Utilising BIM on LCC to Enhance the Sustainability of Saudi Residential Projects Through Simulation. A Case Study at the Kingdom of Saudi Arabia

Esam Alasmari(✉), Pedro Martinez-Vazquez, and Charalampos Baniotopoulos

Department of Civil Engineering, School of Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
Exa855@student.bham.ac.uk

Abstract. There is a growing emphasis in current global construction sector for the incorporating of sustainability ideas into design and construction practices. This present paper investigates the considerable impact of using Building Information Modelling (BIM) techniques to address sustainability and financial concerns in a residential project in the Kingdom of Saudi Arabia (KSA). We propose to further embedding BIM 3D modelling and the development of alternative design scenarios for optimising Life Cycle Cost (LCC) and Life Cycle Assessment (LCA). Four scenarios are assessed using Green Building Studio (GBS) for whole-building analysis, and specific design units are assessed using One Click LCA, which is integrated into Revit. The significance of the study relies on merging of BIM and LCC to improve the sustainability of residential developments at the KSA. It also intends to optimise resource efficiency, reduce environmental impact, and increase cost-effectiveness throughout the whole life cycle of residential structures by using simulation approaches. The findings will benefit industry stakeholders by encouraging sustainable practises that inform decision-making processes in the context of Saudi residential development.

Keywords: Building Information Modelling (BIM) · Life Cycle Costing (LCC) · Life Cycle Assessment (LCA) · Sustainability · Simulation · Optimisation · Residential Projects · Kingdom of Saudi Arabia (KSA)

1 Background

The significance of sustainability worldwide in the construction industry has grown impressively in recent years due to the growing awareness of environmental concerns and the collective acknowledgment of the significant impact of industrial activity on natural resources [1]. The dynamic nature of the construction industry, combined with the constant fluctuation material prices, labour costs, and regulatory changes, contributes to the ongoing problem of complex management and costs increase of residential projects [2, 3]. The complexities of synchronising multiple components of the construction process,

V. Ungureanu et al. (Eds.): CESARE 2024, LNCE 489, pp. 659–668, 2024.
https://doi.org/10.1007/978-3-031-57800-7_61

such as material specifications, labour requirements, and project schedules, highlight the difficulties for resolving and reducing the financial issues associated with residential construction [4–6].

BIM has transformed the construction and design industry by offering a detailed digital depiction of a building throughout its entire lifecycle. One of the most significant benefits of BIM is the impact it has on LCC management [7, 8]. BIM enables stakeholders to make educated decisions regarding a building's design, construction, and operation through the integration of diverse data sources with modelling, hence providing ability to foresee critical scenarios [9–11]. The use of BIM to optimise LCC entails creating a centralised digital model that captures all critical information about a structure, from conception to demolition [12–14]. This model functions as a dynamic database that stakeholders can access at various stages of the building's life. Architects, engineers, contractors, and facility managers may work together in real-time to make informed decisions that consider the long-term financial ramifications of each option.

BIM integration in LCC analysis has shown potential for improving the efficiency and accuracy of the cost estimation throughout the life of construction projects. However, significant challenges remain, which need a deeper comprehension of the elements influencing the effective application of BIM technologies for LCC optimisation. It is therefore critical to address data integration challenges to enable seamless information interchange among various BIM platforms, as well as overcoming cooperation barriers among project stakeholders, while fully embedding BIM into project management workflows. This is important as BIM and Circular Economy principles interact at the forefront of sustainable and efficient construction practices [15–18]. For example, BIM enables stakeholders to cooperate during the structure's full lifecycle. When combined with Circular Economy concepts, BIM becomes a strong tool for optimising resource use, reducing waste, and encouraging material reuse and recycling. The emphasis is on creating structures that can be readily disassembled, reused, or recycled at the end of their life cycles [19–21]. BIM enables efficient disassembly and reassembly procedures by facilitating the tracking and documenting of materials and components [22].

This integration between BIM and circular economy is still underexplored in the building industry, an instance is the insufficient integration of LCA data into BIM processes, which impedes a thorough knowledge of the environmental effect of construction projects across their entire life cycle. To date, the circularity potential of construction materials and components is underutilised in BIM because the industry frequently lacks standardised databases and procedures for analysing and selecting materials based on their recyclability or reusability [23–25]. BIM simulation provides many benefits, one of which is the ability to create a virtual, three-dimensional model of a building, allowing for comprehensive simulation of various design scenarios and accurate cost estimation throughout the entire life cycle [26]. Compatibility concerns between different BIM platforms and standards can also complicate information interchange among project stakeholders, thereby limiting the smooth flow of data required for correct LCC calculations [27, 28].

The present study demonstrates the application of BIM tools in optimising LCC and LCA to meet the challenges that require an integrated approach, incorporating advanced technologies, strategic planning, and innovative methodologies. It aims to exploit the synergies among the design, construction, and operational phases by integrating various techniques, thus achieving a comprehensive understanding of a building's life cycle sustainability. The paper addresses the increasing costs and inefficiencies in residential construction, exemplified by a case study of a residential project in KSA. Its primary objective is to assess how strategic BIM tool utilisation can offer effective solutions for optimising LCC and LCA in residential buildings.

2 Methodology

The research methodology employed in this study aims at addressing the challenges of rising costs in residential construction projects through the integration of BIM tools. The approach adopted for this research involves a multi-step process, combining 3D modelling, simulation, and analysis to optimise LCC and LCA as shown in Fig. 1. The primary BIM tool utilised for 3D modelling was Autodesk Revit 2023, which was selected given its advanced capabilities in creating detailed and accurate building models.

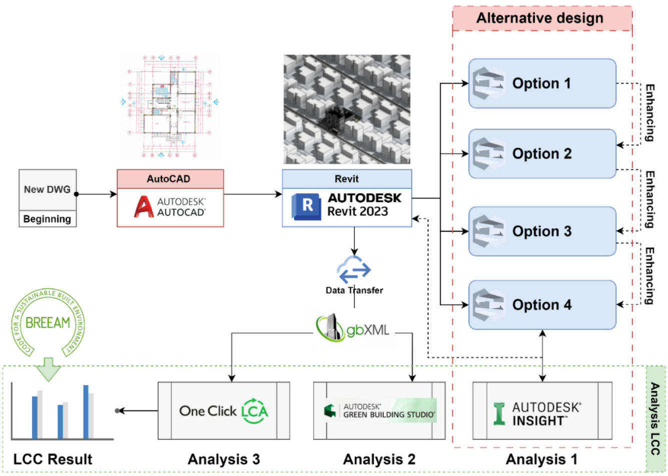

Fig. 1. On the LCC Analysis Methodology.

To initiate the methodology, an existing 3D model of a residential house was created using Autodesk Revit 2023 to determine the technical specifications of the project's materials. This model played a pivotal role in generating the Bill of Quantities (BoQ), correcting omissions observed at the 2D level, thereby contributing to more precise cost estimations. The selection of Revit as the primary software aimed at not only stimulating the design process, but also providing a platform for 3D concept design, physical simulation, and the monitoring of building performance. Following the creation of the 3D model, four alternative design scenarios were developed, each varying wall and floor specifications. These alternative scenarios were crucial in estimating the energy costs associated with LCC. Autodesk Insight, a comprehensive tool integrated with

Revit, was employed to perform the analysis, considering the energy and environmental performance of each scenario. Additionally, Autodesk Green Building Studio (GBS), a whole-building analysis software program, was utilised for a detailed analysis of the four scenarios based on actual model data, local energy sources, and weather data. As a final step in the methodology, the model was transferred to One Click LCA, a web-based analysis service integrated with Autodesk Revit. This platform was instrumental in conducting a detailed analysis of Scenario 1 in the actual design unit and Scenario 4 after enhancing its specifications. The analysis encompassed factors such as Life Cycle Cost, Life Cycle Assessment, BREEAM sustainability criteria, and building circularity.

3 Case Study and Data Analysis

The Residential Development Project is a large project that includes 900 residential structures that address the growing need for housing in the KSA in addition to the necessary utilities including fences, exterior gates, and groundwater tanks. Each residential unit has three bedrooms, a sitting room, a living room, three bathrooms, and a kitchen on one and a half storeys. Each unit has a total building space of roughly 294 m^2 (see Fig. 2).

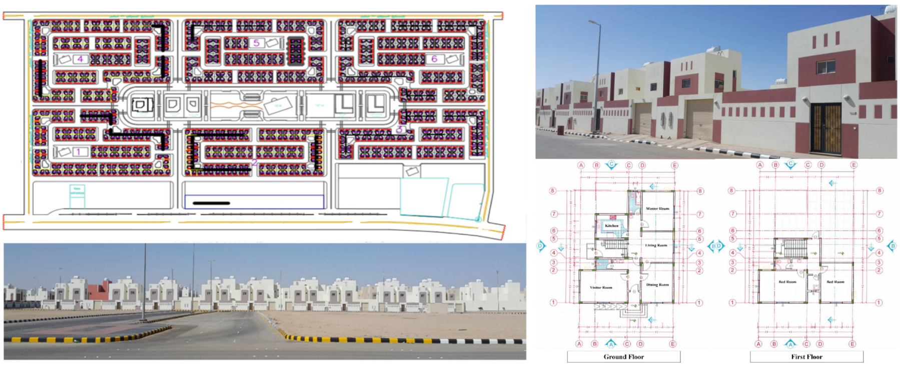

Fig. 2. Views of the Site Plan: Ground and First-Floor Designs.

The residential project has challenges, most notably delays and associated cost increases. The project was originally slated to be completed in 2012, but a three-year delay pushed the completion date to 2015. The main cause of this delay was a two-year extension granted to meet an expanded project scope. The first extension, authorised for 16 months, resulted in a $7,019,257.98 budget increase. Changes in contract conditions and the introduction of goods not originally covered prompted this augmentation. A subsequent 18-month extension increased expenditures by $1,635,840.5, bringing the total budget rise to $8,672,721.81. This delay of 1003 days represented a 92.87% increase over the original contract time. The necessity for an effective project analysis strategy became clear, motivating the look into ways, such as the integration of BIM tools, to optimise LCC and LCA and minimise such issues.

By altering the specs of the walls and flooring, four distinct scenarios were created, introducing a range of design options for the residential construction. The goal was to estimate the energy expenses associated with LCC for each scenario using BIM tools, specifically Autodesk Revit 2023 (see Fig. 3).

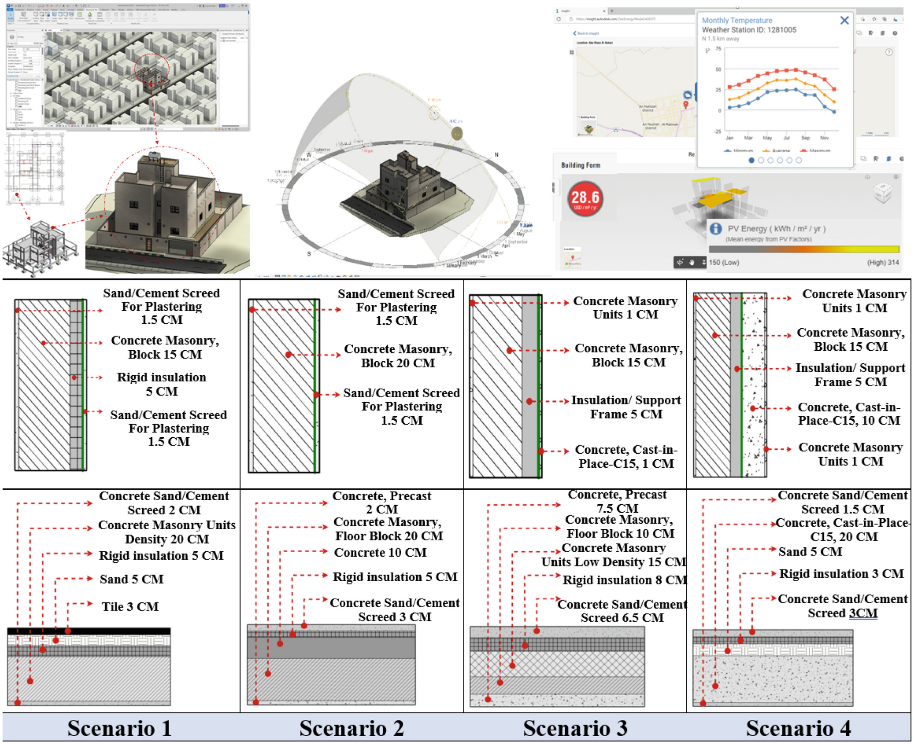

Fig. 3. Differentiated Design Options.

4 Results and Discussion

The study utilised AutoDesk® Revit 2023 to create a 3D model of a residential project, enhancing the accuracy in determining technical specifications of materials. This contrasted with the 2D level, where quantity omissions were noted. The 3D model aided in preparing the Bill of Quantities, leading to significant time and cost savings of approximately $8.67 million. In addition, the analysis of the four alternative design scenarios yielded insightful results, shedding light on the varied impacts of design choices covering energy efficiency, LCC, and environmental sustainability. The presentation of results for each scenario is outlined in Table 1.

For expanding the LCC analysis to a 50-year period from the initial 30-year lifecycle, it is essential to adjust the current LCC data. The original calculation uses a 6.1% discount

Table 1. Results from the alternative scenarios.

	LCC*	Annual CO_2 Emissions (Onsite Fuel)	Energy Use Intensity (EUI)
Scenario 1	$71,739	4.3 Mg	1,715 MJ/m^2/year
Scenario 2	$62,503	4.1 Mg	1,520 MJ/m^2/year
Scenario 3	$54,555	3.6 Mg	1,238 MJ/m^2/year
Scenario 4	$43,529	2.3 Mg	908 MJ/m^2/year

* The estimation is based on a projected lifespan of 30 years and applies a 6.1% discount rate for expenses. It does not consider transmission losses or the possibilities of renewable energy and natural ventilation.

rate, which is retained in the extended analysis. This calculation relies on a formula that determines the present value of future costs Eq. (1):

$$PV = \frac{C}{(1 + r)t} \quad (1)$$

$PV =$ the present value;
$C =$ the future cost;
$r =$ the discount rates;
$t =$ the time in years.

As a result of this formula, LCC can be recalculated over the next 50 years while maintaining the basic assumptions of the original analysis. Based on a fixed annual cost and a discount rate of 6.1%, the LCC for each scenario over 50 years is as follows: Scenario 1: $76,343.84, Scenario 2: $66,514.99, Scenario 3: $58,056.82, and Scenario 4: $46,323.08. A modest increase in LCC can be seen by extending the analysis from 30 to 50 years. Figure 4 shows that the Level(s) lifecycle assessment (EN15804+A1) reveals that a low energy/carbon building (Scenario 4) significantly reduces environmental impact in all categories compared to the baseline of Scenario 1. The greatest emissions reduction is seen in modules A1–A3 materials stage encompass the supply of all materials, products, and energy, along with waste treatment until reaching the end-of-waste state or final residue disposal, focusing exclusively on the building and its components during the product stage, excluding items like furniture or appliances, with emissions dropping from 143,687.72 kg CO_2e in Scenario 1 to 103,258.82 kg CO_2e in Scenario 4. This demonstrates the environmental benefits of low energy/carbon building strategies. Specifically, emissions from external walls decrease by about 50.87%, from 72,058.26 kg CO_2e in Scenario 1 to 35,425.81 kg CO_2e in Scenario 4.

There will be 51.6% of the total material quantity that is recoverable as-is (with a recycling content of 3.1% at stage A), and 7.8% that can be reused. The scenario differs significantly in Scenario 4, however: 9.9% of the materials will be returned (see Fig. 5).

The comparison of the four alternative design scenarios provides an understanding of the implications associated with different design choices in residential construction. Scenario 4, which embraced circular design principles, emerged as a compelling alternative by delivering competitive energy efficiency highlighting the economic viability and sustainability benefits of integrating circular principles into construction practices. The

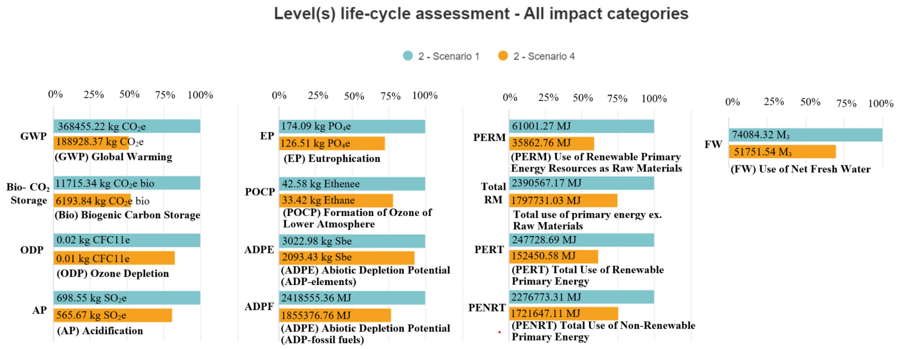

Fig. 4. Comparison of the life cycle assessment (LCA) Scenario 1 with Scenario 4.

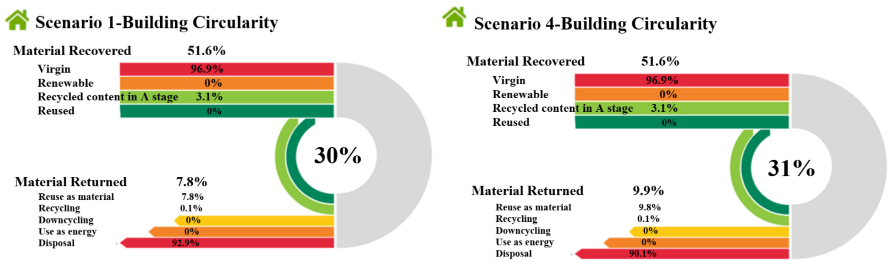

Fig. 5. The outcomes related to the circularity of the building in both Scenario 1 and Scenario 4.

scenario not only exhibited the lowest LCC but also demonstrated a substantial reduction in carbon dioxide (CO_2) emissions, emphasising the potential of circular design to mitigate the environmental impact of residential construction. This outcome aligns with the growing emphasis on sustainable and environmentally conscious construction practices. Scenario 4's cost-effectiveness and sustainability have been enhanced by the strategic integration of LCC analysis through BIM. BIM tools, particularly Autodesk Revit, are critical in modelling and simulating numerous design situations. Engineers could use BIM to thoroughly analyse the technical requirements of project materials, allowing them to create alternative design scenarios. This process enables a thorough examination of the effects of various design options on energy efficiency, costs, and environmental performance. BIM emerges as a critical instrument in aligning construction practices with sustainable development objectives, encouraging a complete approach to building design and operation by optimising LCC and LCA characteristics.

5 Conclusions

This study underlines the critical significance of BIM tools in tackling the issues associated with escalating construction costs in residential construction projects. The study illustrates the effectiveness of BIM in optimising LCC and LCA by applying an extensive approach that incorporates 3D modelling with the appropriately selected software.

The case study of the large-scale residential development project in KSA provides useful information into the details of construction processes, such as delays and cost escalation. The research demonstrates clear benefits from the integration of BIM tools, particularly in the creation of the Bill of Quantities, resulting in significant time and cost savings. The examination of different design scenarios demonstrates BIM's potential to increase energy efficiency, reduce environmental impacts, and, ultimately, contribute to the production of cost-effective and ecologically friendly built environments. A comprehensive analysis of different design scenarios using BIM tools is presented, focusing on their impact on LCC and environmental sustainability in residential construction. The study identifies substantial savings and efficiency improvements, particularly in a scenario incorporating circular design principles, which resulted in the lowest LCC and a remarkable reduction in CO_2 emissions. This scenario also showed a significant decrease in annual CO_2 emissions and Energy Use Intensity (EUI), underscoring the advantages of integrating circular design in construction.

In the future, it is necessary for stakeholders in the construction industry to integrate BIM tools into their project management. These tools offer benefits like speeding up processes, increasing material specification precision, and enabling cost reductions. Utilising BIM-based simulation tools like GBS and One Click LCA for alternative design scenarios can lead to more energy-efficient and sustainable solutions by evaluating multiple design options. Further research into the long-term performance and adaptability of these designs post-construction can enhance understanding of BIM's role in optimising building life cycles. Additionally, exploring BIM collaborative potential may help address issues like project delays and cost overruns. The outcomes from diverse design scenario analyses illuminate BIM capacity to augment energy efficiency, curtail environmental impacts, and foster the development of sustainable and economically viable built environments. Furthermore, this study opens avenues for further exploration into BIM collaborative potential and emphasises the necessity of maintaining data integrity throughout the building lifecycle to fully leverage BIM-LCC integration. These insights not only contribute to the body of knowledge in sustainable construction practices but also provide a strategic framework for future industry applications. This data clearly supports the revised conclusions, emphasising BIM role in enhancing cost-effectiveness and sustainability in residential construction projects.

References

1. Lima L, Trindade E, Alencar L, Alencar M, Silva L (2021) Sustainability in the construction industry: a systematic review of the literature. J Clean Prod 289:125730
2. Alasmari E, Martinez-Vazquez P, Baniotopoulos C (2023) Adopting BIM to enhance sustainability. The Saudi Arabia construction projects case study. In: IOP conference series: earth and environmental science, vol 1196, no 1. IOP Publishing, p 012111
3. Sweis G, Sweis R, Hammad A, Shboul A (2008) Delays in construction projects: the case of Jordan. Int J Project Manage 26(6):665–674
4. Zehro K, Jkhsi S (2020) Management, quality and economy in home building construction. Int J Adv Eng Sci Appl 1(2):12–17
5. Danijela S (2015) Application of construction schedule for monitoring and control of civil engineering projects. Arhiv za Tehnicke Nauke/Arch Tech Sci (12)

6. Alhazmi H, Alduwais K, Tabbakh T, Aljamlani S, Alkahlan B, Kurdi A (2021) Environmental performance of residential buildings: a life cycle assessment study in Saudi Arabia. Sustainability 13(6):3542
7. Alasmari E, Martinez-Vazquez P, Baniotopoulos C (2022) A systematic literature review of the adoption of building information modelling (BIM) on life cycle cost (LCC). Buildings 12(11):1829
8. Santos R, Costa A, Silvestre D, Pyl L (2019) Integration of LCA and LCC analysis within a BIM-based environment. Autom Constr 103:127–149
9. Lu K, Jiang X, Yu J, Tam W, Skitmore M (2021) Integration of life cycle assessment and life cycle cost using building information modeling: a critical review. J Clean Prod 285:125438
10. Alasmari E, Martinez Vazquez P, Baniotopoulos C (2022) Building information modeling (BIM) towards a sustainable building design: a survey. In: Proceedings of the CESARE22, 3rd coordinating engineering for sustainability and resilience, Irbid, Jordan, pp 6–9
11. Alasmari E, Martinez-Vazquez P, Baniotopoulos C (2023) An analysis of the qualitative impacts of building information modelling (BIM) on life cycle cost (LCC): a qualitative case study of the KSA. Buildings 13(8):2071
12. Kehily D, McAuley B, Hore A (2012) Leveraging whole life cycle costs when utilising building information modelling technologies. Int J 3-D Inf Model (IJ3DIM) 1(4): 40–49
13. Biolek V, Hanák T, Marović I (2017) Data flow in relation to life-cycle costing of construction projects in the Czech Republic. In: IOP conference series: materials science and engineering, vol 245, no 7. IOP Publishing, p 072032
14. Peshkov V (2021) BIM-technologies: organizational aspects in different stages of investment and construction project. In: IOP conference series: earth and environmental science, vol 751, no 1. IOP Publishing, p 012108
15. Jayasinghe B, Waldmann D (2020) Development of a BIM-based web tool as a material and component bank for a sustainable construction industry. Sustainability 12(5):1766
16. Xue K et al (2021) BIM integrated LCA for promoting circular economy towards sustainable construction: an analytical review. Sustainability 13(3):1310
17. Charef R (2022) The use of Building Information Modelling in the circular economy context: Several models and a new dimension of BIM (8D). Clean Eng Technol 7:100414
18. AlJaber A, Alasmari E, Martinez-Vazquez P, Baniotopoulos C (2023) Life cycle cost in circular economy of buildings by applying building information modeling (BIM): a state of the art. Buildings 13(7):1858
19. Favi C, Germani M, Luzi A, Mandolini M, Marconi M (2017) A design for EoL approach and metrics to favour closed-loop scenarios for products. Int J Sustain Eng 10(3):136–146
20. Alasmari E, AlJaber A, Martinez-Vazquez P, Baniotopoulos C (2024) Enhancing life cycle costing (LCC) in circular construction of buildings by applying BIM: a literature review. In: Bragança L, Cvetkovska M, Askar R, Ungureanu V (eds) Creating a Roadmap Towards Circularity in the Built Environment. Springer Tracts in Civil Engineering. Springer, Cham, pp 407–417. https://doi.org/10.1007/978-3-031-45980-1_33
21. Mattaraia L, Fabricio M, Codinhoto R (2023) Structure for the classification of disassembly applied to BIM models. Archit Eng Design Manag 19(1):56–73
22. Bartels N, Höper J, Theißen S, Wimmer R (2022) Application of the BIM method in sustainable construction: status quo of potential applications in practice. Springer, Cham. https://doi.org/10.1007/978-3-031-12759-5
23. Akbarnezhad A, Ong G, Chandra R (2014) Economic and environmental assessment of deconstruction strategies using building information modeling. Autom Constr 37:131–144
24. Aguiar A, Vonk R, Kamp F (2019) BIM and circular design. In: IOP conference series: earth and environmental science, vol 225, no 1. IOP Publishing, p 012068
25. Akhimien G, Latif E, Hou S (2021) Application of circular economy principles in buildings: a systematic review. J Build Eng 38:102041

26. Wei X, Bonenberg W, Zhou M, Wang J, Wang X (2018) The case study of BIM in urban planning and design. In: Charytonowicz J (ed) AHFE 2017, vol 600. AISC. Springer, Cham, pp 207–217. https://doi.org/10.1007/978-3-319-60450-3_20
27. Shin J, Kwon S, Lee K, Choi S, Kim J (2015) A study of the establishment of framework for information exchange based on IFC model in domestic collaborative design environment. Korean J Constr Eng Manag 16(1):24–34
28. De Gaetani I, Mert M, Migliaccio F (2020) Interoperability analyses of BIM platforms for construction management. Appl Sci 10(13):4437