OpenBIM-based Lifecycle Management in Infrastructure Delivery: Trends, Challenges, and Opportunities

Abstract
OpenBIM has not yet been fully integrated into the lifecycle management processes of infrastructure projects. However, recent trends in digital transformation and open innovation, which are gaining momentum across various industries, have begun to influence the traditionally conservative construction sector. OpenBIM-based delivery promotes efficient collaboration among multiple stakeholders and the effective management and utilization of building information generated during project delivery. This research aims to increase the adoption rates of the OpenBIM methodology in infrastructure projects by examining current trends, identifying challenges, and exploring the opportunities presented by the OpenBIM system. To achieve these objectives, a comprehensive literature review was conducted, analyzing 25 articles sourced from Scopus and Google Scholar. The articles were selected based on specific inclusion and exclusion criteria, ensuring relevance and quality. The significance of this study lies in its potential to inform and guide the construction industry in adopting OpenBIM practices more widely. By providing a detailed analysis of the trends, challenges, and opportunities associated with OpenBIM, this research offers valuable insights that can facilitate the development of strategies to overcome existing barriers and enhance the efficiency and effectiveness of infrastructure delivery processes. The findings of this study provides a foundation for future developments in the application of OpenBIM in infrastructure delivery.

Keywords
OpenBIM, Building Information Modelling, BIM, Lifecycle, Infrastructure, Whole-life

1. Introduction

The lifecycle of building construction is often complex due to the vast number of activities and stakeholders involved (Armijo et al., 2021); (Ajayi et al., 2023). Additionally, the lack of standardization makes it difficult to understand, as it encompasses a wide variety of typologies, phases, activities, and stakeholders, each requiring different strategies to address (Santos et al., 2017). Consequently, current construction and renovation processes are highly inefficient, creating a strong need for constructing more efficient buildings. While technological advances help mitigate these issues, BIM, though advantageous, remains limited in accessibility and interoperability (Doukari et al., 2022). In this context, OpenBIM is emerging as a promising methodology to improve the entire building process. By applying collaboration principles, adopting BIM in the construction sector can significantly enhance overall efficiency, directly reducing costs, time, and waste (Pour Rahimian et al., 2019). In recent years, BIM-based software has become increasingly prevalent in architecture, engineering, and construction (AEC) applications, covering all phases and types of projects (Onososen and Musonda, 2022).

To address interoperability barriers that hinder information flow, OpenBIM standards such as IFC (ISO 16739) are being promoted by buildingSMART (Afsari et al., 2017). This interoperability extends beyond technical software aspects, encompassing organizational and procedural domains, and requires a cultural shift. The structuring and systematization of information through these standards lead to more efficient construction projects by streamlining collaboration workflows. The introduction of Building Information Modelling (BIM) in the Architecture, Engineering, Construction, and Operation (AECO) industry has provided unparalleled opportunities and better ways of executing projects and delivering life-cycle phases in Infrastructure provision (Liu et al., 2019) (Huang, 2022). However, OpenBIM is not yet fully applied to the management of the lifecycle processes of infrastructure. Recent trends in digital transformation and open innovation across industries have started to gain traction in the construction industry, which is among the most conservative in adopting innovative platforms and technologies dedicated to process efficiency and effectiveness (Liphadzi et al., 2022) (Jo and Choi, 2021). The primary focus of OpenBIM-based delivery is on efficient collaboration of multiple stakeholders during infrastructure delivery processes, and on efficient management and use of Building Information produced during delivery. BIM is the center of open building information modeling (OpenBIM), with a focus on interoperability between various BIM software platforms that use standards such as Industry Foundation Classes (IFC) and BIM to Geographic Information System. However, implementing BIM is neither easy nor straightforward. Several barriers exist in the sector, including a lack of awareness and limited knowledge and expertise due to the current state of the art. Applying BIM to projects and companies is not an all-or-nothing approach; various levels of BIM adoption can be considered, making it crucial to begin lifecycle management of infrastructure using OpenBIM. Promoting and significantly increasing BIM use in the building industry remains an ambitious challenge that requires substantial changes in current working cultures. It is essential to understand the challenges and opportunities to drive implementation effectively. This research aims to enhance the application rates of the OpenBIM methodology in infrastructure delivery. Therefore, the study examines the trends, challenges, and opportunities provided by the OpenBIM system in infrastructure delivery. This information will form the basis for future development. The next section discusses the methods used in the research, while the third section explains the findings, situates them within existing studies, and provides a discussion before concluding the article.

2. Research Methods

We employed a six-step review methodology to examine advancements in computer vision applications within the construction industry, as seen in studies such as Jiang et al. (2021). The study aimed to investigate the trends, opportunities and challenges of OpenBIM. The initial step involved defining the review's scope to facilitate an in-depth exploration of OpenBIM. Our focus was to provide a comprehensive overview of the field's latest developments, barriers, applications, and future directions for research, following approaches used in previous studies such as Onososen and Musonda (2022) and Starzyńska-Grześ et al. (2023).

The second phase involved identifying pertinent literature and documents through predefined search strategies using data sources and keywords (Tjebane et al., 2022). We sourced academic articles from Google Scholar and Scopus, including journal articles, conference papers, and book chapters. Keywords like "OpenBIM," "Challenges," "Opportunities," and "Trends" guided our data retrieval process. Following data acquisition, the next steps included data collection and quality assessment to ensure the inclusion of reliable and relevant resources. Thorough text analysis aligned with the study's objectives facilitated the interpretation of results within the broader research landscape, as described by Tjebane et al. (2023). This process is further illustrated in Figure 1 below.

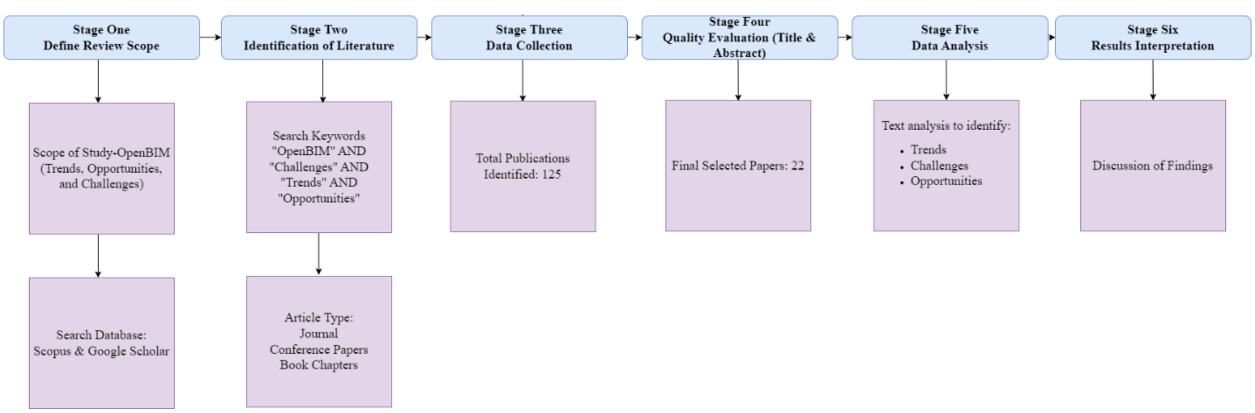

Fig. 1. Research Method

3. Results and Discussion

3. 1 Trends

OpenBIM standards for infrastructure are currently in the process of being developed. Among these standards is the Industry Foundation Classes (IFC), which provides a data framework for modeling infrastructure projects (Ait-

Lamallam et al., 2021). To date, BIM interoperability remains a major focus of research and development in the architectural, engineering, and construction (AEC) industry (Ciccozzi et al., 2023). BuildingSmart is developing OpenBIM standards to ensure continuous use of infrastructure data throughout its lifecycle without needing additional data collection. Unlike ClosedBIM, which relies on proprietary software with opaque processes and data structures, OpenBIM facilitates transparent and sustainable data exchange based on standards. This transparency ensures interoperability of data exchange among project stakeholders, regardless of the software used (Doukari et al., 2022). In this context, BuildingSmart has developed several OpenBIM standards to enable smooth, consistent, interoperable, and lossless data exchanges (Ait-Lamallam et al., 2021). BIM has the potential to revolutionize the construction industry, significantly reducing its environmental impact. The technology supports designers in managing building characteristics throughout the design and construction process (Liu et al., 2024). For instance, it helps predict the exact quantity of materials needed during construction, manage waste during demolition, and choose energy-efficient design solutions.

Since adopting BIM, various efforts have aimed to understand how this tool can contribute to designing green buildings. Integrating and exchanging data between BIM software and lifecycle assessment (LCA) applications can significantly enhance the environmental performance of buildings throughout their lifecycle. BIM aids in the design phase by better managing information and data, while LCA evaluates the environmental impacts of the project. Previous studies, such as Armijo et al. (2021), identified OpenBIM-ready workflows that represent the renovation process and information requirements according to the involvement of different stakeholders. These workflows, based on an analysis of barriers, requirements, and needs, form the foundation for developing specific products and tools to enhance digitalization and interoperability in the renovation process. In "A Methodology for the Digitalization of the Residential Building Renovation Process through OpenBIM-Based Workflows," Jo and Choi (2021) developed a BIM Information Standard Framework to systematically develop guidelines for effective model integration and utilization based on OpenBIM.

Previous work includes an ontology called 'IFCInfra4OM,' developed to define the concepts and processes of operation and maintenance (O&M). Ait-Lamallam et al. (2021) proposed extending the IFC standard to enable road operation and maintenance management through OpenBIM. Ciccozzi et al. (2023) focused on interoperability strategies between BIM and BEM. Emerging research examined adapting to an OpenBIM building permit process, with findings suggesting that the developed process significantly increases the efficiency and transparency of building permit procedures, integrating authorities into the BIM process (Urban et al., 2024).

These studies highlight the need to improve compatibility between BIM and model exchange formats. Khorchi and Boton (2024) developed a method and prototype to integrate an IFC-compliant 3D model and a planning schedule for 4D simulation in a Virtual Reality environment with BCF-based information exchange capabilities. The prototype achieved its objectives, validating the hypothesis that BCF can support 4D simulation-based collaboration in a VR environment (Ait-Lamallam et al., 2021). The proposed method identified success factors and areas for improvement. Integrating BIM with blockchain technology has gained attention for addressing design collaboration issues like poor data security, weak traceability, and low transparency in off-site construction (Urban et al., 2024). However, blockchain implementations in this context lack standardized workflow management and methods for ensuring data completeness. Liu et al. (2024) introduced a blockchain-driven data-checking strategy to ensure OpenBIM completeness at the data level, along with a PaaS architecture to clarify the interaction logic between these systems. Additionally, Choi et al. (2016) improved the interoperability of BIM-based energy performance assessments (EPAs) by developing an environment that includes a process, a materials library, and an EPA support system connecting BIM and energy modeling.

3.2 Challenges

Building Information Modelling (BIM) is a multifaceted concept that specifically involves the collaboration of people, information systems, databases, and software throughout the lifecycle of construction projects (Ait-Lamallam et al., 2021). The adoption of BIM facilitates data-driven decision-making for many participants in construction. Increasingly, various processes throughout a building's lifecycle utilize digital, model-based data, integrating these models into a digitized workflow (Ait-Lamallam et al., 2021). Comparing ClosedBIM and OpenBIM highlights the advantages of the latter. The OpenBIM process, utilizing the IFC standard, consolidates everything into a single IFC-based BIM model. In contrast, ClosedBIM requires multiple containers (system database and three-dimensional model) to manage lifecycle information. Additionally, ClosedBIM's model production is significantly influenced by software versions and access rights to databases. This can lead to data loss due to the link between system databases and 3D models. Furthermore, the effectiveness of use cases in ClosedBIM heavily depends on the software's ability to communicate, leading to interoperability issues (Pour Rahimian et al., 2019). In OpenBIM, the path from BIM model production to the application of various use cases is optimized. An OpenBIM building permit aims to replace traditional 2D permit plans with digital building models in open formats, enabling automatic data checking and validation during the permit process (Choi et al., 2016). An essential component for OpenBIM permits is a code compliance checking system, which allows for the automated validation of digital building models. The digital transformation of the permit process and the adoption of OpenBIM introduce new phases, such as a pre-check of the Building Application Model (BAM) without submission to the building authority, a phase not present in the current system(Khorchi and Boton, 2024) (Urban et al., 2024). Submitting digital building models through OpenBIM allows for the semi-automatic checking of legal issues, as the model data are machine-readable. Some checks can be fully automated, forming the basis for developing the BAM pre-check process. This results in an automatic preliminary check of the building application model using a reduced set of checking rules (Huang et al., 2022).

Despite the potential benefits of OpenBIM, achieving true standardization and interoperability remains a significant challenge. Different stakeholders often use diverse software tools that may not fully support open standards, leading to compatibility issues (Qi et al., 2020). Ensuring seamless data exchange between these systems can be complex, requiring ongoing efforts to maintain and update interoperability standards. Maintaining high-quality and consistent data throughout the lifecycle of an infrastructure project is another major challenge. Inaccuracies or inconsistencies in data can lead to errors and inefficiencies (Malagnino et al., 2021). Ensuring that all stakeholders adhere to standardized data entry and management practices is crucial but can be difficult to enforce across large, multidisciplinary teams. The implementation of OpenBIM-based lifecycle management requires specialized knowledge and skills. Many professionals in the construction industry may lack familiarity with OpenBIM standards and tools. Providing adequate training and support to bridge this skill gap can be time-consuming and costly, and resistance to adopting new technologies can further hinder the process (Pour Rahimian et al., 2019). The transition to OpenBIM can involve significant initial costs. Investing in new software, upgrading existing systems, and training personnel all require substantial financial resources. For smaller firms or projects with limited budgets, these initial investments can be a considerable barrier to adoption (Ozturk, 2020). The construction industry has traditionally been slow to adopt new technologies, and resistance to change can be a significant barrier to implementing OpenBIM. Stakeholders may be hesitant to move away from established practices and workflows, fearing disruptions or uncertainties associated with new systems (Pezeshki et al., 2019). Overcoming this resistance requires effective change management strategies and clear communication of the benefits of OpenBIM. Integrating OpenBIM into existing workflows and systems can be complex and time-consuming. Many infrastructure projects involve legacy systems that may not easily interface with modern OpenBIM platforms. Ensuring a smooth integration process often requires extensive customization and configuration, which can delay project timelines and increase costs. Infrastructure projects generate vast amounts of data over their lifecycles. Managing this data efficiently is a significant challenge, as it requires robust data storage, processing, and retrieval systems (Ciccozzi et al., 2023). Ensuring that all relevant data is easily accessible and usable by stakeholders can be difficult, particularly as projects scale up in size and complexity. The long-term success of OpenBIM-based lifecycle management depends on continuous support and maintenance. As technology evolves, OpenBIM standards and tools must be regularly updated to stay relevant. Ensuring ongoing support and addressing any emerging issues promptly is crucial but can be resource-intensive. Navigating the regulatory and legal landscape associated with OpenBIM can be complex. Different regions and jurisdictions may have varying regulations and standards for digital construction and data management. Ensuring compliance with all applicable laws and regulations requires careful planning and coordination.

3.3 Opportunities

Building Information Modeling (BIM) involves gathering data throughout a building's lifecycle in a 3D model, encompassing various aspects like design, construction, structure, facilities, and maintenance (Malagnino et al., 2021). This building-related information is digitized, managed, and utilized, leveraging the benefits of high accuracy and secure information storage (Mellado and Lou, 2020). However, the construction industry is vast and complex, involving numerous stakeholders and various software applications for different fields. As information technology becomes increasingly integrated into all sectors, the construction industry is beginning its journey towards digital transformation, focusing on digitization, productivity improvements, and automation of production environments (Funtík et al., 2023). During the exchange of information between different software, data can be lost, and errors can occur. To address these issues, buildingSMART introduced the openBIM concept, which promotes interoperability and compatibility between BIM platforms through an open format. With its extensive capabilities, BIM is seen as a pivotal element in the construction industry's digital transformation (Jrade and Jalaei, 2013). OpenBIM is a universal method for collaboratively planning, realizing, and operating buildings using open standards and workflows (Urban et al., 2024). It enables various stakeholders to engage in the BIM process regardless of the software they use (Ait-Lamallam et al., 2021). For authorities, this translates to a permit process based on digital building models in open formats, eliminating the need for submitting 2D plans in the future. The submitted BIM models will facilitate data-driven decision-making by building authorities and allow for the integration of this data into other services provided by the authorities. One of the primary opportunities of OpenBIM-based lifecycle management is the enhancement of collaboration and communication among all stakeholders involved in infrastructure projects. OpenBIM facilitates the sharing of information through standardized formats, ensuring that architects, engineers, contractors, and facility managers have access to accurate and up-to-date data. This transparency helps in reducing misunderstandings, streamlining decision-making processes, and fostering a more cooperative working environment. It ensures compatibility and interoperability between different software platforms used in infrastructure delivery. By adhering to open standards, OpenBIM allows data to be easily exchanged and utilized across various applications, regardless of the software vendor. This reduces the risk of data loss or corruption during transfers, leading to more reliable and efficient project workflows. The use of OpenBIM in lifecycle management can result in significant cost and time savings. By enabling better planning and coordination, OpenBIM helps in identifying potential issues early in the design phase, reducing the likelihood of costly changes and delays during construction. Additionally, the efficient management of information throughout the project lifecycle can lead to more accurate budgeting and scheduling, optimizing resource allocation and minimizing waste. OpenBIM-based lifecycle management allows for comprehensive data management and easy accessibility of information throughout the entire lifespan of an infrastructure project. All relevant data, including design specifications, construction details, and maintenance records, are stored in a centralized, digital repository. This ensures that information is readily available for reference, helping to maintain consistency and accuracy over time. OpenBIM supports sustainable infrastructure development by promoting better resource management and reducing environmental impacts. By providing detailed insights into material usage, energy consumption, and lifecycle costs, OpenBIM helps stakeholders make informed decisions that prioritize sustainability (Lee et al., 2015). Additionally, the ability to simulate and analyze different design scenarios can lead to more efficient and eco-friendly infrastructure solutions. It facilitates improved maintenance and operation of infrastructure assets by providing detailed and accurate information throughout the asset's lifecycle. Facility managers can use this data to plan and execute maintenance activities more effectively, reducing downtime and extending the lifespan of infrastructure components. The availability of up-to-date information also aids in the swift identification and resolution of issues, enhancing the overall performance and reliability of the infrastructure. OpenBIM can assist in ensuring regulatory compliance and managing risks more effectively. The comprehensive documentation and tracking capabilities of OpenBIM make it easier to adhere to regulatory requirements and standards. Additionally, the ability to conduct thorough risk assessments and simulations during the planning and design phases can help identify potential hazards and develop mitigation strategies, enhancing the safety and reliability of infrastructure projects.

4. Conclusions

Building Information Modeling (BIM) is a technology designed to enhance productivity and efficiency in the construction industry by utilizing information generated throughout a facility's lifecycle within a unified system. BIM enables the creation and management of all building-related information over its entire lifespan. In conclusion, OpenBIM-based lifecycle management offers numerous opportunities to improve infrastructure delivery. By enhancing collaboration, ensuring interoperability, and enabling better data management, OpenBIM can lead to cost and time savings, support sustainable development, and foster innovation. Moreover, its capabilities in enhancing maintenance, regulatory compliance, and risk management make it a valuable tool for modern infrastructure projects. while OpenBIM-based lifecycle management offers significant opportunities for improving infrastructure delivery, it also presents several challenges. Addressing issues related to standardization, data quality, training, initial costs, data security, resistance to change, integration complexity, data management, long-term support, and regulatory compliance is crucial for the successful implementation of OpenBIM in the construction industry. By proactively tackling these challenges, stakeholders can unlock the full potential of OpenBIM and drive innovation and efficiency in infrastructure projects.

References

Afsari, K., Eastman, C.M., Castro-Lacouture, D., 2017. JavaScript Object Notation (JSON) data serialization for IFC schema in web-based BIM data exchange. Autom. Constr. 77, 24–51.

Ait-Lamallam, S., Yaagoubi, R., Sebari, I., Doukari, O., 2021. Extending the ifc standard to enable road operation and maintenance management through openbim. ISPRS Int. J. Geo-Information 10.

Ajayi, S.O., Oyebiyi, F., Alaka, H.A., 2023. Facilitating compliance with BIM ISO 19650 naming convention through automation. J. Eng. Des. Technol. 21, 108–129.

Armijo, A., Elguezabal, P., Lasarte, N., Weise, M., 2021. A methodology for the digitalization of the residential building renovation process through openbim-based workflows. Appl. Sci. 11.

Choi, J., Shin, J., Kim, M., Kim, I., 2016. Development of openBIM-based energy analysis software to improve the interoperability of energy performance assessment. Autom. Constr. 72, 52–64.

Ciccozzi, A., de Rubeis, T., Paoletti, D., Ambrosini, D., 2023. BIM to BEM for Building Energy Analysis: A Review of Interoperability Strategies. Energies 16, 1–45.

Doukari, O., Seck, B., Greenwood, D., Feng, H., Kassem, M., 2022. Towards an Interoperable Approach for Modelling and Managing Smart Building Data: The Case of the CESI Smart Building Demonstrator. Buildings 12.

Funtík, T., Makýš, P., Ďubek, M., Erdélyi, J., Honti, R., Cerovšek, T., 2023. The Status of Building Information Modeling Adoption in Slovakia. Buildings 13, 1–24.

Huang, J.C., 2022. From Building Information Modeling to Extended Reality. In: M. Bolpagni et al. (Ed.), Industry 4.0 for the Built Environment, Structural Integrity 20. Springer International Publishing, Chicago, pp. 471–493.

Huang, M.Q., Zhu, H.M., Ninić, J., Zhang, Q.B., 2022. Multi-LOD BIM for underground metro station: Interoperability and design-to-design enhancement. Tunn. Undergr. Sp. Technol. 119.

Jo, C., Choi, J., 2021. Bim information standard framework for model integration and utilization based on openbim. Appl. Sci. 11.

Jrade, A., Jalaei, F., 2013. Integrating Building Information Modeling (BIM) with sustainability to design building projects at the conceptual stage. Build. Simul. 6, 429–444.

Khorchi, A., Boton, C., 2024. An OpenBIM-based 4D approach to support coordination meetings in virtual reality environments. J. Build. Eng. 85, 108647.

Lee, Y.C., Eastman, C.M., Lee, J.K., 2015. Validations for ensuring the interoperability of data exchange of a building information model. Autom. Constr. 58, 176–195.

Liphadzi, M., Musonda, I., Onososen, A.O., 2022. The use of building information modelling tools for effective waste management: A systematic review. In: World Building Congress,IOP Conf. Ser.: Earth Environ. Sci. 1101 062001. IOP.

Liu, Y., Tao, X., Das, M., Gong, X., Liu, H., Xu, Y., Xie, A., Cheng, J.C.P., 2024. Blockchain-enabled platform-as-a-service for production management in off-site construction design using openBIM standards. Autom. Constr.

164, 105447.
Liu, Z., Lu, Y., Peh, L.C., 2019. A review and scientometric analysis of Global Building Information Modeling (BIM) Research in the Architecture, Engineering and Construction (AEC) industry. Buildings 9.
Malagnino, A., Montanaro, T., Lazoi, M., Sergi, I., Corallo, A., Patrono, L., 2021. Building Information Modeling and Internet of Things integration for smart and sustainable environments: A review. J. Clean. Prod. 312, 127716.
Mellado, F., Lou, E.C.W., 2020. Building information modelling, lean and sustainability: An integration framework to promote performance improvements in the construction industry. Sustain. Cities Soc. 61, 102355.
Onososen, A., Musonda, I., 2022. Barriers to BIM-Based Life Cycle Sustainability Assessment for Buildings : An Interpretive Structural Modelling Approach. Buildings 12, 324.
Ozturk, G.B., 2020. Trends in interoperability in building information modeling (BIM) research: A scientometric analysis of authors and articles. A/Z ITU J. Fac. Archit. 17, 169–183.
Pezeshki, Z., Soleimani, A., Darabi, A., 2019. Application of BEM and using BIM database for BEM: A review. J. Build. Eng. 23, 1–17.
Pour Rahimian, F., Chavdarova, V., Oliver, S., Chamo, F., 2019. OpenBIM-Tango integrated virtual showroom for offsite manufactured production of self-build housing. Autom. Constr. 102, 1–16.
Qi, B., Razkenari, M., Li, J., Costin, A., Kibert, C., Qian, S., 2020. Investigating U.S. industry practitioners' perspectives towards the adoption of emerging technologies in industrialized construction. Buildings 10, 1–21.
Santos, R., Costa, A.A., Grilo, A., 2017. Bibliometric analysis and review of Building Information Modelling literature published between 2005 and 2015. Autom. Constr. 80, 118–136.
Tjebane, M.M., Musonda, I., Onososen, A.O., 2022. Eco-innovation in the Built Environment: A Bibliometric and Systematic Literature Review. In: Proceedings of the 4th African International Conference on Industrial Engineering and Operations Management Nsukka, Nigeria, April 5-7, 2022.
Urban, H., Fischer, S., Schranz, C., 2024. Adapting to an OpenBIM Building Permit Process: A Case Study Using the Example of the City of Vienna. Buildings 14.