., 2021; Tupénaité et al., 2020). Managing diverse interests across multiple stakeholders further magnifies this complexity (Chen et al., 2023). The research presented divides the design process into stages using the Level of Detail (LOD) standards, utilizing BIM to ensure a consistent data flow and integrated information tailored to each phase. However, a current trend indicates many design entities use BIM solely as a modeling tool, introducing it after the design phase, leading to gaps in information (Moyano et al., 2020). The international organization, AIA, has provided a foundational definition of LOD, categorizing it into five distinct levels: LOD 100 to LOD 500, to foster streamlined design information and optimize data communication across teams. At LOD 100,

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

VITRUVIO 8 | 2 (2023)
International Journal of Architecture
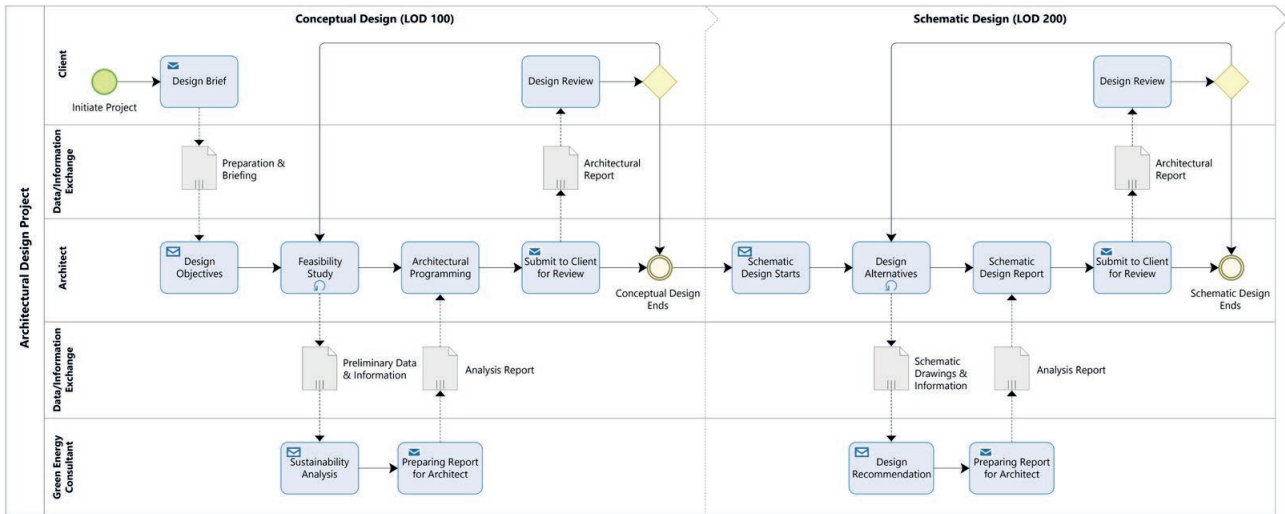Technology and Sustainability

Figure 1 | A general flow of information and data exchange.

elements are largely symbolic, lacking detail, whereas LOD 200 serves as a generic placeholder, offering basic geometric and semantic data. LOD 300 delivers detailed attributes such as size, shape, and orientation. LOD 350, positioned between 300 and 400, facilitates enhanced interaction with other building systems and is recognized for its elevated semantic prerequisites, aiding in seamless trade coordination (Jiang et al., 2023). LOD 400 provides comprehensive details, readying elements for fabrication and installation. LOD 500 represents field-verified elements in exhaustive detail (Jiang et al., 2023). A general flow of information, as illustrated in Figure 1, commences at LOD 100 to LOD 200 and can be systematically progressed to subsequent LODs.

2.2 Multidisciplinary Communication among Stakeholders

Collaboration among professionals from various disciplines in building design remains challenging (Oraee et al., 2019). Predominant issues include the frequent need for coordination meetings over information creation, software interoperability challenges, version compatibility issues, and complications arising from continuous design modifications (Zhang et al., 2023; Chan et al., 2019; Utkucu & Sözer, 2020). Such issues often lead to misunderstandings, data misinterpretation, cost overruns, and project delays (Sacks et al., 2022). To address these concerns, there has been a heightened emphasis on enhancing BIM collaboration in construction (Sacks et al., 2022). Several vendors now provide cloud-based common data environment services in accordance with ISO 19650 standards (Mattern & König, 2018; Sacks et al., 2022; Escrig-Tena et al., 2021).

Figure 2 depicts the interconnected network of stakeholders in the construction lifecycle, along with the flow and dissemination of data and information among them. Such diversity underscores the necessity for teamwork skills for effective BIM project execution (Mellado & Lou, 2020; Chan et al., 2019). However, there remains a gap in comprehensive frameworks, especially regarding seamless data and information transfer among stakeholders. This study suggests that by adopting the Integrated Project Cloud Service (IPCS) as a unified cloud storage and information system, construction projects can experience enhanced efficiency throughout their entire lifecycle, including improved project management. The strategic centralization and dissemination of project data through the cloud are aimed at promoting greater efficiency, safety, and cost savings.

3. Integrated Project Cloud Service (IPCS)

The emergence of a cloud BIM platform seeks to seamlessly integrate virtual design with analysis, simulation, and documentation. A foundational advantage of BIM is its capacity to enhance coordination among a diverse array of stakeholders. This strength is magnified by cloud computing, allowing teams to share crucial building data regardless of their geographical locations. Cloud BIM acts as an advanced tool for communication and coordination for all project participants. It allows users to oversee construction advancements, manage activities, detect potential clashes, and share information irrespective of their physical location (Zhang et al., 2023). Several benefits of cloud BIM have been highlighted in literature (Sacks et al., 2022; Zheng, 2018; Zhao & Taib, 2022). It primarily
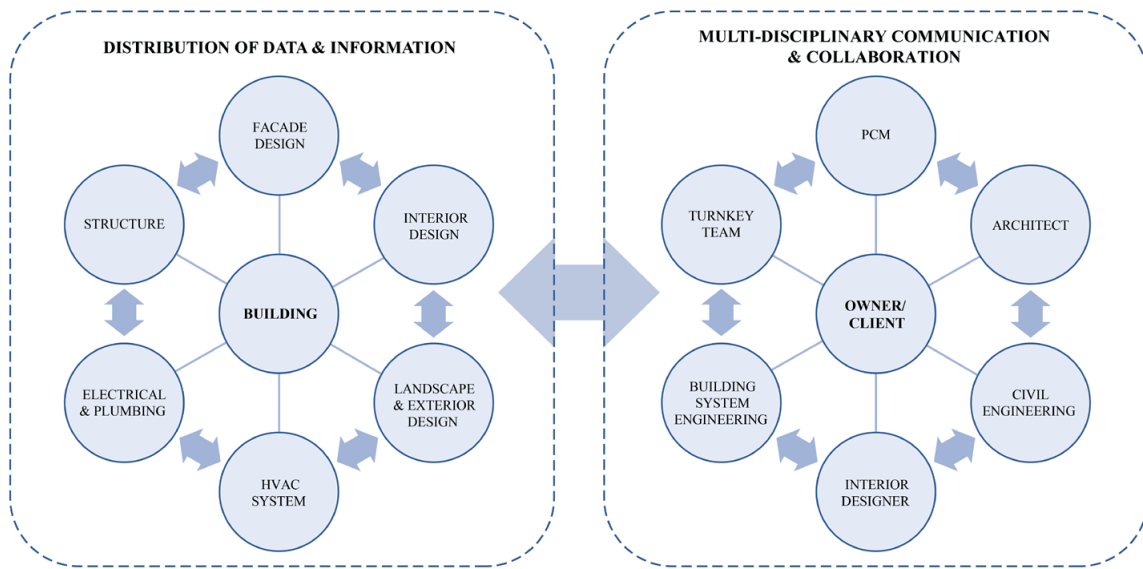
VITRUVIO 8 | 2 (2023)
*International Journal of Architecture
Technology and Sustainability*

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

Figure 2 | Interconnected network of information and stakeholders.

provides universal access to project data, facilitating real-time connection of stakeholders from all over the world (Zhang et al., 2023). Furthermore, the use of a centralized data center negates the need for end-users to possess high-end hardware; they can retrieve building information using an internet browser (Zhang et al., 2023).

The Integrated Project Cloud Service (IPCS) marks a significant evolution in cloud BIM platforms (https://handbim.com/ProductIPCSDetail.aspx). Developed through a strategic collaboration between The Public Works Information Institute of the Republic of China (CPWEIA) and Luxor Digital Co., Ltd., IPCS draws on the expertise of BIM industry leaders. Merging the disciplines of information engineering and architectural design, IPCS streamlines construction management processes, promoting long-term corporate resilience amidst industry upheavals. Unlike its traditional BIM counterparts, which house static data, IPCS presents a dynamic, web-based BIM database management system. This not only centralizes the BIM model, evolving it into a crucial information repository (Figure 3), but also facilitates real-time collaboration. Moreover, the platform's multilingual interface fosters global collaboration, while its unique blend of BIM modeling with project management provides tracking and collaborative editing capabilities (Ullah et al., 2023; Murimi et al., 2023; Nawari & Ravindran, 2019). Features like Gantt chart tracking and integrated dashboards further bolster project oversight (Figure 4). Unlike traditional BIM which holds static information, IPCS offers dynamic, web-based BIM database management system. This empowers elevated collaboration among

stakeholders, setting a new benchmark in engineering project management (Zhao & Taib, 2022; Zhang et al., 2023). Thus, merging BIM with IPCS to harness distributed storage is a pivotal stride for the AEC industry (Celik & Rezgui, 2023). It ensures that stakeholders operate within a secure network, minimizing service node failure risks (Xu & Wang, 2023). Given its significance, this study zeroes in on IPCS, positioning it at the forefront of cloud BIM research.

3.1 Project and File Management

BIM-IPCS stands as a pivotal management approach that needs consistent implementation throughout a project to realize its full advantages. It expertly manages information throughout the building's lifecycle, facilitating the seamless integration and dissemination of data (Seminara et al., 2022; Kamyab et al., 2020). The integration of various disciplines, including architecture, structures, MEP, HVAC, and fire safety, can lead to increased conflicts. BIM-IPCS addresses this with its invaluable conflict analysis feature. One notable feature of BIM-IPCS is its capability to provide virtual visualizations of planned constructions. This capability aids in identifying potential design or construction challenges and pchartromotes cost efficiency and robust project management (Adepoju, 2021; Omrany et al., 2023). The continuous data exchange between disciplines necessitates effective coordination. The early integration of metadata during the design phase enhances this coordination, mitigating potential clashes and inconsistencies.
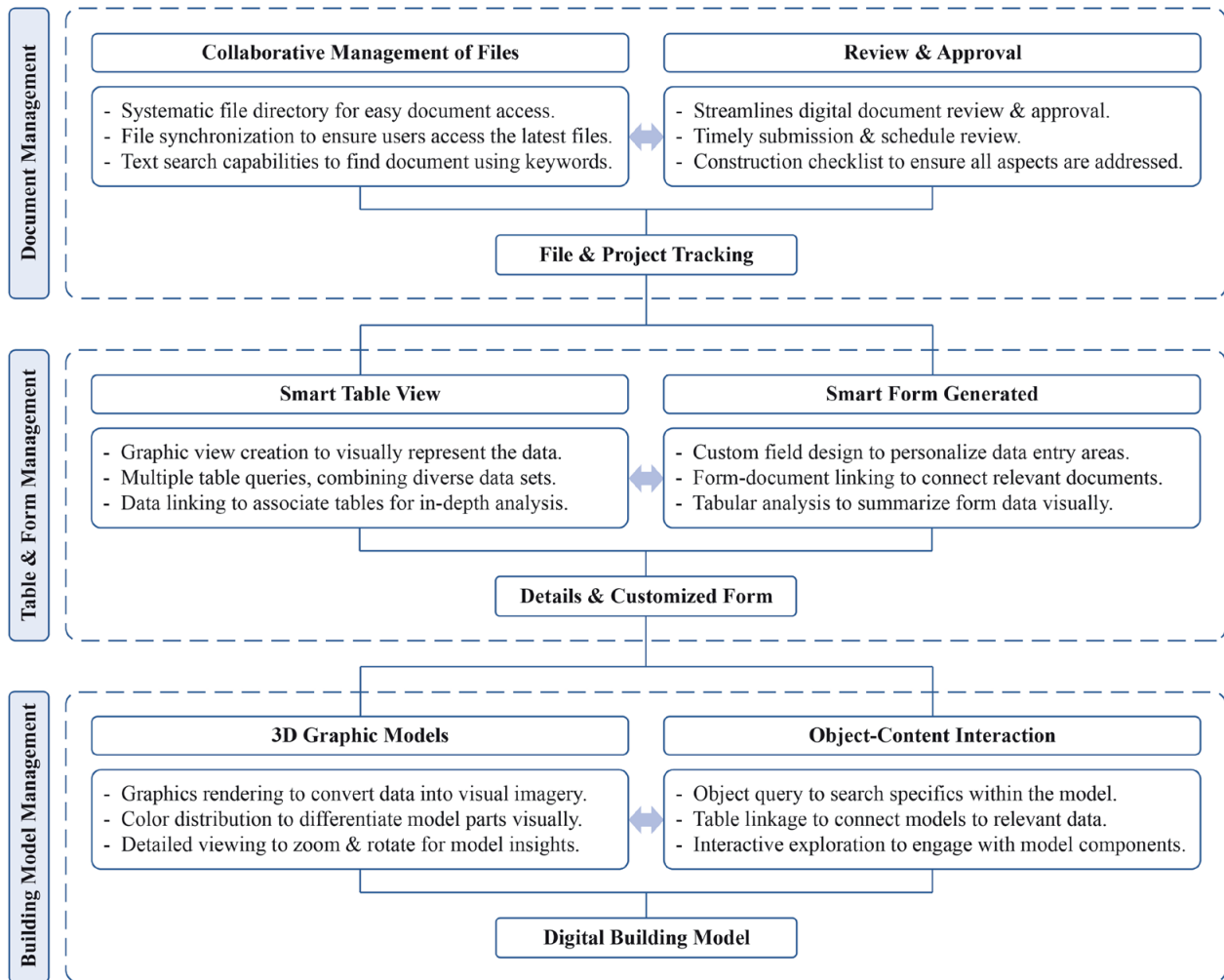
Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

VITRUVIO 8 | 2 (2023)
International Journal of Architecture
Technology and Sustainability

Figure 3 | Integrated Project Cloud Service (IPCS) system diagram.

The strength of the platform is evident in its ability to centralize data, promote collaboration, and improve task monitoring, marking a departure from traditional project management approaches (Figure 5). Stakeholders benefit from real-time access to the most recent project information, reducing communication lags and ensuring optimal resource allocation and progress tracking. BIM-IPCS excels in risk management, an essential facet of successful project management. Its continuous data analysis enables proactive risk identification and management. By leveraging the computational capabilities of the cloud, BIM-IPCS offers predictive insights, arming managers with a view into potential future challenges and enabling proactive solutions. The platform also provides a centralized space for discussions, feedback, and modifications, ensuring consistent alignment among all participants. In conclusion, BIM-IPCS ushers in a new era of agility, transparency, and foresight in project management.

3.2 IPCS Building Models

BIM-IPCS is based on a parametric modeling approach that combines detailed building representations with an integrated information database. This database is systematically organized, facilitating easy access and continuous updates throughout the building's design, construction, and operational stages (Tupėnaitė et al., 2020). In BIM-IPCS system, parametric objects represent construction elements such as floor, walls, ceilings, and columns, encompassing both geometric parameters and material properties. Interoperability, the ability of various software systems to communicate, is crucial. While specific software formats exist, the broader industry gravitates towards universal data standards. The International Alliance for Interoperability (IAI) introduced the International Foundation Class (IFC) format as a standard for these benchmarks (Lai & Deng, 2018). IFC language not only addresses parameter characteristics
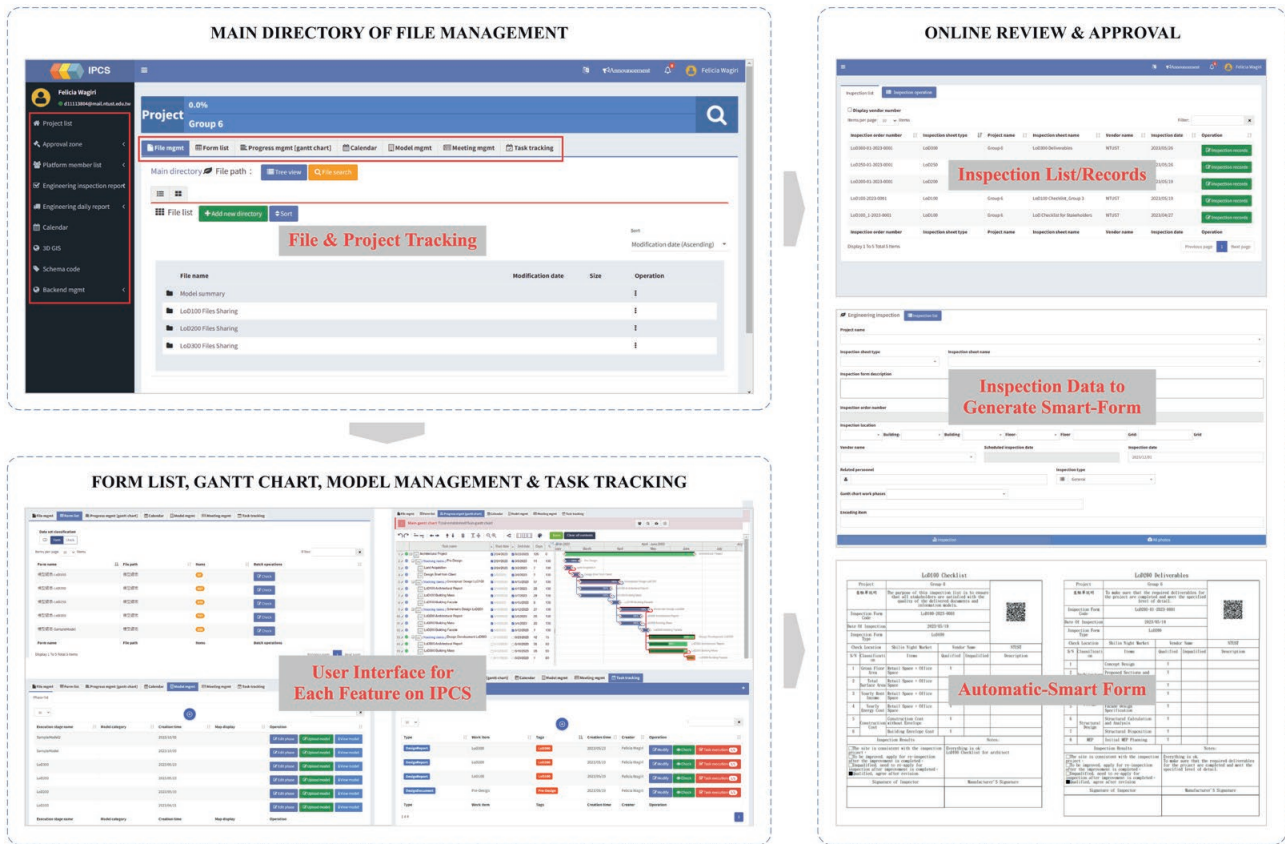
VITRUVIO 8 | 2 (2023)
International Journal of Architecture Technology and Sustainability

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

Figure 4 | Overview of the IPCS platform's user interface: a simplified case study.

but also includes rules and constraints (Sacks et al., 2022). Although widely adopted in BIM now, IFC was initially designed for archiving model content, encapsulating terms and specifics from associated disciplines (Lilis et al., 2018; Lai & Deng, 2018). Figure 6 illustrates the integration of Grasshopper with VisualARQ (version 2.13.1) to generate IFC models, which are essential for data exchange in the building industry. These models ensure the retention of detailed design information and efficient categorization based on object attributes. The figure presents building models at three Levels of Detail (LOD), where LOD 100 provides a basic massing model, LOD 200 includes more defined elements, and LOD 300 encompasses comprehensive facade details. The illustration further draws attention to the capabilities of model management, the assortment of visualization options, and the detailed inventory of equipment components. Such functionalities highlight the system's proficiency in managing complex data, offering varied views for thorough project analysis, and aiding in efficient project oversight.

4. Discussion

BIM-IPCS stands as a leading example of innovation in the AEC industry. Representing the significant potential for supporting decision-making at the early stages of building designs, BIM-IPCS promises unparalleled efficiency and integration. However, behind this promise, there are formidable challenges and potential drawbacks with which the industry must contend. As AEC professionals navigate this new frontier, it is essential to delve deep into the complexities and implications of adopting BIM-IPCS. Firstly, the rapid digitization integral to BIM-IPCS presents both opportunities and obstacles. Although it promises streamlined processes, there is a pronounced learning curve that professionals must address. Transitioning to BIM-IPCS is not merely an exercise in mastering a new software tool; it requires a holistic shift in the paradigms of design, construction, and subsequent maintenance. However, smaller firms find themselves in a predicament. Many are reluctant to invest in new technologies such as BIM-IPCS because of limited resources. Even if they acknowledge its potential, the initial costs associated with tools, training, and infrastructure can deter them. This
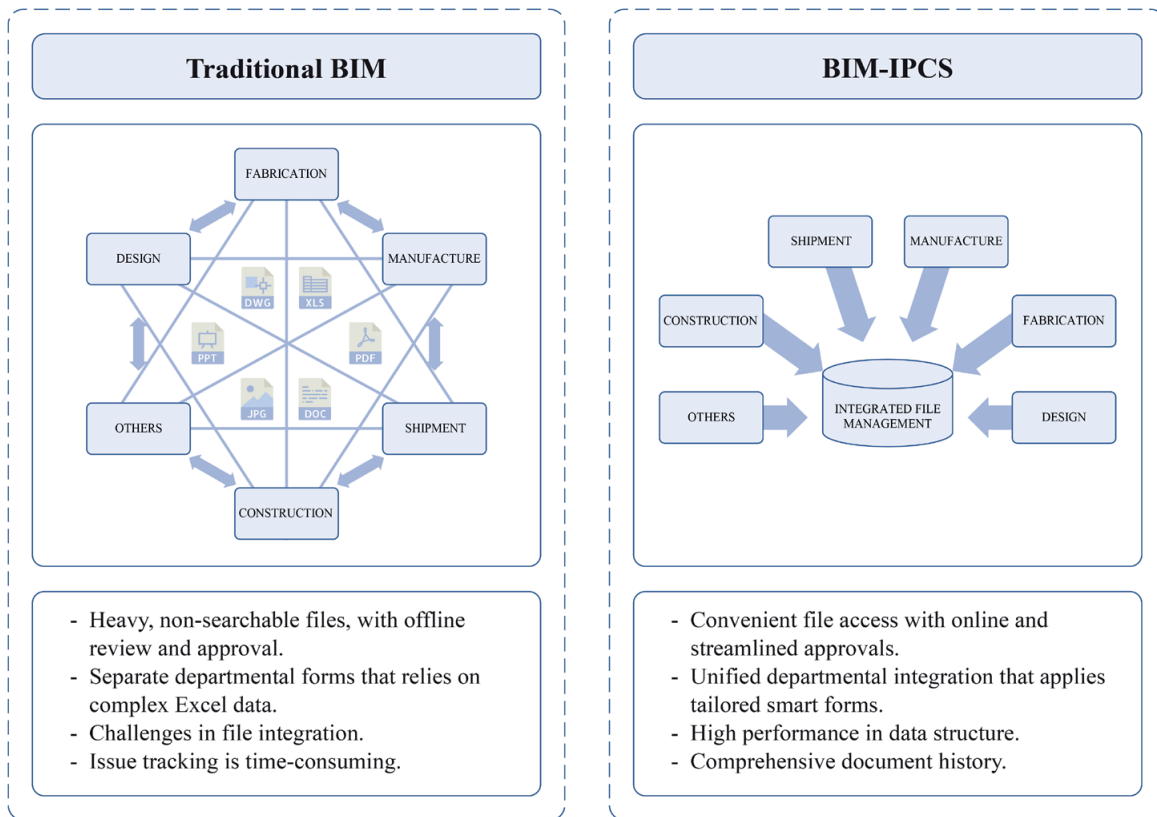
Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

VITRUVIO 8 | 2 (2023)
International Journal of Architecture
Technology and Sustainability

Figure 5 | Comparative overview of traditional BIM and BIM-IPCS features.

reluctance grows when they understand the considerable commitment of time and finances required to educate their staff in BIM-IPCS, making it a venture many view as too ambitious. A clear gap emerges between large corporations that can seamlessly adopt such technologies and smaller entities that struggle to keep up. Furthermore, although many BIM-IPCS advocates emphasize its universality, the actual situation on the ground varies. Some segments of the construction industry use BIM-IPCS only at a basic level. This inconsistency makes it difficult to find stakeholders with the necessary expertise for detailed BIM projects. Such a varied adoption pattern indicates a deeper issue: the implementation of BIM-IPCS is not as simple as software vendors might suggest.

A recurring challenge faced by many firms is the integration of a multitude of file formats. When firms undertake tasks such as calculating material volumes, discrepancies can emerge. Data procured directly from original building information models might differ markedly from values obtained after their conversion to formats like IFC. These inconsistencies not only challenge the reliability of BIM-IPCS but also cast doubt on its efficacy in real-world situations. Legal challenges

further exacerbate these technical problems. In many jurisdictions, only 2D illustrations derived from domain-specific models hold legal validity. Therefore, while BIM-IPCS can offer a comprehensive array of information in three dimensions, its legal standing is limited to two-dimensional representations. This disparity between technological capability and legal recognition is a point of tension that the industry must confront. Determining the level of detail in an information model presents another dilemma. It is crucial to strike the right balance. Filling a model with too many details can lead to excessive consumption of resources, both in terms of time and money. On the other hand, models that are too simplified might lack essential data, making them ineffective. The issue of when to integrate data adds another layer of complexity. Since adding data retroactively becomes more challenging as projects advance, essential decisions regarding data inclusion often require forward-thinking.

Another concern pertains to data ownership and privacy. With BIM-IPCS, vast amounts of data are stored in the cloud. This arrangement can lead to uncertainty about data ownership. In the event of disputes or breaches, this lack of clarity can precipitate legal challenges.
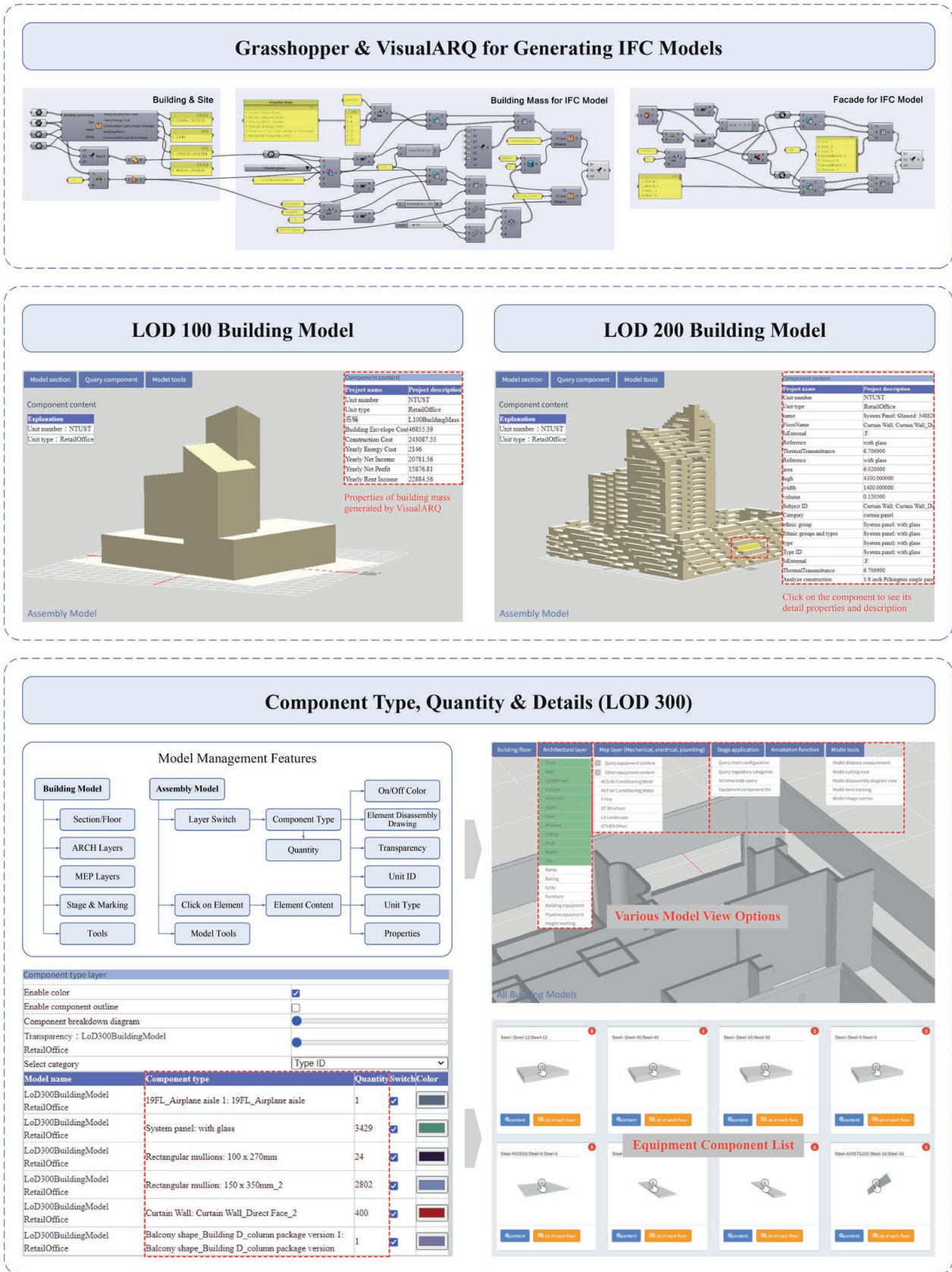
VITRUVIO 8 | 2 (2023)
International Journal of Architecture
Technology and Sustainability

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

Figure 6 | IPCS building model: overview of model management capabilities.

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

VITRUVIO 8 | 2 (2023)
International Journal of Architecture
Technology and Sustainability

Furthermore, as data privacy laws become more stringent globally, AEC firms must ensure compliance, introducing another layer of complexity to the process. There is also the challenge of interoperability. Although BIM-IPCS pledges seamless integration, the actual experience can differ. The AEC industry encompasses various stakeholders, from architects and engineers to contractors and facility managers. Each might utilize different tools and software. Ensuring that BIM-IPCS is compatible with all these diverse systems is an immense task. Any hiccup in integration can result in data loss, miscommunication, and project delays. At the heart of BIM-IPCS's appeal is its promise of integration and centralization. BIM-IPCS consolidates all data and processes into a single platform. While this centralization enhances coordination and reduces redundancies, it also exposes the system to vulnerabilities. A singular breach or malfunction can jeopardize an entire project, threatening data integrity and project timelines. In an era where cyber-attacks grow ever more sophisticated, placing heavy reliance on one system may be a perilous choice. In conclusion, while BIM-IPCS undoubtedly marks a new chapter in the AEC industry, it is vital to approach it with a balanced view. It possesses transformative potential, promising to revolutionize the way projects are conceptualized, executed, and managed. Yet, the path to its comprehensive adoption is strewn with technical, financial, and legal hurdles. As the industry advances, addressing these challenges directly will be imperative, ensuring that BIM-IPCS fulfills its potential without undermining the stability and integrity of construction projects.

5. Conclusion

Exploring the integration of Building Information Modeling (BIM) and Integrated Project Cloud Service (IPCS) sheds light on the upcoming trends in project management and cross-organizational teamwork. Below are the key findings from the study:

- Shift in paradigm: BIM-IPCS signifies a transition from traditional document-centric approaches to a more integrated cloud-based project database, ensuring real-time monitoring, enhanced communication, clash detection, and data sharing without geographical constraints.

- Enhanced collaboration: The integration of BIM-IPCS fosters improved inter-stakeholder communication, reducing issues stemming from miscommunication and enabling more efficient project information exchange.

- Project efficiency: BIM-IPCS significantly augments construction planning, reducing wasted time and resources. When utilized across various models such as architectural, structural, and MEP, BIM ensures an alignment of disciplines, eliminating potential conflicts and providing a comprehensive visualization of construction projects.

- Productivity in construction: Utilizing BIM-IPCS specifically for prefabrication, coordination, and construction planning results in a notably more efficient and productive construction process.

- Future research directions: There is a pressing need for comprehensive evaluations of technological adoptions across all project phases including construction and operation. Issues like minimizing user response latency and change management sequences within the BIM-IPCS framework warrant in-depth investigations to further optimize and refine their applications in the AEC sector.

Acknowledgement

References

Adepoju, O. (2021). Building information modelling. In *Re-skilling Human Resources for Construction 4.0* (pp. 43–64). Springer International Publishing. https://doi.org/10.1007/978-3-030-85973-2_3

Atazadeh, B., Olfat, H., Rajabifard, A., Kalantari, M., Shojaei, D., & Marjani, A. M. (2021). Linking Land Administration Domain Model and BIM environment for 3D digital cadastre in multi-storey buildings. *Land Use Policy, 104*, 105367. https://doi.org/10.1016/j.landusepol.2021.105367

Celik, Y., Petri, I., & Rezgui, Y. (2023). Integrating BIM and Blockchain across construction lifecycle and supply chains. *Computers in Industry, 148*, 103886. https://doi.org/10.1016/j.compind.2023.10388

Chalhoub, J., & Ayer, S. K. (2019). Exploring the performance of an augmented reality application for construction layout tasks. *Multimedia Tools and Applications, 78*(24), 35075–35098. https://doi.org/10.1007/s11042-019-08063-5

VITRUVIO 8 | 2 (2023)
International Journal of Architecture
Technology and Sustainability

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

Chan, D. W. M., Olawumi, T. O., & Ho, A. M. L. (2019). Perceived benefits of and barriers to Building Information Modelling (BIM) implementation in construction: The case of Hong Kong. *Journal of Building Engineering, 25*, 100764. https://doi.org/10.1016/j.jobe.2019.100764

Chen, Q., Adey, B. T., Haas, C. T., & Hall, D. M. (2021). Exploiting digitalization for the coordination of required changes to improve engineer-to-order materials flow management. *Construction Innovation, 22*(1), 76–100. https://doi.org/10.1108/ci-03-2020-0039

Chen, S., Zeng, Y., Majdi, A., Salameh, A. A., Alkhalifah, T., Alturise, F., & Ali, H. E. (2023). Potential features of building information modelling for application of project management knowledge areas as advances modeling tools. *Advances in Engineering Software, 176*, 103372. https://doi.org/10.1016/j.advengsoft.2022.103372

Chu, M., Matthews, J., & Love, P. E. D. (2018). Integrating mobile Building Information Modelling and Augmented Reality systems: An experimental study. *Automation in Construction, 85*, 305–316. https://doi.org/10.1016/j.autcon.2017.10.032

Escrig-Tena, A. B., Segarra-Ciprés, M., & García-Juan, B. (2021). Incremental and radical product innovation capabilities in a quality management context: Exploring the moderating effects of control mechanisms. *International Journal of Production Economics, 232*, 107994. https://doi.org/10.1016/j.ijpe.2020.107994

Hamidavi, T., Abrishami, S., & Hosseini, M. R. (2020). Towards intelligent structural design of buildings: A BIM-based solution. *Journal of Building Engineering, 32*, 101685. https://doi.org/10.1016/j.jobe.2020.101685

Jiang, S., Feng, X., Zhang, B., & Shi, J. (2023). Semantic enrichment for BIM: Enabling technologies and applications. *Advanced Engineering Informatics, 56*, 101961. https://doi.org/10.1016/j.aei.2023.101961

Kamyab, H., Klemeš, J. J., Fan, Y. V., & Lee, C. T. (2020). Transition to sustainable energy system for smart cities and industries. *Energy, 207*, 118104. https://doi.org/10.1016/j.energy.2020.118104

Kincelova, K., Boton, C., Blanchet, P., & Dagenais, C. (2020). Fire safety in tall timber building: A bim-based automated code-checking approach. *Buildings, 10*(7), 121. https://doi.org/10.3390/buildings10070121

Kubicki, S., Guerriero, A., Schwartz, L., Daher, E., & Idris, B. (2019). Assessment of synchronous interactive devices for BIM project coordination: Prospective ergonomics approach. *Automation in Construction, 101*, 160–178. https://doi.org/10.1016/j.autcon.2018.12.009

Lai, H., & Deng, X. (2018). Interoperability Analysis of IFC-Based Data Exchange Between Heterogeneous BIM Software. *Journal of Civil Engineering & Management, 24*(7), 537–555. https://doi.org/10.3846/jcem.2018.613

Li, J., Afsari, K., Li, N., Peng, J., Wu, Z., & Cui, H. (2020). A review for presenting building information modeling education and research in China. *Journal of Cleaner Production, 259*, 120885. https://doi.org/10.1016/j.jclepro.2020.120885

Lilis, G. N., Giannakis, G., Katsigarakis, K., & Rovas, D. V. (2018). A tool for IFC building energy performance simulation suitability checking. In *eWork and eBusiness in Architecture, Engineering and Construction* (pp. 57–64). CRC Press. https://doi.org/10.1201/9780429506215-8

Liu, D., Zhang, Y., Jia, D., Zhang, Q., Zhao, X., & Rong, H. (2022). Toward secure distributed data storage with error locating in blockchain enabled edge computing. *Computer Standards & Interfaces, 79*, 103560. https://doi.org/10.1016/j.csi.2021.103560

Manzoor, B., Othman, I., Pomares, J. C., & Chong, H.-Y. (2021). A research framework of mitigating construction accidents in high-rise building projects via integrating building information modeling with emerging digital technologies. *Applied Sciences, 11*(18), 8359. https://doi.org/10.3390/app11188359

Mattern, H., & König, M. (2018). BIM-based modeling and management of design options at early planning phases. *Advanced Engineering Informatics, 38*, 316–329. https://doi.org/10.1016/j.aei.2018.08.007

Mehrbod, S., Staub-French, S., Mahyar, N., & Tory, M. (2019). Characterizing interactions with BIM tools and artifacts in building design coordination meetings. *Automation in Construction, 98*, 195–213. https://doi.org/10.1016/j.autcon.2018.10.025

Mellado, F., & Lou, E. C. W. (2020). Building information modelling, lean and sustainability: An integration framework to promote performance improvements in the construction industry. *Sustainable Cities and Society, 61*, 102355. https://doi.org/10.1016/j.scs.2020.102355

Mijwel, A., Hadi, Al-Zwainy, F., Mohammed, Chiad, A., Salam, Hussein, A., Rouwaida, & Hayder, G. (2022). Adopting building information modeling in claims management in construction industry. *Journal of Applied Engineering Science, 20*(4), 1152–1164. https://doi.org/10.5937/jaes0-39433

Moyano, J., Odriozola, C. P., Nieto-Julián, J. E., Vargas, J. M., Barrera, J. A., & León, J. (2020). Bringing BIM to archaeological heritage: Interdisciplinary method/strategy and accuracy applied to a megalithic monument of the Copper Age. *Journal of Cultural Heritage, 45*, 303–314. https://doi.org/10.1016/j.culher.2020.03.010

Murimi, R., Bell, G., Rasheed, A. A., & Beldona, S. (2023). Blockchains: A review and research agenda for international business. *Research in International Business and Finance, 66*, 102018. https://doi.org/10.1016/j.ribaf.2023.102018

Exploration of Building Information Modeling and Integrated Project Cloud Service in early architectural design stages
Wagiri et al.

VITRUVIO 8 | 2 (2023)
International Journal of Architecture
Technology and Sustainability

Nawari, N. O., & Ravindran, S. (2019). Blockchain and the built environment: Potentials and limitations. *Journal of Building Engineering, 25*, 100832. https://doi.org/10.1016/j.jobe.2019.100832

Olofsson Hallén, K., Forsman, M., & Eriksson, A. (2023). Interactions between Human, Technology and Organization in Building Information Modelling (BIM) - A scoping review of critical factors for the individual user. *International Journal of Industrial Ergonomics, 97*, 103480. https://doi.org/10.1016/j.ergon.2023.103480

Omrany, H., Ghaffarianhoseini, A., Chang, R., Ghaffarianhoseini, A., & Pour Rahimian, F. (2023). Applications of Building information modelling in the early design stage of high-rise buildings. *Automation in Construction, 152*, 104934. https://doi.org/10.1016/j.autcon.2023.104934

Oraee, M., Hosseini, M. R., Edwards, D. J., Li, H., Papadonikolaki, E., & Cao, D. (2019). Collaboration barriers in BIM-based construction networks: A conceptual model. *International Journal of Project Management, 37*(6), 839–854. https://doi.org/10.1016/j.ijproman.2019.05.004

Sacks, R., Wang, Z., Ouyang, B., Utkucu, D., & Chen, S. (2022). Toward artificially intelligent cloud-based building information modelling for collaborative multidisciplinary design. *Advanced Engineering Informatics, 53*, 101711. https://doi.org/10.1016/j.aei.2022.101711

Seminara, P., Vand, B., Sajjadian, S. M., & Tupenaite, L. (2022). Assessing and monitoring of building performance by diverse methods. *Sustainability, 14*(3), 1242. https://doi.org/10.3390/su14031242

Shariati, M., Davoodnabi, S. M., Toghroli, A., Kong, Z., & Shariati, A. (2021). Hybridization of metaheuristic algorithms with adaptive neuro-fuzzy inference system to predict load-slip behavior of angle shear connectors at elevated temperatures. *Composite Structures, 278*, 114524. https://doi.org/10.1016/j.compstruct.2021.114524

Sujan, S. F., Wynford Jones, S., Kiviniemi, A., Wheatcroft, J. M., & Mwiya, B. (2020). Holistically assessing collaborative culture in the AEC industry. *Journal of Information Technology in Construction, 25*, 272–286. https://doi.org/10.36680/j.itcon.2020.016

Tupénaité, L., Žilénaité, V., Kanapeckiené, L., Sajjadian, S. M., Gečys, T., Sakalauskiené, L., & Naimavičiené, J. (2020). Multiple Criteria Assessment of High-Rise Timber Buildings. *Engineering Structures and Technologies, 11*(3), 87–94. https://doi.org/10.3846/est.2019.11952

Ullah, A., Ayat, M., He, Y., & Lev, B. (2023). An analysis of strategies for adopting blockchain technology in the after-sales service supply chain. *Computers & Industrial Engineering, 179*, 109194. https://doi.org/10.1016/j.cie.2023.109194

Utkucu, D., & Sözer, H. (2020). Interoperability and data exchange within BIM platform to evaluate building energy performance and indoor comfort. *Automation in Construction, 116*, 103225. https://doi.org/10.1016/j.autcon.2020.103225

Wang, Z., & Liu, J. (2020). A seven-dimensional building information model for the improvement of construction efficiency. *Advances in Civil Engineering, 2020*, 1–17. https://doi.org/10.1155/2020/8842475

Wu, K., García de Soto, B., Adey, B. T., & Zhang, F. (2020). BIM-based estimation of vertical transportation demands during the construction of high-rise buildings. *Automation in Construction, 110*, 102985. https://doi.org/10.1016/j.autcon.2019.102985

Xu, L., & Wang, B. (2023). Peer-to-peer electricity trading considering voltage-constrained adjustment and loss allocation in blockchain-enabled distribution network. *International Journal of Electrical Power & Energy Systems, 152*, 109204. https://doi.org/10.1016/j.ijepes.2023.109204

Xue, J., & Hou, X. (2022). High-Rise building construction progress measurement from top view based on component detection. *Buildings, 12*(2), 106. https://doi.org/10.3390/buildings12020106

Yang, Y., Pan, M., Pan, W., & Zhang, Z. (2021). Sources of uncertainties in offsite logistics of modular construction for high-rise building projects. *Journal of Management in Engineering, 37*(3). https://doi.org/10.1061/(asce)me.1943-5479.0000905

Zhang, L., Huang, S., Tian, C., & Guo, H. (2020). How do relational contracting norms affect IPD teamwork effectiveness? A social capital perspective. *Project Management Journal, 51*(5), 538–555. https://doi.org/10.1177/8756972820911241

Zhang, T., Doan, D. T., & Kang, J. (2023). Application of building information modeling-blockchain integration in the Architecture, Engineering, and Construction / Facilities Management industry: A review. *Journal of Building Engineering, 77*, 107551. https://doi.org/10.1016/j.jobe.2023.107551

Zhao, Y., & Taib, N. (2022). Cloud-based Building Information Modelling (Cloud-BIM): Systematic literature review and Bibliometric-qualitative Analysis. *Automation in Construction, 142*, 104468. https://doi.org/10.1016/j.autcon.2022.104468

Zheng, J. (2018). Analysis of collaborative design and construction collaborative mechanism of cloud bim platform construction project based on green computing technology. *Journal of Intelligent & Fuzzy Systems, 34*(2), 819–829. https://doi.org/10.3233/jifs-169375