POTENTIAL USE OF DIGITAL TECHNOLOGIES FOR CIRCULAR CONSTRUCTION PRACTICES

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Abstract
Advocates for digital technologies, as well as the need to minimise carbon emissions in the building industry, have been pushed forward through national regulations and global efforts. Existing research has demonstrated the practices of circular construction as well as how construction technologies increase productivity. However, there is a critical research gap, as it is uncertain whether the technologies support circular construction practices. The purpose of this article is to identify the potential applications of technology that promote circular construction practices. The research methodology used is a qualitative approach in which interviews with large contractor organisations were conducted. The results showed that contractors believed that the use of technologies could support circular construction practices. Building Information Modelling was shown to be the most effective technology for supporting circular construction practices. Whereas Blockchain provides the least support for circular construction practices. The findings have significant importance as it will aid policymakers strategise which technologies to prioritise for encouraging sustainable construction.

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INTRODUCTION

Malaysia produces approximate 26,000 metric tonnes of building and demolition waste daily, which adds to overflowing landfills and environmental issues (Ting et al., 2022). Given the high amount of construction waste generated, adopting circular construction practices is essential to reduce carbon emissions in construction projects. Circular construction practices encompass five key practices: Design for Disassembly (DfD), selection of sustainable materials, development of material passports, life cycle assessment, and enhanced collaboration among stakeholders. DfD reduces waste by designing buildings with the intention of disassembling and reusing their constituent parts rather than demolishing them and sending the materials to landfills (Ostapska et al., 2021). The choice of appropriate building materials in the construction sector depends much on several elements, including product qualities, cost, availability, safety, durability, embodied energy, legal requirements, and environmental impact (Akadiri, 2018).Material passports help with traceability by recording building product modifications and usage during their lifetime. (Göswein et al., 2022). Collaboration enhances trust, communication, and mutual understanding among stakeholders, improving decision-making, problem-solving, and innovation in the project lifecycle, which align with circular construction goals (Fulford & Standing, 2014). Life cycle assessment is a systematic approach to assess the environmental repercussions associated with a product, process, or activity over its complete life cycle, encompassing raw material procurement, manufacturing, utilisation, and eventual disposal. Hence, based on the concept of circular construction practices, it is unclear how digital technologies can facilitate these practices.The adoption rate of these circular construction practices in Malaysia in general are reported to be low (Agamuthu & Mehran, 2019; Zulki-Li et al., 2025).

With the low adoption of circular construction practices, the utilization of digital technologies can expedite the process by enhancing efficiency. In contrast, most research on digital technologies in construction primarily focuses on enhancing project productivity and reducing project duration (Windapo, 2021). There is a limited understanding of the adoption of digital technologies to support circular construction practices, especially from the perspective of contractors.

There are six digital technologies identified in international countries that may facilitate the circular construction approach, including Building Information Modelling (BIM), Virtual and Augmented Reality (VR/AR), Artificial Intelligence (AI), the Internet of Things (IoT), Blockchain and Digital Twin technology (Setaki & Van Timmeren, 2022). Studies in Malaysia have indicated that the adoption of these technologies ranges from low to moderate use (Jaafar et al., 2025). The uses of these technologies were primarily recognized for enhancing productivity, reducing costs, and improving efficiency, underscoring the advantages of digital technology (Jaafar et al., 2025). Nevertheless, there is a lack of explanation and studies explaining how these technologies facilitate circular construction practices, underscoring the need for further research in this area. Hence, this study extended the prior studies by identifying the potential uses of these digital technologies for circular construction practices from the perspective of large size contractor firms.

LITERATURE REVIEW

Digital technology is essential for enabling circular construction processes within the industry. Numerous digital technologies are introduced, each serving distinct roles (Banihashemi et al., 2023; Meng et al., 2023).

Building Information Modelling (BIM)

Building Information Modelling (BIM) has emerged as a revolutionary digital tool in the construction sector, facilitating the adoption of circular construction principles by integrating design, data, and sustainability analysis (Jemal et al., 2023). BIM facilitates design for disassembly (DfD) by offering a digital model of buildings and components, enabling stakeholders to simulate disassembly scenarios, identify potential conflicts, and assess end-of-life options such as reuse and recycling (Ostapska et al., 2021). BIM enables educated decision-making throughout the design phase to optimise material recovery and reduce waste. BIM-based material selection strategies mitigate challenges associated with cost, availability, and environmental impact by allowing contractors to evaluate the influence of material choices on a project's performance and carbon footprint, thus encouraging the utilisation of low-impact materials (Makhoul, 2024). The technology facilitates the concept of material passports by functioning as a centralised platform for the storage and management of comprehensive material data, encompassing composition, characteristics, and environmental indicators (Atta et al., 2021). This interface enables stakeholders to automate sustainability assessments, including deconstructability and recovery ratings, so enhancing productivity and minimising human error. BIM, when integrated with life cycle assessment (LCA) tools, augments environmental analysis by measuring energy consumption, greenhouse gas emissions, and waste production during a building's life cycle (Santos et al., 2020). These functionalities collectively illustrate how BIM enhances circular construction through data-driven design, material traceability, low-carbon decision-making, and the promotion of sustainable and resource-efficient building practices (Ullah et al., 2024).

Virtual and Augmented Reality (VR/AR)

Virtual Reality (VR) and Augmented Reality (AR) technologies are progressively facilitating circular construction practices by improving visualisation, collaboration, and decision-making across the building life cycle. These technologies facilitate the modelling and visualisation of disassembly activities, permitting designers to virtually engage with structures to evaluate feasibility, identify problems, and optimise design strategies before to actual construction (Tan et al., 2022). They also enable collaborative material selection procedures, allowing stakeholders to interact with virtual models and materials in immersive settings to assess sustainable solutions more efficiently (Zahrizan et al., 2022; IrisVR, 2020). The incorporation of material passports enhances material traceability, enabling users to interactively visualise material data—such as origin, composition, and environmental impact—through VR and AR (Caldas et al., 2022). On-site applications, such as AR-enabled maintenance via QR codes or smart glasses, improve operational efficiency and prolong the lifespan of building components (Havard et al., 2016). Furthermore, immersive visualisation capabilities enhance stakeholder communication and spatial comprehension, facilitating informed design decisions and collaborative workflows (Lee, 2024). These technologies enhance life cycle assessment (LCA) by facilitating realistic and interactive simulations for assessing environmental performance (Uwa & Agboola, 2025), while

VR- and AR-based training tools bolster workforce competencies in safety and equipment operations (Jenolek et al., 2022). Virtual Reality (VR) and Augmented Reality (AR) collectively connect digital design with sustainable construction results by facilitating reuse, optimising resource management, and enhancing decision-making, therefore expediting the shift towards circular construction (Yeung et al., 2021).

Artificial Intelligence (AI)

Artificial Intelligence (AI) has emerged as a significant facilitator of circular building methodologies by improving design for disassembly (DfD), material selection, material passport creation, and life cycle assessment (LCA). AI enhances flexibility in Design for Disassembly (DfD) through generative and parametric design, allowing architects and engineers to investigate various design options that emphasise modular components, standardised connections, and separable building elements, thereby facilitating reuse and efficient disassembly during a building's lifecycle (Banihashemi et al., 2024). In material selection, AI utilises data analytics, machine learning, and natural language processing (NLP) to analyse extensive datasets, forecast material performance, and evaluate cost-effectiveness, resulting in more sustainable and resource-efficient decisions (Abioye et al., 2021; Regona et al., 2022). AI enhances material passport procedures by identifying and forecasting hazardous substances like asbestos, facilitating proactive and safer decision-making in maintenance and destruction (Caldas et al., 2022). When combined with Building Information Modelling (BIM), AI enhances real-time collaboration, streamlines operations, and reduces risks throughout project phases (Bagasi et al., 2025). Moreover, AI-driven predictive analytics augment LCA by anticipating environmental performance across a building’s life cycle, so enhancing waste management, energy efficiency, and risk reduction (Hua et al., 2025; Liu & Lin, 2021). Despite its nascent use in construction, especially in Malaysia, AI exhibits considerable promise to enhance data-driven, intelligent, and sustainable methodologies that support circular construction worldwide.

Internet of Things (IoT)

The Internet of Things (IoT) is essential for facilitating circular construction methods through real-time data collecting, monitoring, and optimisation throughout a building's life cycle. In the construction sector, the Internet of Things (IoT) interlinks physical entities—such as materials, components, and equipment—via embedded sensors, software, and network connectivity to optimise energy consumption, improve resource efficiency, and reduce waste (Setaki & Van Timmeren, 2022). Integrating sensors into building components enables the Internet of Things (IoT) to continuously evaluate structural integrity, durability, and performance over time, yielding data that can guide design for disassembly (DfD) initiatives and encourage the reuse or recycling of materials. These insights assist designers and engineers in making educated decisions on materials that facilitate dismantling and recycling, so prolonging their life cycle and minimising environmental effect. IoT devices collect data on environmental parameters, including temperature, humidity, and air quality, facilitating material selection based on durability and thermal efficiency (Mohammed et al., 2022). Technologies such as radio-frequency identification (RFID) tags provide the tracking of materials and components throughout their life cycle, ensuring transparency and accountability in design, building, and maintenance operations. Furthermore, IoT integration enhances material passport procedures through the incorporation of sensors that gather and refresh real-time data on material characteristics, location, utilisation, and condition, thus augmenting traceability and circular resource management (Atta et al., 2021). Moreover, IoT promotes collaboration among stakeholders by enabling remote monitoring and control of building processes and equipment, hence facilitating efficient communication and decision-making (Srivastava et al., 2024). These features collectively establish IoT as a transformative facilitator of circular construction, enhancing material utilisation, prolonging asset lifespan, and fostering sustainable resource management within the built environment.

Blockchain

Blockchain technology possesses considerable potential to promote circular building by improving transparency, traceability, and collaboration throughout the construction supply chain (Incorvaja et al., 2022; Rashidian et al., 2025). Blockchain, through its decentralised and immutable ledger, allows stakeholders to obtain precise and trustworthy information regarding materials and components, thus minimising waste, enhancing resource efficiency, and facilitating circular decision-making (Rashidian et al., 2025). Smart contracts utilising blockchain technology can automate the verification and monitoring of materials to guarantee adherence to disassembly and reuse standards, hence enhancing the efficiency of Design for Disassembly (DfD) procedures (Banihashemi et al., 2024). The amalgamation of blockchain with Building Information Modelling (BIM) and the Internet of Things (IoT) enhances material traceability by establishing transparent and secure platforms for the oversight and management of materials throughout their life cycles (Trubina et al., 2024). An exemplary case is the Madaster platform in the Netherlands, which utilises blockchain technology to allocate unique digital passports to building components, encompassing comprehensive details on material origins, performance metrics, and disassembly guidelines, thereby facilitating sustainable design and reuse methodologies (Madaster Global, 2024). Blockchain enhances material passport systems by securely documenting any alterations to material data, creating an immutable chain that ensures information integrity and accessibility. Collaborative efforts like the Construction Blockchain Consortium (CBC) have illustrated how blockchain improves transparency, efficiency, and sustainability in construction processes (Widyasningrum, 2021). Simultaneously, systems such as Brickschain employ distributed ledgers to provide real-time data sharing and collaborative decision-making, hence enhancing confidence among project stakeholders. Despite the restricted implementation of blockchain technology in Malaysia's construction industry owing to sluggish technological adoption (Charef et al., 2021), global advancements illustrate its potential to facilitate life cycle assessment (LCA) through precise monitoring of environmental impacts and material flows. These applications collectively demonstrate blockchain's capacity to alter circular construction by enhancing data reliability, transparency, and traceability across the project lifecycle.

Digital Twin

Digital Twin (DT) technology, described as a virtual representation of a physical asset, system, or process, has arisen as a significant facilitator of circular construction practices by improving resource efficiency, sustainability, and collaboration across the entire life cycle (El-Din et al., 2022). Digital technology improves salvage value and reduces waste through real-time monitoring of materials, energy consumption, and CO_2 emissions, facilitating informed decision-making to mitigate environmental effect (Meng et al., 2023; Stephen et al., 2025). Case studies such as The Edge Amsterdam demonstrate how DT optimizes energy performance and supports the selection of recyclable materials, directly contributing to waste reduction, while a London case study illustrates its role in facilitating Design for Disassembly (DfD) by enabling structures to be designed for deconstruction and reuse (Zaland et al., 2025). Case studies such as The Edge Amsterdam demonstrate how DT optimizes energy performance and supports the selection of recyclable materials, directly contributing to waste reduction, while a London case study illustrates its role in facilitating Design for Disassembly (DfD) by enabling structures to be designed for deconstruction and reuse (Zaland et al., 2025). DT also enables Life Cycle Analysis (LCA) to enhance environmental performance, as demonstrated in wood building projects (Morganti et al., 2025). In addition to performance monitoring, digital twin technology has been utilised in venues like the Johan Cruyff Arena to optimise resource management via sensor-derived insights on environmental factors (Bel, 2020). The amalgamation of digital twin technology with material passports facilitates predictive maintenance and material tracking, hence enhancing the management of material flows from design to destruction (Caldas et al., 2022; Meng et al., 2023). Moreover, DT fosters collaboration, communication, and transparency among project stakeholders, hence augmenting productivity and reducing errors (Opoku et al., 2021). The combination of Building Information Modelling (BIM) and Internet of Things (IoT) with Digital Twin (DT) facilitates real-time environmental monitoring and optimisation, enhancing sustainability and circularity results across a building's life cycle (Petri et al., 2025). These applications collectively demonstrate the potential of Digital Twin technology to revolutionise traditional building into a circular, data-centric, and resource-efficient methodology.

RESEARCH METHODOLOGY

The population of this study focusses on large size contractor firms with the classificate grade G7 registered with Construction Industry Development Board (CIDB) in the Malaysian construction industry. This study focusses on large size contractor firm as large size organizations often adopt and willing to adopt technologies as their resource capability is stronger (Jaafar et al., 2025). Seven respondents consented to participate in the interviews. The seven interviews were conducted online using platforms such as Webex, Google Meet, Microsoft Teams, and Zoom on the following dates: May 15, 21, and 23, 2024; June 6, 8, 10, and 21, 2024. All interviews were recorded for data analysis and future reference. Each interview duration was between 30 minutes to 1 hour. All respondents are professionals employed by G7 contractor companies, with work experience ranging from 5 to 29 years. The profiles offer general information on two aspects: position within the organisation, and years of work experience. The names of the respondents and companies are not disclosed in this academic research. Each respondent is assigned a code to facilitate identification, such as Respondent 1 (R1). Table 1 summarises the respondents' profiles.

Table 1 Respondent Profile

Respondents	Aspects		
	Position in company	**Types of company**	**Years of work experience**
R1	General Manager	G7 contractor company	14
R2	Managing Director	G7 contractor company	13
R3	Project Engineer	G7 contractor company	5
R4	Project Manager	G7 contractor company	29
R5	Assist. Project Manager	G7 contractor company	6
R6	Construction Manager	G7 contractor company	18
R7	Project Engineer	G7 contractor company	5

RESULTS AND DISCUSSION

Table 2 provides a summary of the respondents' findings. The frequency of references (R1–R7) that emerged from interview responses was used to map each technology against these practices. This method offers a comparative perspective on the extent to which practitioners perceive the role of each technology in facilitating circular construction. It also serves as a foundation for further discussion regarding the extent to which these findings are consistent with or divergent from the existing literature.

Table 2 Digital technologies that potentially facilitate circular construction practices

Digital Technology / Circular Practices	BIM	VR/AR	AI	IoT	Blockchain	Digital Twin
Design for disassembly	R1, R2, R3, R4, R5, R6, R7	R1, R2, R3, R4, R5, R6	R1, R2, R3, R4, R5, R6	R1, R2, R3, R4, R7	R1, R2, R3	R1, R2, R3
Selection of reuse and recycle materials	R1, R2, R3, R4, R5, R7	R1, R2, R3, R4	R1, R2, R3, R4, R5, R6	R1, R2, R3, R4	R1, R2, R3	R1, R2, R3, R6
Implementation of material passports	R1, R2, R3, R4, R5, R7	R1, R2, R3, R4, R5	R1, R2, R3, R4	R1, R2, R3, R4	R1, R2, R3, R6	R1, R2, R3
Execute life cycle assessment (LCA)	R1, R2, R3, R4, R5	R1, R2, R3, R4, R5, R6	R1, R2, R3, R4, R7	R2, R3, R4, R5	R2, R3	R1, R2, R3, R6
Promote collaboration and engagement among all stakeholders	R1, R2, R3, R4	R1, R2, R3, R4	R1, R2, R3, R4	R1, R2, R3, R4, R5, R6, R7	R1, R2, R3, R5, R6	R1, R2, R3, R6

Building Information Modelling (BIM)

The data indicates that BIM is perceived as the most dominant technology in circular construction, as it supports all five circular practices with the highest frequency of respondents (R1–R7). This is consistent with the literature that identifies BIM as the primary digital enabler for Design for Disassembly (DfD), material selection, material passports, Life Cycle Assessment (LCA), and collaborative integration (Ostapska et al., 2021; Jemal et al., 2023; Santos et al., 2020). Consistent with the findings of Makhoul (2024) and Ullah et al. (2024), the robust representation across all references suggests that BIM is widely acknowledged for its ability to improve visualisation, information management, and sustainability evaluation.

Virtual and Augmented Reality (VR/AR)
Four out of six respondents (R1–R6) percieved that VR/AR are able to support circular construction practices. The respondents percieved that this technology is able to facilitate the adoption of DfD as well as LCA in a construction project. These respondents also believed that the use of this technology is able to proote collaboration among stakeholders in a construction project. This supports prior studies suggesting that immersive visualization enhances stakeholder understanding and coordination during design and disassembly (Ostapska et al., 2021). Respondents in this study also recognised that VR/AR technology can enhance the selection of construction materials and the creation of material passports. This finding provides a unique addition to current understanding, as previous research has not clearly illustrated the function of VR/AR in facilitating circular construction processes.This suggests that industry perception of VR/AR's applicability has expanded beyond its traditionally documented scope, indicating an evolving role in decision-making for circular construction.

Artificial Intelligence (AI)
AI exhibits broad distribution throughout circular activities, as evidenced by responders R1–R7 for Design for Disassembly (DfD), R1–R6 for material selection, and R1–R7 for Life Cycle Assessment (LCA), underscoring its extensive impact. Literature recognises AI as a prospective facilitator of predictive analytics, optimisation, and decision support for sustainable design and material reutilization (Makhoul, 2024; Santos et al., 2020). The results corroborate these assertions, validating AI's capacity to facilitate automation and lifecycle optimisation in circular construction. Although academic literature frequently characterises AI as nascent and insufficiently embraced in reality, the evidence indicates that contractors already regard it as broadly applicable, suggesting that industry confidence may be surpassing scholarly documentation.

Internet of Things (IoT)
The data indicates robust IoT involvement across all five circular practices, especially in collaboration (R1–R7) and Design for Disassembly (DfD) (R1–R7), corroborating research that emphasises IoT's capacity to improve real-time tracking, resource monitoring, and lifecycle data exchange (Santos et al., 2020). Literature substantiates the role of IoT in facilitating material passport installation and life cycle assessment via sensor-based monitoring (Atta et al., 2021), aligning with the extensive reference coverage of the data. The data indicates a greater practical recognition of IoT's role in collaboration than the literature suggests, implying that practitioners may perceive IoT as a more developed and feasible solution for integrating circular construction than previously documented.

Blockchain
Blockchain had the lowest frequency of respondents among the five technologies, with only respondents R1–R3 agreeing. This findings corroborate prior research that describes it as the least accepted technology (Atta et al., 2021). The evidence from the results in this paper and prior studies emphasise blockchain's principal contribution to material passports and stakeholder collaboration via safe data exchange and traceability (Ullah et al., 2024). The scarcity of references to DfD, material selection, and LCA indicates practical obstacles identified in the literature, including interoperability issues and insufficient industry awareness. This substantiates the assertion that blockchain is predominantly theoretical in its application to circular building, with adoption still in infant phases.

Digital Twin
The table's results show that the Digital Twin received support from respondents for its application in Design for Disassembly (R1–R3), material selection (R1–R6), and Life Cycle Assessment (R1–R6).The findings are consistent with prior studies where it supports the versality of Digital Twin in the similar circular construction practices (Meng et al., 2023; Morganti et al., 2025; Zaland et al., 2025). These insights suggest that practicioner perceptions indicates a growing awareness of Digital Twin's potential to promote circular construction practice. Nevertheless, the limited number of respondents implies that the practical implementation remains at infancy stage among contractors.

CONCLUSIONS
The objective of this research was to identify the potential of technologies to facilitate circular construction practices. This research demonstrated that the technologies have significant potential for future application in circular construction practice, particularly among large contractor firms in Malaysia. Building Infromation Modelling was identified as the most robust technology that supports circular construction practice. Nevertheless, this research has yielded limited results, as the specifics of how

these technologies can be implemented in circular construction practices remain unclear. This aspect may be addressed in future research, as it will offer more significant insights into the utilisation of these technologies. The study contributes to the body of knowledge by addressing the perspective of industry from a contractors point of view on the potential of these technologies to be used in circular construction practice, as prior research had primarily focused on the adoption level of these technologies. Therefore, this research offers the fundamental preliminary studies on the technologies that can be employed to facilitate circular construction practices. The results contribute to the development of the National Construction Policy 2030 by the Malaysian government.

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