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BIM Role for Circular Economy in the Built Environment Context: A Review and Way Forward

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Abstract: With the advent of digitization, the integration of advanced technologies in operations and projects across all sectors is in progress. Accordingly, efforts are being made to utilize cutting-edge technologies to improve the circularity of the built environment. This study aimed to review the existing applications and limitations of building information modeling (BIM) tools for circular economy (CE) implementation from this perspective. A literature review was conducted to provide an overview of the use of BIM tools for conducting life cycle assessments, energy analysis, waste management, and formulation of material passports for buildings. It was found that BIM tools, which are available across all life cycle phases of building, have a great potential to improve the circularity of the sector. The overview provided on the use of various BIM tools may help stakeholders of the built environment understand the role of BIM for CE adoption in the sector.

Keywords: circular economy; building information modeling; built environment; building sector; digitalization

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1. Introduction

Undoubtedly, the building sector plays a contributory role in the global GDP and workforce [1]. Nevertheless, this sector is also among the major waste-generating and resource-consuming sectors of the economy across the globe [2]. According to the International Energy Agency (IEA) report, construction activities account for 39% of CO_2 emissions, 36% of final energy use, and approximately one-third of global waste generation [1]. The depletion of resources and environmental degradation has raised the alarm for both policymakers and academics worldwide. This has brought the notion of circular economy (CE) into the limelight, and resultantly, research on CE has increased manifold during the past decade [3]. The paradigm of CE has the potential to overcome the imminent issues of resource scarcity, energy crisis, and waste generation through closed resource loops [4].

To adopt the closed materials loops and other aspects of CE, a lot of data and information is required, and due to lack of the same, the entire potential of CE cannot be tapped [5]. Thanks to the recent advancements in the field of information technology, which have made the availability of information and data far easier [6]. With the advent of Industry 4.0, like other fields, the need to integrate digital tools in the building sector has been realized [5]. Building information modeling (BIM), which is a visual representation of buildings, has been used for several lifecycle phases of buildings owing to its capability to integrate information from multiple stakeholder [7],[8],[9]. In addition to several other benefits, BIM has also opened new opportunities for better adoption and implementation of the CE concept in the built environment.

During recent years, there has been a proliferation of research studies on the integration of BIM for CE implementation in the building sector. However, it has been found that mostly a specific aspect of BIM from the perspective of CE has been focused on by researchers and there is a need to present an overview on use of BIM tools within this domain. As a result, by reviewing the existing literature on the subject, this study provides the overall picture of various applications of BIM for CE implementation from the built environment perspective. Figure 1 depicts an overview of the CE model.

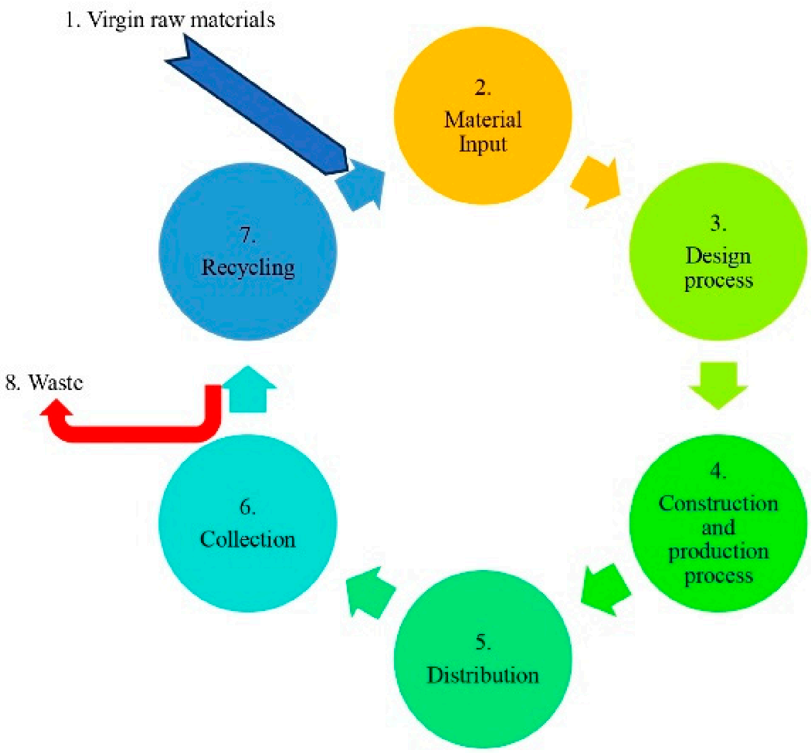

Figure 1. An overview of the circular economy model.

2. BIM and Circular Economy

Complex work processes and tedious managerial activities make the management of construction projects a difficult task [10]. This challenge can, however, be mitigated through the digitalization of construction processes [11,12]. The same has been validated by a study conducted by Mavropoulos and Nilsen [13], which highlighted that 93 % of construction professionals, for their study, agreed that digitalization has the potential to affect construction processes. Given the benefits of digitalization during the construction phase, this digital transformation can be equally good for the implementation of the CE concept in the built environment [14]. The action plan for CE, proposed by the European Commission (2020), has also emphasized on inclusion of digital tools as CE decision support [15].

In recent years, the use of BIM has increased significantly, and to this end, governments in several countries have also made it mandatory to use BIM on public sector projects [7]. Being the latest generation of designing software, BIM is much more than a drafting tool. In contrast to conventional design software, each building component in BIM also contains details about manufacturers and the composition of materials in addition to its dimensions [16]. The capability of the BIM to store life cycle information of building components and its capacity for information exchange and effective coordination makes it suitable for the implementation of CE in the building sector [17]. By reviewing the literature, it has been found that different aspects of BIM can help in the implementation of CE; the following sections will shed light on these facets.

2.1. BIM Application for Life Cycle Assessments

Life cycle assessments (LCA) are considered important as these techniques help in knowing the monetary and environmental implications of the projects in advance and thus help in rational decision-making. LCA is an effective method to calculate the harmful effects of buildings on the environment in objective terms. Knowing the detrimental impacts in advance can help in making informed decisions and thereby support in devising strategies to reduce the environmental degradation of the industry by promoting the circularity of the sector. There are several tools available for conducting environmental impact assessments of structures; however, the conventional tools are not well integrated. This is to say that these traditional methods do not consider all the aspects of the projects and thereby lack in presenting the whole picture to the decision-makers. On the other hand, BIM has the capacity to integrate information from multiple stakeholders, and this can greatly help in undertaking the life cycle assessments of the buildings [18].

Researchers have studied the prospects for life cycle sustainability assessment (LCSA) of buildings at the design stage utilizing BIM. The study conducted by Llatas, et al. [19] is pertinent to mention wherein a framework for the implementation of LCSA was developed, and the lack of standardization was mentioned as a major impediment to the adoption of the concept. Similarly, studies have also explored the possibilities for conducting life cycle cost analysis (LCCA) using BIM. A recent study by AlJaber, et al. [20] highlighted the potential use of BIM for LCCA in order to calculate the overall cost of the building; nevertheless, the lack of quality data and standardization were mentioned as the key impediments to the concept. Although studies on life cycle assessments through BIM have increased manifold during recent years, better presentation of information on the integration of these assessment methodologies is considered deficient [21]. It is therefore suggested that future studies may be undertaken to bridge this gap.

2.2. BIM Application for Material Passports

The construction industry is the largest resource-consuming sector and accounts for almost 60 % of resource extraction from the lithosphere [22]. In order to reduce the extraction of virgin materials, the main strategy of CE is to improve the recycling rates [23]. To this end, the concept of building as a material bank (BAMB) focuses on increasing the value of existing building components and materials with the potential to inject them back into the loop. For improving the recycling rates, it is important that information about existing building components and materials is available. The material passport (MP) contains the qualitative and quantitative details of materials and identifies the potential of building components to bring them back into the supply chain either by reusing or recycling [24].

The BIM-based MP can provide the requisite details about the building materials and have the potential to enhance the recycling rates of construction materials [25]. This can also help to evaluate the recycling potential of different proposals and to make informed decisions. A study conducted by Honic, et al. [26], proposed a methodology for BIM-based MP and tested the toolchain on the roof of a residential building to identify the recycling potential of timber; nevertheless, authors highlighted the need for parametrization of layers by BIM as lack of it makes the process tedious. While using ground penetrating radars and laser scans, Honic, et al. [27] presented a methodology for the generation of semi-automated BIM-based MP for existing structures and tested the proposed method for generating material passports on an exterior wall. It was suggested by them that future studies may work on the compilation of an automated MP while using the bi-directionally connected tool. In a recent study by [28], authors advocated the use of blockchain-enabled material passports in BIM for their potential to provide better information flow and verified data. Future studies may work on the integration of BIM with several other available industry 4.0 tools for improvements in BIM-based MP.

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2.3. Bim Application For Waste Minimization

Waste generation due to construction activities accounts for the most significant part of global landfill [29] and this fact has prompted the industry to adopt the CE concept in order to reduce its waste [30]. The agenda of CE in the building sector is to eliminate waste at the design stage, reduce waste during the construction process, and promote the reuse and recycling of materials at the end-of-life cycle stage instead of discarding materials as done in liner supply chains. Several features of BIM, such as automatic clash detection, quantity take-off, design error reduction, site planning, 3D coordination, digital fabrication, early collaboration of stakeholders, and construction system design, have the capacity to minimize waste [7]. Due to the unique information handling capacity of BIM throughout the lifecycle stages of buildings, waste from the design to demolition stages can be substantially reduced using BIM [24].

Previous research on the subject has highlighted the potential use of BIM for waste minimization. In this regard, Won, et al. [31] proposed a method for the calculation of waste minimization through the utilization of BIM constructability review and clash detection potentials. The study conducted by [32] proposed a BIM-based model whereby the designer can assess the deconstructability score of various design proposals based on their potential for recyclability, reusability, and toxicity of materials and can select the best option. Similarly, Lu, et al. [33] proposed a tool for the selection of the least waste-generating alternative not only based on design options but also considering construction schemes. The study undertaken by Ganiyu, et al. [30] on the identification of BIM competencies for waste reduction from the perspective of the built environment is also relevant to mention. They broadly categorized competencies into four categories including construction-related, project management-related, design-related, and procurement-related. Even though BIM has great potential to minimize waste, vagueness in legal policies, lack of BIM awareness, and resources are considered the major impediments to BIM implementation in the waste management [34]. Efforts need to be made by concerned quarters to overcome these barriers to BIM for waste management from the perspective of the built environment.

2.4. BIM Application for Energy Analysis

Almost one-third of global energy is consumed by buildings and owing to the prevailing energy shortfall globally, serious steps are being taken by policymakers and researchers to minimize energy consumption through the adoption of energy-efficient measures [35]. Various simulation tools are available to evaluate the energy efficiency potential of buildings at the designing stages [36]. Nevertheless, the drawback of the conventional energy modeling approach is that it creates a separate model for the building, based on traditional drawings, which is subject to inconsistencies, misinterpretation of drawings, and, most importantly, it is more time-consuming [37]. However, building energy modeling (BEM), a subset of BIM, is used for the integration of energy analysis throughout the building life cycle stages. This makes the whole process of energy modeling automated, gives consistent results, and can produce complex models effectively [38],[39]. During the design stage, BEM can be used to evaluate the energy performance of different alternatives, while in the construction phase, BEM can help in comparing the different options available as a result of any change order [38]. Likewise, BEM can be used during the operational phase to calculate the actual energy consumption of buildings [40]. Furthermore, BEM tools can also be tailored according to specific user groups, such as engineers, architects, contractors, and facility managers [38].

Researchers have focused on several aspects of BEM, Gao, et al. [40] reported in their study that the creation of a building model by BEM saves 75 % time in contrast to the conventional tools as the BEM model is created based on the BIM model. Similarly, thermal zones created by BEM are closely aligned with mechanically designed zones, and there is no need to create theoretical thermal zones. Given that the BEM has great potential for performing energy analysis, however, there exist some interoperability issues between BIM and BEM methodology, which need improvement to make the process smoother [41]. Future studies may be conducted to overcome this impediment.

3. Conclusions

This study has focused on several areas where the application of BIM can help in improving the circularity of the built environment; moreover, the limitations of BIM tools in this regard were also highlighted. It has been found that BIM tools have enormous potential for implementation of the CE concept throughout the lifecycle stages of buildings.

According to the findings, the application of BIM for undertaking lifecycle assessments of the building has a competitive edge over the conventional life cycle assessment methodologies due to its capability for enhanced information flow throughout the lifecycle stages of the building. Similarly, the use of BIM-based energy analysis through BEM is also more effective than the other available software for energy evaluations as it not only saves time but also helps in generating complex models effectively. Furthermore, potential uses of BIM for waste management and utilization of the MP concept for the reuse and recycling of materials were also discussed.

Future studies may be conducted to overcome the limitations highlighted in the paper for better integration of BIM tools to enhance the circularity of the built environment. Moreover, the overview of various BIM tools for CE provided in the study may help practitioners and decision-makers in selecting the relevant BIM tools for their projects and operations to improve CE adoption in the built environment.

References

1. IEA, "Global Status Report for Buildings and Construction, IEA, Paris," 2019. [Online]. Available: www.iea.org/reports/global-status-report-for-buildings-and-construction-2019
2. UNDP, "United Nations environment programme, buildings and climate change summary for decision makers," 2009. [Online]. Available: https:// www.uncclearn.org/sites/default/files/inventory/unep207.pdf/.
3. P. Rosa, C. Sassanelli, A. Urbinati, D. Chiaroni, and S. Terzi, "Assessing relations between Circular Economy and Industry 4.0: a systematic literature review," *International Journal of Production Research*, vol. 58, no. 6, pp. 1662-1687, 2020.
4. M. Bilal, K. I. A. Khan, M. J. Thaheem, and A. R. Nasir, "Current state and barriers to the circular economy in the building sector: Towards a mitigation framework," *Journal of Cleaner Production*, vol. 276, p. 123250, 2020.
5. S. Çetin, V. Gruis, and A. Straub, "Digitalization for a circular economy in the building industry: Multiple-case study of Dutch social housing organizations," *Resources, Conservation & Recycling Advances*, vol. 15, p. 200110, 2022.
6. M. Honic, I. Kovacic, and H. Rechberger, "Improving the recycling potential of buildings through Material Passports (MP): An Austrian case study," *Journal of Cleaner Production*, vol. 217, pp. 787-797, 2019.
7. T. N. Handayani, K. N. Putri, N. A. Istiqomah, and V. Likhitruangsilp, "The Building Information Modeling (BIM)-based system framework to implement circular economy in construction waste management," in *J. Civ. Eng. Forum*, 2022, vol. 8, pp. 31-44.
8. M. Afzal, R. Y. M. Li, M. F. Ayyub, M. Shoaib, and M. Bilal, "Towards BIM-based Sustainable Structural Design Optimization: A Systematic Review and Industry Perspective," in *Preprints*, ed: Preprints, 2023.
9. M. Afzal, "BIM 7D: Research on Applications for Operations & Maintenance," presented at the 1st BIM A+ International Conference, University of Minho, Portugal, 30/09/2021, 2021.
10. Q. K. Jahanger, J. Louis, C. Pestana, and D. Trejo, "Potential positive impacts of digitalization of construction-phase information management for project owners," *Journal of Information Technology in Construction*, vol. 26, 2021.
11. S. Durdyev, J. Mbachu, D. Thurnell, L. Zhao, and M. R. Hosseini, "BIM adoption in the Cambodian construction industry: key drivers and barriers," *ISPRS International Journal of Geo-Information*, vol. 10, no. 4, p. 215, 2021.
12. K. Schober and P. Hoff, "Digitization in the construction industry—Building Europe's road to "Construction 4.0". Think Act. Munich: Roland Berger Gmbh, Civil Economics," *Energy & Infrastructure Competence Center*, 2016.
13. A. Mavropoulos and A. W. Nilsen, *Industry 4.0 and circular economy: Towards a wasteless future or a wasteful planet?* John Wiley & Sons, 2020.
14. M. Behún and A. Behúnová, "Advanced Innovation Technology of BIM in a Circular Economy," *Applied Sciences*, vol. 13, no. 13, p. 7989, 2023.
15. E. Commission, "A New Circular Economy Action Plan for a Cleaner and More Competitive Europe," 2020. [Online]. Available: https://ec.europa.eu/environment/pdf/circular-economy/

16. T. M. O'Grady, N. Brajkovich, R. Minunno, H.-Y. Chong, and G. M. Morrison, "Circular economy and virtual reality in advanced BIM-based prefabricated construction," *Energies*, vol. 14, no. 13, p. 4065, 2021.
17. L. A. Akanbi *et al.*, "Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator," *Resources, Conservation and Recycling*, vol. 129, pp. 175-186, 2018.
18. K. Xue *et al.*, "BIM integrated LCA for promoting circular economy towards sustainable construction: An analytical review," *Sustainability*, vol. 13, no. 3, p. 1310, 2021.
19. C. Llatas, B. Soust-Verdaguer, and A. Passer, "Implementing Life Cycle Sustainability Assessment during design stages in Building Information Modelling: From systematic literature review to a methodological approach," *Building and Environment*, vol. 182, p. 107164, 2020.
20. A. AlJaber, E. Alasmari, P. Martinez-Vazquez, and C. Baniotopoulos, "Life Cycle Cost in Circular Economy of Buildings by Applying Building Information Modeling (BIM): A State of the Art," *Buildings*, vol. 13, no. 7, p. 1858, 2023.
21. G. Guignone, J. L. Calmon, D. Vieira, and A. Bravo, "BIM and LCA integration methodologies: A critical analysis and proposed guidelines," *Journal of Building Engineering*, vol. 73, p. 106780, 2023.
22. E. Commission, "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Closing the loop-An EU action plan for the Circular Economy, Brussels," 2015.
23. I. Kovacic, M. Honic, and H. Rechberger, "Proof of concept for a BIM-based material passport," in *Advances in Informatics and Computing in Civil and Construction Engineering: Proceedings of the 35th CIB W78 2018 Conference: IT in Design, Construction, and Management*, 2019: Springer, pp. 741-747.
24. Y.-C. Kim, W.-H. Hong, J.-W. Park, and G.-W. Cha, "An estimation framework for building information modeling (BIM)-based demolition waste by type," *Waste Management & Research*, vol. 35, no. 12, pp. 1285-1295, 2017.
25. M. Honic, I. Kovacic, and H. Rechberger, "Concept for a BIM-based Material Passport for buildings," in *IOP Conference Series: Earth and Environmental Science*, 2019, vol. 225: IOP Publishing, p. 012073.
26. M. Honic, I. Kovacic, and H. Rechberger, "BIM-based material passport (MP) as an optimization tool for increasing the recyclability of buildings," *Applied Mechanics and Materials*, vol. 887, pp. 327-334, 2019.
27. M. Honic, I. Kovacic, I. Gilmutdinov, and M. Wimmer, "Scan-to-BIM for the semi-automated generation of a material passport for an existing building," in *37th CIB W78 Conference*, 2020, pp. 338-346.
28. Q. Li, M. Agyemang, J. Gosling, and Y. Wang, "The application of blockchain-enabled material passports for circular supply chains," 2023.
29. A. Razak Bin Ibrahim, M. H. Roy, Z. U. Ahmed, and G. Imtiaz, "Analyzing the dynamics of the global construction industry: past, present and future," *Benchmarking: An International Journal*, vol. 17, no. 2, pp. 232-252, 2010.
30. S. A. Ganiyu, L. O. Oyedele, O. Akinade, H. Owolabi, L. Akanbi, and A. Gbadamosi, "BIM competencies for delivering waste-efficient building projects in a circular economy," *Developments in the Built Environment*, vol. 4, p. 100036, 2020.
31. J. Won, J. C. Cheng, and G. Lee, "Quantification of construction waste prevented by BIM-based design validation: Case studies in South Korea," *Waste Management*, vol. 49, pp. 170-180, 2016.
32. O. O. Akinade *et al.*, "Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS)," *Resources, conservation and recycling*, vol. 105, pp. 167-176, 2015.
33. W. Lu, C. Webster, K. Chen, X. Zhang, and X. Chen, "Computational Building Information Modelling for construction waste management: Moving from rhetoric to reality," *Renewable and Sustainable Energy Reviews*, vol. 68, pp. 587-595, 2017.
34. N. M. Liphadzi, I. Musonda, and A. Onososen, "The use of building information modelling tools for effective waste management: A systematic review," in *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 1101, no. 6: IOP Publishing, p. 062001.
35. I. E. Agency, "Transition to Sustainable Buildings," 2013.
36. S. Beazley, E. Heffernan, and T. J. McCarthy, "Enhancing energy efficiency in residential buildings through the use of BIM: The case for embedding parameters during design," *Energy Procedia*, vol. 121, pp. 57-64, 2017.
37. S. J. Hayter, P. A. Torcellini, R. B. Hayter, and R. Judkoff, "The energy design process for designing and constructing high-performance buildings," 2001.
38. H. Kim and K. Anderson, "Energy modeling system using building information modeling open standards," *Journal of Computing in Civil Engineering*, vol. 27, no. 3, pp. 203-211, 2013.
39. M. Afzal, K. Widding, E. Hjelseth, and M. Hamdy, "Systematic investigation of interoperability issues between BIM and BEM," in *ECPPM 2022-eWork and eBusiness in Architecture, Engineering and Construction 2022*: CRC Press, 2023, pp. 713-720.
40. H. Gao, C. Koch, and Y. Wu, "Building information modelling based building energy modelling: A review," *Applied energy*, vol. 238, pp. 320-343, 2019.

 doi:10.20944/preprints202310.0027.v1

41. G. Gourlis and I. Kovacic, "Building Information Modelling for analysis of energy efficient industrial buildings–A case study," *Renewable and Sustainable Energy Reviews,* vol. 68, pp. 953-963, 2017.