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Mahdi Kioumarsi
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The 1st International Conference on Net-Zero Built Environment

Innovations in Materials, Structures, and Management Practices

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Preface

The *1st International Conference on Net-Zero Built Environment: Innovations in Materials, Structures, and Management Practices* was successfully held on June 19–21, 2024, in Oslo, Norway. This conference was part of the *Net-Zero Future* project sponsored by the Research Council of Norway and the Norwegian Directorate for Higher Education and Skills. Through the referenced project, a unique international alliance was formed among Norway, the United States, Germany, South Africa, and India to conduct collaborative research and educational activities toward achieving a net-zero built environment, capitalizing on mutual interests and the diversity of practices. This alliance is in line with sustainable development goals, such as quality education, industry and innovation, sustainable cities, climate action, and partnerships.

The pressing global challenges associated with the degradation of the built environment due to mounting stressors and, on the other hand, the environmental footprint of growth in the built environment serving communities have necessitated a profound transformation in how we design and develop our infrastructure. Civil engineering is the primary field responsible for infrastructural development and is at the forefront of this transformation. The conference series on Net-Zero Built Environment: Innovations in Materials, Structures, and Management Practices has been dedicated to exploring the concept of net-zero within the realm of civil engineering and a variety of relevant domains, emphasizing the critical importance of achieving a net-zero carbon footprint in our built environment.

Net-zero in the built environment refers to the knowledge and practice of delivering, maintaining, and managing civil infrastructures that produce zero net carbon emissions throughout their lifecycle. This ambitious goal requires a holistic effort, encompassing methodological approaches to design, construction, operation, and eventual decommissioning. This motivated us to establish three main themes for this conference series, capturing innovations in materials, structures, and management practices. The first conference of this conference series attracted a large group of participants from the academic, industry, and public sectors, presenting the latest developments in each of the identified main themes.

After a rigorous peer-review process performed by the conference's international scientific committee members and other expert reviewers, 158 full-text papers have been selected to be included in this book. The selected papers represent a diverse group of authors and research groups from around the globe, providing original perspectives and insights into how we can pave the way toward a net-zero built environment. Converging on this ultimate goal, the selected papers offer the latest advances in (i) new materials and manufacturing processes for zero carbon footprint, (ii) robotic construction technologies for minimum formwork and on-site activities, (iii) novel structural designs and details for optimal performance with the least materials, (iv) advanced condition assessment and health monitoring strategies, and (v) innovative life-cycle analyses and civil infrastructure management strategies.

We recognize that achieving net zero is not merely a development goal but a moral imperative to ensure a sustainable future for all. Reducing carbon emissions can help stabilize temperature patterns, decrease the frequency and severity of extreme weather events, and protect vulnerable ecosystems. All who contributed to this book share the same passion to positively impact the communities around the world. Through the dissemination of the latest findings and innovations, this book's main themes and individual chapters directly contribute to the net-zero domain. By equipping scientists, engineers, policymakers, and the general public with relevant knowledge and expertise, we hope to collectively drive a global transition toward a net-zero future.

Oslo, Norway | Mahdi Kioumarsi
Ames, IA, USA | Behrouz Shafei

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Towards Net-Zero Construction Projects by Applying BIM-Enabled Circular Economy

Ana Julie Foseid Bjerke and Omar Amoudi

Contents

1 Background

The built environment is currently in a dire moment of change to achieve further sustainable solutions and to reduce the carbon footprint [1–3]. The Linear economic model has been predominantly adopted in the construction industry, in addition to the introduction of recycling of construction waste. In alignment with the findings in UNEP [4] where the built environment was found to account for 39% of the global carbon emissions. Giorgi et al. [5] stated that linear economic models and recycling are no longer a solution due to limited resources available. The concept of the CE is relatively new and generating further recognition across many respective fields, including the construction industry [6]. Some existing challenges interluding the further adoption of CE principles within the AEC industry include but not limited to;

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the traditional construction and design strategies, construction and demolition waste management, poor supply chain management, Ignorance of End-of-Life (EOL) principles, lack of regulations and strategies to encourage the adoption of the CE principles, lack of collaboration, and lack of information exchange of CE practices (Al [7, 8]).

Building Information Modelling has been a vital element in the construction industry allowing for improved communication, collaboration, and interoperability in construction projects. Digitalisation, especially BIM as a promising tool, facilitates the collaboration between project teams to incorporate and manage information of building processes that may lead towards more sustainable construction projects, and reinvents contemporary design [9]. This paper aims to assess the potential utilisation of BIM as an enabler to achieve further implementation of CE principles within the built environment. BIM's role, when aiming to achieve CE-related goals within construction projects, is to be clarified, showing the emerging challenges and barriers, recommendations, and key findings.

2 Concept of Circular Economy

Ellen MacArthur Foundation [10] founded the 3Rs principles that describe circular economy processes to facilitate the transition towards more circularity: reduce, recycle, and reuse. Stated in the works of Ellen MacArthur Foundation [11], CE is a regenerative economy where the target is to retain the highest values for products and materials in a permanent circular system for their optimal reuse, recycling, remanufacturing, and refurbishment. In general, CE illustrates the impact on the economy that natural resources sustain, and give further insight into waste, production, economic systems, and waste within the construction industry [12]. Xue et al. [13] proposed the alignment of CE principles and the technical requirements within the construction industry in terms of resource mass consumption. Similarly, Suárez-Eiroa et al. [14] found supporting evidence that the adoption of CE concept maintains the economic growth, creates further job opportunities, and reduces CO_2-emissions. Conclusively, CE maintains and retains added high value in materials, products, and components in a restorative and regenerative design system until their EOL [15, 16].

2.1 Digitalisation and Enabling CE Adoption

Digitalisation is considered as one of the key enablers of CE as it offers improved intelligence, information management, design and construction process visibility, and condition of assets and products. This in turn assists in managing resources and the facility information and reduces the uses of resources [17, 18]. Another key enabler is the 3DR index coined by O'Grady et al. [19]: Disassembly, Deconstruction, Resilience. Enabling the principles of 3DR generates increased knowledge on implementation of CE in the context of transforming waste into new suitable resources. Furthermore, O'Grady et al. [19] found emerging benefits in all stages within a project's lifecycle when 3DR is applied. Digitalisation could hold a significant role in empowering the 3DRs, because these principles require strong information management which could be missed or mis-coordinated if the traditional tools/practices used for managing the information is required. Depending on the traditional tool of storing and managing information could lead to more errors in the 3DRs processes, that results in extra cost and more waste.

2.2 Challenges Facing CE

The biggest challenges facing the adoption of CE in the construction industry, is the lack of knowledge and awareness among project parties, lack of clear design incentives for reuse of assets and materials' EOL, and lack of the concept of design for disassembly [20–22]. Purchase et al. [23] found other challenges prohibiting the further adoption of CE principles that include poor governance, high cost, lack of awareness and poor information management, and lack of clear specifications on recycled assets and materials.

The existing structure and characteristics of the construction industry were mentioned by Adams et al. [20] as leading to the fragmentation within the supply chain, which is again one of the key barriers facing the CE implementation [24]. Fulford and Standing [25] found that the efficiency and productivity are severely impacted by the supply chain fragmentation within the construction industry and the lack of standardisation. To obtain a comprehensive understanding of standardisation and apply it properly into projects, BIM emerges as a tool to meet the continuous improvement that standardisation acquires. Bradley et al. [26] found BIM use is commonly applied for any standards in projects where the BIM model is utilised for design purposes, rather than using 4D and 5D BIM model for cost and programme management. It is a requirement in the construction industry for standardisation regarding BIM, which is found within the exchange information between used software applications [27]. BIM's flexibility could provide the tools to monitor and manage the required sustainability measures in terms of waste reduction during the building's entire lifespan [28].

2.3 Synergies Between BIM and CE

The current use of BIM during an asset's life cycle could enhance the possibility of recovering the asset's history in the events of partial or whole destruction in an asset refurbishment, which is one of the current existing synergies between BIM and CE [29]. It is argued by Göswein et al. [30] that dependent factors already in use within the built environment, such as facility and design management, resource management, and waste management, altogether sustain the synergy currently between BIM and CE. BIM utilisation for waste management is already enabling some of these factors such as quantity take-off, site utilisation planning, 3D coordination and planning, digital fabrication, phase planning, and design review [31]. Performing a BIM-Deconstructability Assessment Score allows for the further enabling of BIM as a tool for Circularity to prolong the EOL of materials, additionally with the use of as-built BIM models for building operations and maintenance using laser scanners [32, 33]. Previous research could identify the as-built BIM models as tools for cost analysis for demolitions plans in selected waste systems including design for disassembly, assets, and waste management [34, 35].

2.4 Barriers and Opportunities of Current BIM-Enabled CE Principles

To help the Built Environment shift from the linear economic model to the circular economic model, Hai et al. [36] suggested assessing benefits such as increased CE awareness and improved recycling rates to aid this shift. Enhancing the building's performance by encouraging further usage of BIM to match EOL assessments of projects, will reduce waste and help preserve the embodied energy in construction projects [37]. Xue et al. [13] found in general that the widespread use of BIM and LCA within the construction industry to not being fully applied. Existing concerns regarding BIM-enabled CE revolve around the whether industry professionals obtain sufficient BIM knowledge, BIM competency, and BIM software training, and the BIM documentation and models in cloud-share collaboration [6]. However, Göswein et al. [30] purport that the main challenges facing BIM-enabled CE are lack of data, poor procedures, and interoperability issues. It is clear that several studies referred to the potential relations between BIM features and the principles of the CE. This will be further explored in this paper.

3 Research Methodology

The research methodology adopted in this study was a simple mixed methodology consisting of a quantitative and qualitative approach to obtain the primary data through two stages: (1) A questionnaire survey and (2) An interview. A pilot study was carried out to validate both the questionnaire survey questions and interview questions. The questionnaire survey was employed to obtain professionals opinion on the current use of BIM in the industry, its use with link to sustainability practices, and its potential use to enhance CE principles. Thirty-seven questionnaire responses were received where the 3 biggest positions at 20% each were identified as working as BIM Modeller or Coordinator, Architects, and Engineers as shown in Fig. 1.

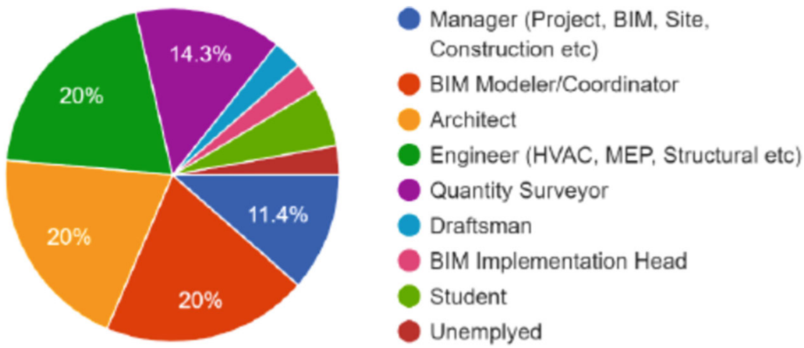

Fig. 1 Participants' current role within their organisations

Then, five interviews were carried out with experts (i.e. 2 BIM Managers, 2 BIM Coordinators, and 1 Asset Manager) to explore in depth the potential utilisation of BIM in facilitating the adoption of CE in the AEC industry. The collected data from the questionnaire survey was statistically analysed to demonstrate the significance of various variables in each theme. Then, thematic analysis was employed to analyse the data collected from interviews. Then, a conceptual framework is produced to show the potentials of BIM in facilitating the CE in the AEC industry.

4 Data Analysis and Findings

4.1 Current BIM Practices

Invaluable BIM insights were provided by the participants as a total of 62% of the participants were revealed to be directly involved in the daily utilisation of BIM, and they could reveal the main utilisation of BIM is for design purposes as shown in Fig. 2. However, the use of BIM for waste recycling, reuse of building components, and deconstruction receives less importance and understanding on how to use BIM for these practices.

4.2 Awareness of CE

In general, the participants' perception of the CE was for recycling and reuse of construction elements and materials. It can be seen from Fig. 3 that there is significant awareness of the participants with a score of 77% on the utilisation of the 3Rs (recycle, repurpose, reuse) which is already applied in construction projects, with the other common CE principles such as design for lessened energy consumption and prefabrication of elements.

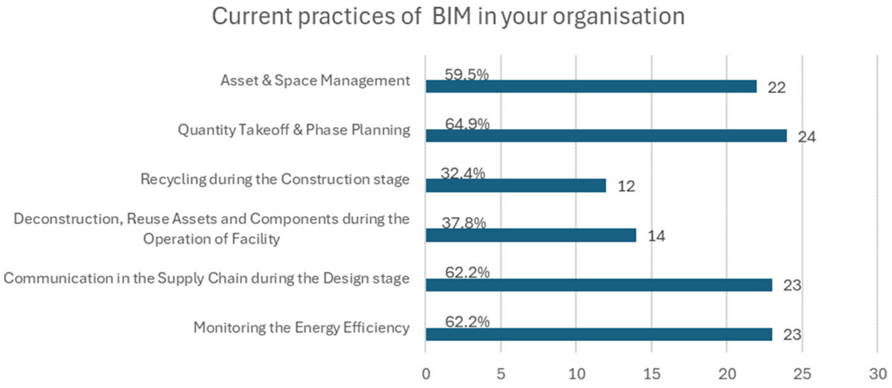

Fig. 2 Current practices of BIM in your organisation

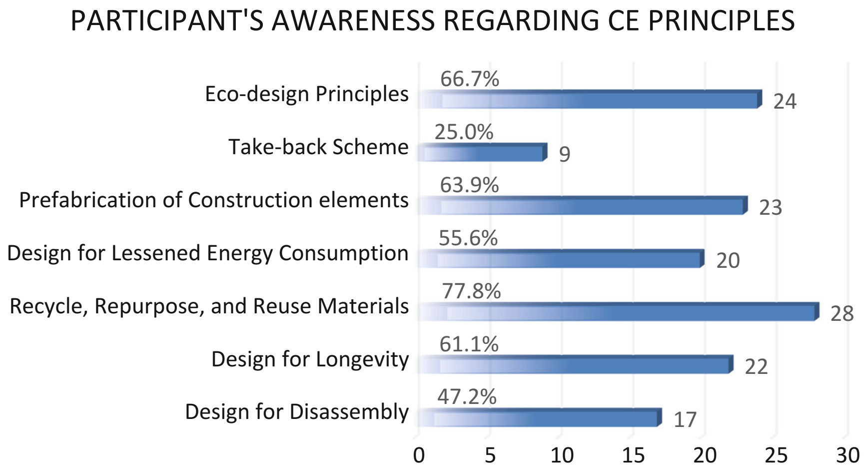

Fig. 3 Participant's awareness regarding CE principles

4.3 *Perceived Benefits from Utilising BIM as a Tool for Circularity*

Figure 4 demonstrates the participants' perceived benefits for construction projects adopting BIM for facilitating the CE principles include; improved interoperability and communication within the supply chain, improved life cycle cost estimation of assets, and standardisation using BIM in projects. The general recommendation is the need for a general shift in the paradigm in addition to complete EOL review when BIM is used. This is aligned with 3 out of 5 interviewees who stated that BIM has high potential in facilitation circularity as quoted by one professional: '*We've had success applying principles such as Design for Disassembly, mainly due to the*

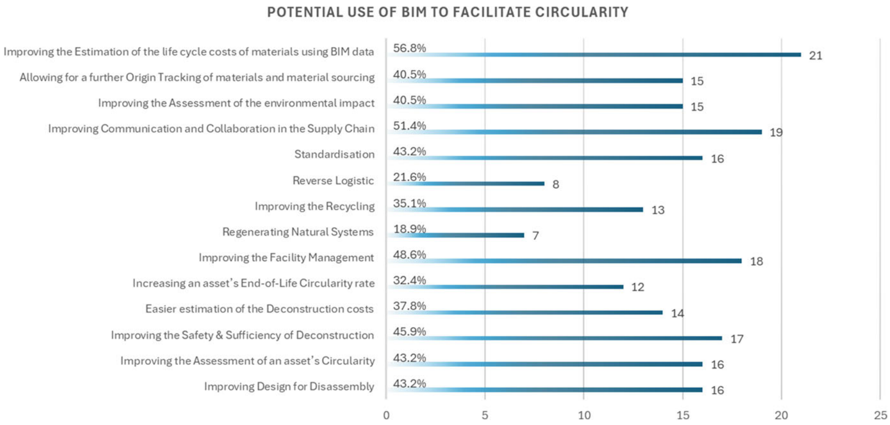

Fig. 4 Potential use of BIM to facilitate circularity

central origin of data and information BIM provides'. And another quoted*: 'We used BIM in a recent project to develop digital twin to optimise and stimulate the building energy performance. Due to the creation of that digital twin. It allowed us to alter the design swiftly and assess the sustainability metrics. This resulted in the achievement of a LEED Platinum certification for our organisation*'.

The results reveal there is a reasonable awareness on the potential use of BIM to facilitate circularity within the AEC industry. However, there are some barriers such as the absence of demands to apply the CE principles from clients, professional bodies, and the government. This is aligned with Charef's [6] finding. Additionally, the client was identified as holding the main responsibility for the encouragement and development for adopting CE within built environment projects. It was suggested that stakeholders might not comprehend the desired awareness and knowledge of the CE principles to enable it.

5 Discussion

BIM utilisation was identified by all interviewees to foster stakeholders' communication and collaboration that yields a sustainable work environment for improved, sustainable construction projects, which aligns with Kuzina's [38] suggestion of enabling BIM for life cycle management. 4 out of 5 of the interviewees reported on BIM generated benefits includes material and energy efficiency, energy simulation, risk analysis, cost savings, improved design and decision making. Sustainability efforts emerging from their organisations BIM use was energy analysis, data integration, resource management, and design optimisation.

In terms of stakeholder engagement and perception of BIM's sustainability potential, 80% of the interviewees could acknowledge that the perception among stakeholders varies due to differences in knowledge, willingness, and adjustment to adopt BIM completely for sustainable procedures. Among the identified barriers were legal concerns, change resistance, high cost, and complete knowledge of BIM. Designers, engineers, and architects demonstrate a high interest in enabling the complete sustainable potentials that BIM offers. One of the interviewees suggested that to combat stakeholders' reservations, BIM specialists could display the benefits to gain further support from stakeholders. One of the interviewees suggests the identified barriers could be solved by organisations introducing proper data integration and BIM training.

Sixty per cent of the interviewees agreed to the existing alignment between the CE principles and the BIM features in the construction industry that can be found in procedures such as resource efficiency, and material consumption, selection and tracking. BIM was particularly identified as an enabler for practices of Design for Disassembly (DFD), with an interviewee describing the emerging success within a project with DFD was solely due to the central origin of project information data provided by BIM. Although, another interviewee stated that BIM in 4D which is very useful for resource utilisation in various locations in construction projects, is a level of BIM maturity yet to be seen. Eighty per cent of the participants stated that increased building performance and waste reduction are the two commonly witnessed BIM enabling the CE principles. Interviewee 4 particularly stated that their use of digital twin allowed for quick design alterations and assessment of sustainability metrics yielding their organisation's a LEED Platinum certification.

A total of 60% of the interviewees identified security, management, quality, and data interoperability to be the most common areas to causes challenges when BIM was promoted for sustainability efforts and CE procedures. One interviewee stated the main issue was still resistance and sceptics among stakeholders. Interviewee 4 provided valuable insight of the further need of complete demonstration of BIM's advantages to combat these challenges, that aligned with Charef's [6] common user concern including the lack of BIM expertise and knowledge within the project team.

Applicable demonstration of BIM's benefits will gain further awareness and decrease the occurrence of challenges. This concern was discovered by Xue et al. [13] on how BIM in coordination with a LCA is not utilised to its desired outcome. Applying standardisation and BIM training was suggested by 20% of the interviewees to prevent these challenges, where standardisation was found promising in Poljanšek [27] for exchange information in the application of different software.

Emerging examples of BIM-enabled CE principles, also found by Kevin van Langen et al. [39], are reported by all interviewees, including economic growth, reduced carbon footprint, lessened energy consumption, lessened environmental impact, and reduced costs on a material, operational, and constructional level. This theme is in accordance with what was purported by Manzoor et al. [40], that BIM offers a vast selection of tools to enhance that sustainability in construction projects. Based on the above findings, in the following section a proposed conceptual framework is produced to demonstrate the potential relationship between BIM features and circularity principles within the built environment.

6 Conceptual Framework

A proposed framework presented in Fig. 5 is developed in combination with the analysis and results emerging from the above existing literature and data analysis, in order to display how the competencies of BIM can aid the further adoption of the CE principles in the BE. The various BIM competencies are highlighted in colours on the left, and the CE principles are located on the right hand side in non-coloured segments. Highlighted texts in red within the links between BIM competencies CE principles show the faciliated outcome that in the link could achieve sustainable aspects within the CE principles.

The conceptual framework in Fig. 5 sheds light on the existing gap between the competencies of BIM and the CE principles, in exhibiting an interconnection that could aid further sustainable approaches, resilient projects, and resource efficiency within the BE. BIM's data driven capacities aligns with procedures to achieve CE, and the framework can be used as a practical tool by industry professionals and stakeholders to analyse and navigate for more sustainable, net-zero carbon projects. For example, 'data and information management' as one of the key BIM

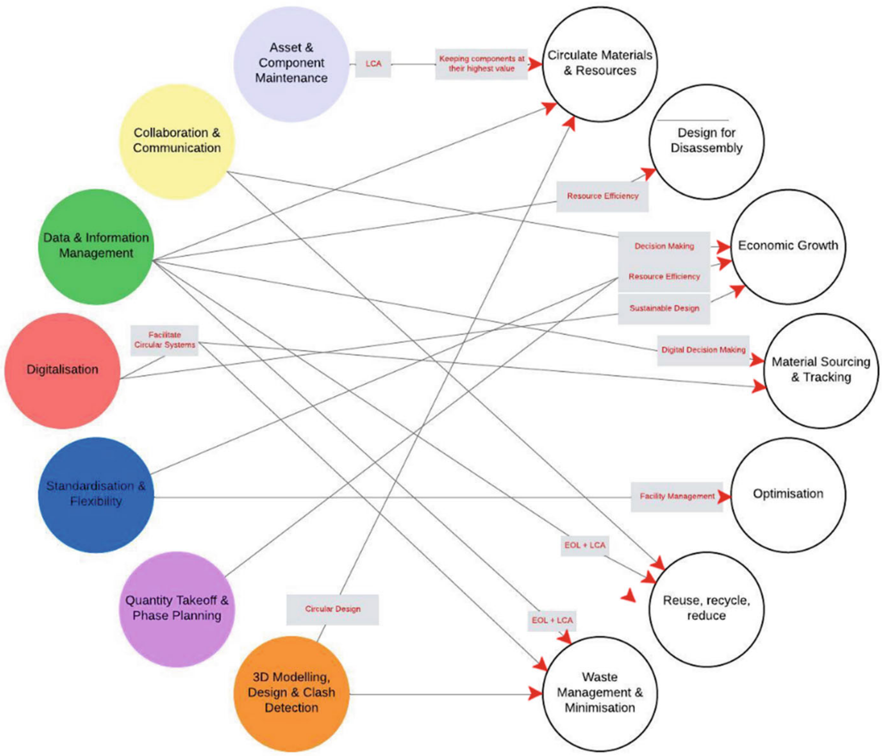

Fig. 5 Links between BIM Competencies and the CE principles

competences plays a crucial role in enabling ‘Design for Disassembly’, ‘tracking materials and provide information on life span and circularity’, and updating the data on ‘reuse, recycle, reduce principles’ which in turn enable waste management and minimisation. No doubt DfD and Standardisation goes hand in hand, which are essentials for circularity, reuse, repurpose and waste minimisation. The potentials of using BIM to enable circularity principles are many and difficult to cover them here.

Vital synergy, patterns, and themes between the BIM competencies and the CE principles can be identified when applying the framework which facilitates through knowledge of current synergies and challenges within the AEC sector. Critical insight emerging from the framework: circular strategies, collaboration & communication, design for adaptability, decision-making, efficiency gains, interdependence of competencies and principles, and lifecycle perspectives.

7 Conclusion

The most vital role as an enabler can be found in stakeholders and their resilience to apply BIM requirements that facilitate and foster sustainable procedures, and the shared BIM model’s data allows for sufficient interoperability between stakeholders. To achieve BIM-enabled CE principles within the BE, it is crucial that stakeholders, and mainly the client, encourage various construction project participants to increase their training of BIM’s use and explore its wide potentials. These findings align with both relevant literature and the suggested growing interest of BIM-enabled CE principles for preservation of embodied energy and waste reduction, and reports of increased recycling rates that occur when shifting to a Circular Economic Model.

Some of the frequently used BIM competencies emerging from the data include asset & space management, communication & collaboration in the supply chain, energy efficiency management, phase planning, and quantity take-off. These competencies enable the possibility of design and resource optimisation, deconstruction, energy analysis for operational costs and waste reduction, material sourcing and tracking, and displays the interconnection between BIM and CE principles. As seen in the conceptual framework, these links can facilitate the proper adoption of circularity in construction projects. Emerging from the qualitative data, most frequent principles of CE currently utilised within the BE include the 3Rs, design for eco-principles, design for lessened energy consumption, design for longevity, and prefabrication of construction elements. Furthermore, the findings of this research and the proposed conceptual framework could be used as a basis for further research and investigation, where some case studies could be used to demonstrate the most significant contributions of BIM towards enhancing circularity and sustainability within the built environment.

References

1. Fridrich, J., Kubečka, K.: Bim – the process of modern civil engineering in higher education. Procedia. Soc. Behav. Sci. **141**, 763–767 (2014). Available at: https://doi.org/10.1016/j.sbspro.2014.05.134
2. Mukherjee, A., Muga, H.: An integrative framework for studying sustainable practices and its adoption in the AEC industry: a case study. J. Eng. Technol. Manag. **27**(3–4), 197–214 (2010). Available at: https://doi.org/10.1016/j.jengtecman.2010.06.006
3. Opoku, D.-G.J., Agyekum, K., Ayarkwa, J.: Drivers of environmental sustainability of construction projects: a thematic analysis of verbatim comments from built environment consultants. Int. J. Constr. Manag. **22**(6), 1033–1041 (2019). https://doi.org/10.1080/15623599.2019.1678865
4. UNEP: Guidelines on Education Policy for Sustainable Built Environments – United Nations Environment Programme, Sustainable Buildings and Climate Initiative [Preprint] (2017). Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/7997/-Guidelines%20on%20Education%20Policy%20for%20Sustainable%20Built%20Environments-2010993.pdf
5. Giorgi, S., Lavagna, M., Wang, K., Osmani, M., Liu, G., Campioli, A.: Drivers and barriers towards circular economy in the building sector: stakeholder interviews and analysis of five European countries policies and practices. J. Clean. Prod. **336**, 130395 (2022). Available at: https://doi.org/10.1016/j.jclepro.2022.130395
6. Charef, R.: 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 (2022). Available at: https://doi.org/10.1016/j.clet.2022.100414
7. Hossain, M.U., Ng, S.T., Antwi-Afari, P., Amor, B.: Circular economy and the construction industry: existing trends, challenges and prospective framework for sustainable construction. Renew. Sust. Energ. Rev. **130**, 109948 (2020). Available at: https://doi.org/10.1016/j.rser.2020.109948
8. Yu, Y., Yazan, D.M., Junjan, V., Iacob, M.E.: Circular economy in the construction industry: a review of decision support tools based on Information & Communication Technologies. J. Clean. Prod. **349**, 131335 (2022). Available at: https://doi.org/10.1016/j.jclepro.2022.131335
9. Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., Raahemifar, K.: Building information modelling (BIM) uptake: clear benefits, understanding its implementation, risks and challenges. Renew. Sust. Energ. Rev. **75**, 1046–1053 (2017). Available at: https://doi.org/10.1016/j.rser.2016.11.083
10. Ellen MacArthur Foundation: How the Circular Economy Tackles Climate change (2019)
11. Ellen MacArthur Foundation: Growth Within: A Circular Economy Vision for a competitive Europe (2015)
12. Geissdoerfer, M., Savaget, P., Bocken, N.M., Hultink, E.J.: The circular economy – a new sustainability paradigm? J. Clean. Prod. **143**, 757–768 (2017). Available at: https://doi.org/10.1016/j.jclepro.2016.12.048
13. Xue, K., Hossain, M.U., Liu, M., Ma, M., Zhang, Y., Hu, M., et al.: Bim integrated LCA for promoting circular economy towards sustainable construction: an analytical review. Sustain. For. **13**(3), 1310 (2021). Available at: https://doi.org/10.3390/su13031310
14. Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G., Soto-Oñate, D.: Operational principles of circular economy for sustainable development: linking theory and practice. J. Clean. Prod. **214**, 952–961 (2019). Available at: https://doi.org/10.1016/j.jclepro.2018.12.271
15. Akhimien, N.G., Latif, E., Hou, S.S.: Application of circular economy principles in buildings: a systematic review. J. Build. Eng. **38**, 102041 (2021). Available at: https://doi.org/10.1016/j.jobe.2020.102041
16. Velenturf, A.P.M., Purnell, P.: Principles for a sustainable circular economy. Sustain. Prod. Consum. **27**, 1437–1457 (2021). Available at: https://doi.org/10.1016/j.spc.2021.02.018

17. Antikainen, M., Uusitalo, T., Kivikytö-Reponen, P.: Digitalisation as an enabler of circular economy. Proc. CIRP. **73**, 45–49 (2018). Available at: https://doi.org/10.1016/j.procir.2018.04.027
18. Glöser-Chahoud, S., Huster, S., Rosenberg, S., Baazouzi, S., Kiemel, S., Singh, S., et al.: Industrial disassembling as a key enabler of circular economy solutions for obsolete electric vehicle battery systems. Resour. Conserv. Recycl. **174**, 105735 (2021). Available at: https://doi.org/10.1016/j.resconrec.2021.105735
19. O'Grady, T., et al.: Design for disassembly, deconstruction and resilience: a circular economy index for the built environment. Resour. Conserv. Recycl. **175**, 105847 (2021). Available at: https://doi.org/10.1016/j.resconrec.2021.105847
20. Adams, K.T., Osmani, M., Thorpe, T., Thornback, J.: Circular economy in construction: current awareness, challenges and enablers. Proc. Inst. Civ. Eng. Waste Resour. Manage. **170**(1), 15–24 (2017). Available at: https://doi.org/10.1680/jwarm.16.00011
21. Al Hosni, I.S., Amoudi, O., Callaghan, N.: An exploratory on challenges of circular economy in the built environment in Oman. Proc. Inst. Civ. Eng. Manag. Procure. Law. **173**(3), 104–113 (2020)
22. Thomas, D., Amoudi, O.: Barriers and drivers associated with the adoption of circular economy in Kuwait's construction industry. The International Conference on Advancing Sustainable Future (ICASF 2023), Organised by Abu Dhabi University in the UAE from 5–6 December (2023)
23. Purchase, C.K., Al Zulayq, D.M., O'Brien, B.T., Kowalewski, M.J., Berenjian, A., Tarighaleslami, A.H., Seifan, M.: Circular economy of construction and demolition waste: a literature review on lessons, challenges, and benefits'. Materials. **15**(1), 76 (2021). https://doi.org/10.3390/ma15010076. Radaelli, C.M., Pasquier, R.: (2008) 'Conceptual issues', Europeanization, pp. 35–45. Available at: https://doi.org/10.1057/9780230584525_3
24. Shooshtarian, S. Hosseini, M., Kocaturk, T.: The circular economy in the australian built environment; the state of play and a research agenda. Deakin University (2021)
25. Fulford, R., Standing, C.: Construction industry productivity and the potential for collaborative practice. Int. J. Proj. Manag. **32**(2), 315–326 (2014). Available at: https://doi.org/10.1016/j.ijproman.2013.05.007
26. Bradley, A., Li, H., Lark, R., Dunn, S.: BIM for infrastructure: an overall review and constructor perspective. Autom. Constr. **71**, 139–152 (2016). Available at: https://doi.org/10.1016/j.autcon.2016.08.019
27. Poljanšek, M.: Building Information Modelling (BIM) Standardization, JRC Technical Reports – European Commission [Preprint] (2017)
28. Chen, G., Chen, J., Tang, Y., Ning, Y., Li, Q.: Collaboration strategy selection in BIM-enabled construction projects: a perspective through typical collaboration profiles. Eng. Constr. Archit. Manag. **29**(7), 2689–2713 (2021). Available at: https://doi.org/10.1108/ecam-01-2021-0004
29. Charef, R., Emmitt, S.: Uses of building information modelling for overcoming barriers to a circular economy. J. Clean. Prod. **285**, 124854 (2021). Available at: https://doi.org/10.1016/j.jclepro.2020.124854
30. Göswein, V., Carvalho, S., Lorena, A., Fernandes, J., Ferrão, P.: Bridging the gap – a database tool for BIM-based circularity assessment. IOP Conf. Ser. Earth Environ. Sci. **1078**(1), 012099 (2022). Available at: https://doi.org/10.1088/1755-1315/1078/1/012099
31. Handayani, T.N., Putri, K.N., Istiqomah, N.A., Likhitruangsilp, V.: The Building Information Modeling (BIM)-based system framework to implement circular economy in construction waste management. J. Civ. Eng. Forum.. Universitas Gadjah Mada. (2021). Available at: https://doaj.org/article/38ba0e152a1c4c209c3c069f3f36b408. Accessed 1 Mar 2023
32. Jung, J. et al.: Productive modeling for development of AS-built BIM of existing indoor structures. Autom. Constr. **42**, 68–77 (2014). Available at: https://doi.org/10.1016/j.autcon.2014.02.021

33. Akinade, O.O., Oyedele, L.O., Bilal, M., Ajayi, S.O., Owolabi, H.A., Alaka, H.A., Bello, S.A.: Waste minimisation through deconstruction: a BIM based deconstructability assessment score (BIM-DAS). Resour. Conserv. Recycl. **105**, 167–176 (2015). Available at: https://doi.org/10.1016/j.resconrec.2015.10.018
34. Ge, X.J., Livesey, P., Wang, J., Huang, S., He, X., Zhang, C.: Deconstruction waste management through 3D reconstruction and BIM: a case study. Vis. Eng. **5**(1) (2017). Available at: https://doi.org/10.1186/s40327-017-0050-5
35. Hamidi, B., Bulbul, T., Pearce, A., Thabet, W.: Potential application of BIM in cost-benefit analysis of demolition waste management. In: Construction Research Congress 2014 [Preprint] (2014). Available at: https://doi.org/10.1061/9780784413517.029
36. Hai, Y., Yang, L., Sepasgozar, S.: Bim applications in waste and demolition management in circular economy concept. The 3rd Built Environment Research Forum [Preprint] (2022). Available at: https://doi.org/10.3390/environsciproc2021012013
37. Akanbi, L.A., Oyedele, L.O., Akinade, O.O., Ajayi, A.O., Delgado, M.D., Bilal, M., Bello, S. A.: Salvaging building materials in a circular economy: a BIM based whole-life performance estimator. Resour. Conserv. Recycl. **129**, 175–186 (2018). Available at: https://doi.org/10.1016/j.resconrec.2017.10.026
38. Kuzina, O.: Information technology application in the construction project life cycle. IOP Conf. Ser. Earth Environ. Sci. **869**(6), 062044 (2020). Available at: https://doi.org/10.1088/1757-899x/869/6/062044
39. Van Langen, S.K., Vassillo, C., Ghisellini, P., Restaino, D., Passaro, R., Ulgiati, S.: Promoting circular economy transition: a study about perceptions and awareness by different stakeholders groups. J. Clean. Prod. **316**, 128166 (2021). Available at: https://doi.org/10.1016/j.jclepro.2021.128166
40. Manzoor, B., Othman, I., Gardezi, S.S.S., Harirchian, E.: Strategies for adopting building information modeling (BIM) in sustainable building projects—a case of Malaysia. Buildings. **11**(6), 249 (2021). Available at: https://doi.org/10.3390/buildings11060249