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Employing Circular Economy Approach for Construction & Demolition (C&D) Waste Management in Application of Industrialised Building System (IBS)

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Abstract

The construction industry is increasingly adopting the Circular Economy (CE) to promote sustainability. Industrialised Building Systems (IBS), which involve the off-site manufacturing of building components, are recognised as a key method for advancing CE goals due to their potential for waste reduction and efficient resource use. In Malaysia, the adoption of IBS has been limited. This is primarily due to significant knowledge gaps among stakeholders, including a lack of understanding, inadequate education, and the perceived complexity of integrating IBS with circular economy practices. This research aims to bridge this gap by developing a robust framework to evaluate circular economy performance criteria specifically for Industrialised Building Systems. The study conducts a rigorous analysis of existing evaluation tools, such as lifecycle cost analysis (LCA) and material reuse indicators. It organises and categorises these resources to create a practical framework that addresses the root causes of stakeholder resistance. The research confirms the significant potential of IBS to drive CE objectives, from waste minimisation to lifecycle sustainability. However, it also highlights the critical need for refined evaluation tools and enhance stakeholder education to fully realise these benefits. The proposed framework provides actionable insights for policymakers and industry practitioners to seamlessly integrate CE principles into all phases of IBS projects. By adopting this structured approach, the construction industry can transform IBS into a cornerstone of sustainable practice, setting a new benchmark for CE-driven innovation in Malaysia.

1. Introduction

Malaysia's construction industry, a major source of waste, struggles to incorporate Circular Economy (CE) principles into Industrialised Building Systems (IBS) [1]. While IBS produces less waste than traditional methods, it still contributes significantly to overall waste generation [2], [3]. In fact, IBS-related waste in Malaysia is estimated to reach 77,188 tons per year [4]. Waste management in IBS construction continues to face challenges, particularly with costs, due to issues like poor material storage, mishandling, and a lack of skilled workers for component installation and construction tasks [5]. Despite policy discussions on CE, Malaysia lacks clear regulatory incentives to integrate CE principles into IBS projects. Unlike the EU’s Circular Economy Action Plan, which mandates secondary material use and extended producer responsibility, Malaysia’s regulatory framework does not enforce modular deconstruction or track material reuse in IBS. Addressing these gaps requires targeted policy interventions such as tax incentives for sustainable materials, mandatory lifecycle assessments, and subsidies for waste-free construction methods. Addressing the barriers to IBS adoption within a Circular Economy framework is critical to reducing this environmental impact and achieving the nation’s sustainability goals. This study addresses these gaps by developing a structured framework to evaluate CE performance in IBS, providing actionable strategies for enhancing resource efficiency and zero-waste construction goals.

Recent developments in the circular economy, including strategies like lifecycle cost analysis and circular supply chain management, present a systematic approach to achieving zero waste [6]. IBS has the potential to improve sustainability in construction by incorporating circular economy principles. Applying circular economy principles in IBS, like material recovery and deconstruction for reuse, allows the construction industry to cut down on waste, conserve natural resources, and drive sustainable growth. The Ellen MacArthur Foundation [7] has introduced a framework to help governments, cities, and businesses transition to a circular economy, focusing on key policy areas for worldwide adoption.

Despite numerous studies emphasising the potential of IBS for sustainable development, there is limited research on a structured framework for integrating Circular Economy principles into IBS practices in Malaysia. However, for the proposed framework to be widely adopted, its effectiveness must be validated through practical applications or case studies. Such validation will ensure that the framework is adaptable to real-world construction projects and can effectively address existing industry challenges. This study aims to fill that gap by developing actionable strategies and evaluation tools for stakeholders. This study develops a comprehensive framework for evaluating Circular Economy performance criteria in IBS, offering practical insights for policymakers and industry practitioners to optimise sustainability practices. It will explore the relationship between IBS and the circular economy, assess existing decision tools and guidelines, investigate research opportunities for adapting IBS to circular economy principles, and evaluate the current progress of this research project. This analysis aims to enhance understanding of IBS performance, support circular economy development, and improve the sustainability of built environments.

2. Industrialised Building System (IBS)

IBS embodies core principles of circular construction by incorporating prefabrication, modular design, and resource-efficient production processes. Beyond efficiency, CE integration in IBS requires strategic approaches, including secondary raw material utilisation, lifecycle assessment-based decision-making, and flexible design for deconstruction and reuse. While IBS can significantly contribute to waste reduction, its full potential within CE is currently underexplored due to regulatory barriers, lack of standardisation in reusable components, and insufficient investment in material recovery technologies [8]. IBS offers a sustainable construction method by incorporating lean manufacturing principles and utilising secondary raw materials to improve project outcomes [9]. While the Industrialised Building System (IBS) holds promise for waste reduction and sustainability, its adoption in Malaysia remains limited due to stakeholder misunderstandings, inadequate technical expertise, and perceived complexities [8]. This prevents the construction industry from fully adopting Circular Economy principles, which play a key role in reaching sustainability goals [10], [11].

The Circular Economy is a system designed to eliminate waste and maximise resource use [12]. Integrating IBS with CE principles offers a pathway to greater sustainability by minimising waste and improving resource efficiency [13]. IBS can also promote the secondary raw material utilisation by using prefabricated components that can be disassembled and reused in other projects [12]. However, the scalability of CE practices within IBS raises questions about material sourcing, end-of-life management, and socio-economic implications [13]. Leveraging prefabricated components and lean management principles in IBS can contribute significantly to waste reduction and resource optimisation [9]. Zairul, M [6] and Ly et al [14] focus on the synergy between CE and modular construction, noting the importance of using secondary raw materials, sustainable design, and technological innovation. These themes are central to IBS, where materials and processes are often optimised for prefabrication and assembly. However, the practical validation of CE strategies in real-world IBS projects remains limited, which can hinder their widespread adoption. Wuni & Shen [15] and Kabirifar et al. [16] highlight the challenges of managing construction and demolition waste (C&DW). While IBS has the potential to enhance waste management, key lifecycle stages such as deconstruction and material recycling are often neglected. This oversight may be due to a focus on initial construction costs, timelines, and technological advancements, rather than long-term sustainability outcomes.

Recent research has broadened the understanding of resource recovery and recycling strategies within the Circular Economy. Singh and Ordoñez [17] highlight valuable insights into material recovery and recycling, showcasing how IBS can improve resource efficiency and minimise environmental impact during construction and demolition. Effectively applying CE principles in IBS requires a thorough understanding of their impact across the construction lifecycle [18]. Integrating these principles into the construction sector, particularly within Industrialised Building Systems, can lead to significant waste reduction and a smaller environmental footprint [19]. Leising et al. [20], through an analysis of three BREEAM-certified projects, found that incorporating Circular Economy strategies and sustainable building practices enhances the overall sustainability of construction projects.

Integrating Building Information Modelling (BIM) with Circular Economy strategies can enhance design efficiency and material reuse. However, challenges such as higher energy consumption during prefabrication and difficulties with disassembly and recycling at the end of a project require careful evaluation [18]. Leising et al. [21] highlight that combining BIM with Circular Economy principles can support the development of more sustainable buildings. Additionally, adopting CE principles in construction can help tackle both the challenges and opportunities linked to Industrialised Building Systems [22]. Researchers also stress the importance of embracing sustainable business models and construction practices to shift away from the industry's traditional linear approach and drive long-term sustainability [19].

Shifting the construction industry away from its linear approach and toward sustainability requires a comprehensive strategy [23]. This includes reevaluating business models, restructuring supply chains, and refining regulatory frameworks to actively promote sustainable practices [23]. By adopting systemic changes and embracing sustainability, the industry can significantly reduce its environmental impact and move toward a more sustainable future.

3. Limitation and Barriers

Maximising the waste reduction potential of Industrialized Building Systems (IBS) requires well-structured and systematic strategies. However, despite its advantages, several challenges still prevent the full adoption of Circular Economy principles in IBS construction.

One of the biggest challenges in implementing CE principles within IBS is the industry's limited expertise in circular design strategies. Key aspects like designing for disassembly, closed-loop material management, and digital tracking for material reuse are not widely practiced [24], [25]. In contrast to countries like the Netherlands and Sweden, where structured CE frameworks, materials passports, and secondary material markets are well established, Malaysia's construction sector lacks essential training, policy incentives, and digital tools to support circularity in IBS. This gap extends to the technical skills and knowledge needed for effective CE implementation [24], [26]. The concept of a Circular Economy in construction remains vague, with limited understanding and widespread uncertainty [27]. Further research is crucial to uncover barriers preventing the adoption of sustainable design and end-of-life (EOL) management aligned with CE principles [28]. The shortage of technical expertise and skills continues to be a major roadblock to the widespread adoption of Circular Economy practices in the industry [29], [30].

Structural and adaptability barriers also pose significant challenges, as existing buildings may not be easily adaptable for reuse due to design complexities and limitations [31]. It is crucial to assess the structural elements thoroughly to facilitate reuse with minimal necessary adjustments. This evaluation is vital as structural constraints may complicate the reuse of materials from older buildings in new construction endeavours [32]. The intricate and diverse designs of traditional buildings contribute to their limited adaptability. The adaptability level corresponds directly to the building's flexibility; traditional buildings, designed for permanence on-site, lack this adaptability [33].

Financial challenges, including high initial costs and a lack of incentives for circular products, make it difficult to implement CE practices in IBS construction [24]. The significant upfront investment required, combined with insufficient incentives and low consumer demand for circular products, can slow their adoption [30]. Furthermore, the lack of supportive policies and regulatory frameworks creates additional barriers to integrating CE principles within the construction industry [32].

The construction industry encounters several challenges in implementing Circular Economy practices, particularly environmental factors that hinder progress. One key issue is the limited availability of materials suitable for reuse or recycling, making it difficult to apply CE principles effectively [25]. Misconceptions surrounding sustainable materials such as the view that earth-based construction is inferior and need to be addressed to encourage broader acceptance [34]. Additionally, the stigma around second-hand materials, along with a general lack of awareness and knowledge among stakeholders, creates further obstacles [35]. Resistance to change, weak collaboration, and a slow-moving construction sector also pose significant challenges [36]. Kabirifar et al. [16] point to inefficiencies in construction and demolition waste (C&DW) management, largely due to a poor understanding of stakeholder perspectives and lifecycle integration. Many decision-makers prioritise short-term project concerns, like cost and deadlines, over long-term sustainability benefits. Without a clear framework for integrating Circular Economy principles throughout planning, design, and construction, IBS projects may fall short in optimising resource efficiency and reducing waste.

From an architectural perspective, the lack of standardised measures and the need for design standards that incorporate sustainable end-of-life asset management are essential for advancing CE practices [37]. Challenges also arise from a fragmented supply chain, limited awareness among stakeholders, and the underdeveloped market for reused building components [38]. Additionally, the slow transition of circular economy initiatives from small-scale pilot projects to larger implementations hinders their broader adoption within the construction industry [39].

The use of advanced technologies like BIM and risk assessment tools play a vital role in improving the sustainability of IBS construction. However, these technologies require real-world validation to evaluate their practical effectiveness. Conducting case studies can help identify challenges, refine frameworks, and ensure smooth integration into construction processes. Tabatabaee et al. [40] and Abkar et al. [41] highlight how BIM and material management strategies optimise resource use, minimise waste, and align construction practices with Circular Economy principles. These technologies enable precise planning and resource tracking, making it easier to integrate circular practices throughout a building's lifecycle. Additionally, incorporating recycled and waste materials such as fly ash and waste glass into concrete production can significantly enhance the sustainability of IBS projects [42], [43], [44], [45]. However, these materials are often overlooked during the design phase, limiting their potential benefits. Using them in IBS can reduce reliance on virgin resources and contribute to a more sustainable built environment. Saad et al. [46] and Tabatabaee et al. [40] examine challenges in adopting Offsite Modular Construction (OMC) and integrating BIM into IBS, pointing to issues like resource availability, process management, and technological alignment with Circular Economy principles. Addressing these barriers require a structured approach to implementing CE practices in construction. This could strengthen resource efficiency, align projects with environmental goals, improve human well-being, and enhance economic growth in developing countries.

4. Employing Circular Economy in IBS

This research aims to establish guidelines for implementing IBS within a Circular Economy (CE), focusing on the designer's perspective. As the pivotal "first decision-makers," designers establish a project's potential for waste reduction and material recovery through their initial specifications. Consequently, providing targeted guidelines directly addresses the foundational knowledge gap, ensuring CE principles are integral to the project from its conception. To achieve this, it will critically examine the relationship between CE principles and IBS. The key objectives include:

- Analysing how current implementation practices align with Circular Economy-driven IBS construction.
- Identifying Circular Economy aspects in IBS that may be overlooked or deprioritised by key stakeholders during early decision-making.
- Developing a framework to help designers enhance the integration of Circular Economy practices in IBS projects.

The authors are conducting research on the Malaysian construction industry using a mix of quantitative and qualitative methods. This study systematically assesses the integration of CE principles within current Industrialised Building System (IBS) workflows. The analysis pinpoints both existing alignments and critical gaps to identify barriers to a fully circular construction process. To validate the proposed framework, the researchers will analyse case studies of ongoing IBS projects, assessing its practical application. These real-world insights will help refine the framework based on industry feedback, demonstrating its feasibility and benefits.

A comprehensive literature review has been completed to define the research scope and ensure alignment with current industry trends. This review has helped identify key variables and integrate relevant findings creatively. Based on this, the authors have outlined essential attributes to encourage the adoption of CE principles in IBS. These attributes will serve as the foundation for a stakeholder survey in Malaysia.

The survey would identify critical factors needed to implement a Circular Economy in IBS, with responses analysed using quantitative methods before the framework is finalised. Structural equation modeling would be used to explore relationships between descriptive, behavioural, and attitudinal data. Additionally, multiple case studies would be conducted to assess and validate the framework, ensuring comprehensive, credible, and reliable results. This approach was chosen to enhance the accuracy and consistency of findings, strengthening the framework's real-world applicability.

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5. Framework of Employing Circular Economy in IBS

The adoption of the Industrialised Building System (IBS) offers great potential for promoting sustainable development by minimising waste through Circular Economy principles [24]. Pomponi & Moncaster [47] introduced a 'six pillars' framework that emphasises the integration of various disciplines, including environmental (Env), technological (T), economic (Eco), societal (S), governmental (G), and behavioural (B) aspects, to achieve the goals of CE research.

5.1 Planning and Design Stage

Studies emphasise the importance of incorporating sustainability early in the construction process, especially during the design phase [48]. From an environmental perspective (Env), designing building components for easy disassembly and reuse is essential. This could be achieved through selective deconstruction techniques and lifecycle cost analysis to assess long-term economic advantages [49]. Additionally, sustainable and recyclable materials should be prioritised in component design, taking into account factors such as embodied carbon, durability, and recyclability [33].

BIM offers a detailed digital representation of buildings, enabling visualisation, simulation, and coordination as key factors for efficient planning, construction, and management [50]. Additionally, digital twin technology enhances construction projects by optimising component design and production workflows, leading to better efficiency, quality, and resource use [51]. These technological advancements support the Circular Economy (CE) from a technological perspective (T).

From an economic standpoint (Eco), conducting lifecycle cost analysis is essential for assessing the financial benefits of circularity. This includes cost savings from reduced material use, lower disposal expenses, and potential revenue from recycling or refurbishing components [52]. Implementing cost-effective strategies such as component standardisation, bulk purchasing of sustainable materials, and forming collaborative partnerships with supplier which can further lower production costs and boost competitiveness [53].

To strengthen the societal dimension (S), investing in training and upskilling programmes for workers involved in component design and production is essential. These programmes should focus on CE principles, sustainable practices, and emerging technologies [54]. By enhancing workforce education and development, companies can ensure that employees have the necessary skills to actively support and implement Circular Economy initiatives.

From the governmental perspective (G), collaboration with government agencies and industry associations is key to establishing standards for circular design, production, and certification of building components. These efforts help build market acceptance and consumer confidence in sustainable construction practices [55]. Additionally, securing government funding and grants for research and innovation in Circular Economy solutions, sustainable materials, and circular design methodologies is vital for driving progress in the construction sector [56]. By supporting these initiatives, policymakers can accelerate the transition toward more sustainable and resource-efficient building practices..

Lastly, engaging with local communities and stakeholders is crucial for raising awareness about the benefits of circularity, gathering feedback, and incorporating societal needs into component design and production [57]. This inclusive approach encourages community involvement and ensures that construction projects reflect local values and priorities. These efforts contribute to the circular economy from a behavioural perspective (B), promoting greater acceptance and long-term sustainability in the industry.

5.2 Production and Assembly Stage

Integrating closed-loop systems for materials within the production process through circular supply chain management and waste diversion rate improvement, such as recycling waste materials into new components or using renewable energy sources for manufacturing, is essential for promoting sustainability in construction [58]. Furthermore, to enhance the environmental dimension (Env) of implementing Circular Economy (CE) into Industrialised Building Systems (IBS) by prioritising the reuse of components and materials during the assembly process to minimise waste generation and resource consumption [59]. Additionally, optimising energy use during assembly is essential. This could be achieved by employing efficient equipment, utilising renewable energy sources, and designing passive energy strategies to reduce the environmental impact [60]. Prioritising energy efficiency during assembly could significantly lower the environmental impact of industrialised building systems.

To strengthen the technological dimension (T), adopting advanced manufacturing technologies such as 3D printing, robotic assembly, and digital fabrication is essential [61]. These innovations streamline production, minimise material waste, and allow for greater customisation of components. Additionally, utilising digital tools like Building Information Modeling (BIM), augmented reality (AR), and robotics can improve efficiency and reduce errors in assembly processes [62]. Furthermore, integrating smart building systems and sensors during assembly helps monitor energy consumption, occupancy patterns, and overall building performance, contributing to more sustainable and efficient construction practices [63].

Optimising assembly processes is essential to reduce labour costs, enhance productivity, and minimise downtime which contribute to the economical dimension (Eco). The optimisation could be achieved through the utilisation of efficient workflows, standardised components, and skilled workforce training [64]. Furthermore, designing components and assemblies with the potential for value recovery at the end of their lifecycle is crucial for capturing economic benefits from circularity. Factors such as remanufacturing, refurbishment, resale, and material recycling should be considered during the design phase to maximise the economic returns from building components [65]. This strategy not only enhances resource efficiency, but also supports the long-term economic sustainability of IBS.

Next, for the societal dimension (S), it is vital to prioritise worker safety, health, and well-being during assembly processes. This could be achieved by providing proper training, protective equipment, ergonomic facilities, and a safe working environment to ensure the welfare of workers [66]. By focusing on these aspects, the construction industry can create a conducive environment that promotes worker satisfaction, productivity, and overall societal well-being. Moreover, ensuring that assembled buildings and components meet accessibility standards and accommodate diverse user needs is essential for promoting inclusivity and enhancing societal benefits. By designing spaces that accommodate a diverse range of users, including individuals with varying abilities and needs, the construction sector can help create more inclusive and accessible built environments [67]. This not only improves the functionality of buildings but also promotes social cohesion and equity within communities.

From a governmental perspective (G), achieving a Circular Economy requires strict adherence to regulatory requirements and standards, including building codes, environmental regulations, worker safety, and quality assurance during assembly. Partnering with government agencies for compliance and oversight ensures that construction processes align with established regulations, reinforcing safety, environmental responsibility, and quality in building projects [68]. Collaborating with governmental bodies helps the construction industry maintain high standards that support sustainability and societal well-being. Additionally, obtaining green building certifications that recognise CE practices can enhance market competitiveness and credibility [69]. Certifications highlighting sustainable assembly methods and strong environmental performance allow construction firms to stand out, attract environmentally conscious clients, and demonstrate their commitment to circular economy principles.

Fostering collaboration and communication among stakeholders is crucial to driving collective action towards circularity in the assembly stage [70]. The integration is categorised in the behavioural dimension (B). By engaging designers, suppliers, contractors, and end-users in collaborative efforts, aligning goals, and sharing best practices, the construction industry can promote knowledge exchange, innovation, and a shared commitment to circular economy principles.

5.3 Operation and Maintenance Stage

During the operation and maintenance stage, the environmental dimension (Env) could be addressed by integrating renewable energy sources such as solar panels, wind turbines, and geothermal systems to reduce energy demand and dependence on fossil fuels [71]. Additionally, conducting a Life Cycle Assessment (LCA) is essential for evaluating the environmental impact of building operations, including energy consumption, water usage, waste generation, and emissions. This analysis helps pinpoint key environmental challenges and prioritise sustainability improvements for more eco-friendly building practices [72].

To enhance the technological dimension (T), leveraging advanced technologies is essential. One effective approach is installing Internet of Things (IoT) sensors throughout the building to gather real-time data on energy consumption, water usage, indoor air quality, occupancy patterns, and equipment performance [73]. Additionally, using predictive maintenance algorithms and machine learning models to analyse this data allows for proactive maintenance scheduling, early failure detection, and optimised asset lifespan. This approach minimises downtime, improves efficiency, and ensures the long-term sustainability of building operations [74].

Evaluating the long-term economic feasibility of Industrialised Building System (IBS) solutions requires a Total Cost of Ownership (TCO) analysis. This approach enhances sustainability and supports the adoption of Circular Economy principles within the economic dimension (Eco). TCO analysis considers factors such as maintenance costs, material lifespan, and potential savings from circular practices [75]. By assessing these elements, organisations can gain a clearer picture of the overall costs associated with IBS implementation, allowing for more informed decision-making regarding its economic viability [76].

Prioritising local hiring supports the CE by fostering social inclusivity, economic resilience, and community well-being within the social dimension (S). This strategy not only drives economic growth but also improves the quality of life for community members [77]. By utilising local talent and resources, construction projects can strengthen community relationships, creating lasting social and economic benefits.

From the governmental dimension (G), establishing monitoring and reporting mechanisms is essential for tracking key performance indicators (KPIs), metrics, and targets related to CE goals, energy efficiency, waste reduction, water conservation, and overall environmental performance in buildings [78]. By systematically tracking these KPIs, governments can inform policy development, optimise resource allocation, and refine regulatory frameworks to accelerate the shift toward more sustainable and resource-efficient building systems.

The behavioural dimension (B) could be addressed by implementing awareness campaigns, sustainability challenges, and green initiatives within buildings to educate and encourage occupants to adopt responsible practices, minimise resource consumption, and support circularity [72]. Fostering a culture of continuous improvement through regular sustainability evaluations, feedback collection, and targeted action plans could further strengthen behavioural engagement. By promoting learning and adaptation, organisations can enhance both sustainability outcomes and overall environmental impact.

5.4 Demolition and Recovery

For the environmental dimension (Env), integrating Circular Economy (CE) principles could be achieved through selective demolition techniques. This involves dismantling and sorting materials by type with a well-documented system on-site, making it easier to recycle, upcycle, and reuse materials in future construction projects. Advanced material recovery strategies and circular business models further enhance this process [13]. A strong waste segregation system is essential, categorising materials into recyclable, reusable, hazardous, and non-recyclable groups. This ensures proper disposal, recycling, and appropriate treatment of waste streams [79]. Additionally, identifying salvageable materials that could be repurposed, reused in other projects, or sold to salvage yards promotes resource efficiency and minimises waste, aligning with CE principles.

Moreover, it is vital to employ Circular Economy for technological dimension (T) to track and manage waste streams, ensuring compliance with waste regulations and optimising resource recovery [72]. By exploring advanced recycling technologies such as mobile recycling units, onsite crushers, and material recovery facilities (MRFs) could process demolition waste into reusable aggregates, metals, plastics, and other materials for construction applicaions [24]. The selection of technologies can be done by examining the return of investment and other criteria including availability of resources for demolition operations.

From an economic perspective (Eco), adopting circular business models such as product-as-a-service or leasing arrangements can encourage the recovery, refurbishment, and reuse of building components, shifting from a linear to a Circular Economy approach [80]. These models enhance sustainability by extending the lifecycle of materials and reducing waste, ultimately creating long-term economic and environmental benefits.

Integrating Circular Economy (CE) into Industrialised Building Systems (IBS) during the demolition and recovery stage could be employed in the societal dimension (S) by maintaining transparent communication channels with the community. Providing regular updates, progress reports, and information on demolition schedules, waste management practices, and environmental monitoring results is essential [81]. In addition, establishing mechanisms for accountability, grievance redressal, and feedback collection from community members allows for transparency, trust-building, and responsiveness to community concerns [82].

From the governmental dimension (G), securing the necessary permits, licenses, and approvals for demolition activities, waste handling, recycling operations, and environmental monitoring is crucial to ensure compliance with legal requirements and industry best practices [83]. Additionally, advocating for policies, incentives, and regulations that support CE principles in construction and demolition such as extended producer responsibility (EPR), waste management targets, and incentives for material reuse and recycling plays a vital role in fostering sustainable practices [84]. These measures could drive the industry's transition toward a more resource-efficient and environmentally responsible approach.

For the behavioral dimension (B), providing real-time feedback to workers and teams on their waste management performance, recycling rates, and environmental impact metrics is essential [85]. This allows them to monitor progress, identify areas for improvement, and adjust their practices accordingly. Additionally, leading by example and demonstrating best practices in waste management, resource recovery, and Circular Economy initiatives within the organisation can inspire others to adopt similar sustainable behaviours [86]. This approach fosters a culture of environmental responsibility and continuous improvement.

The findings of the analysis are presented in a developed framework, as shown in Fig. 1. The framework consists of four (4) main processes: 1) planning and design, 2) production and assembly, 3) operation and maintenance, and 4) demolition and recovery. While this structured approach provides a theoretical foundation, its practical applicability must be validated through real-world case studies. Practical applications would demonstrate how the framework performs in actual IBS projects, identify any necessary adjustments, and provide empirical evidence of its effectiveness. The factors influencing the employment of Circular Economy are categorised according to the appropriate process and classified into environmental, technological, economic, societal, governmental, and behavioural aspects.

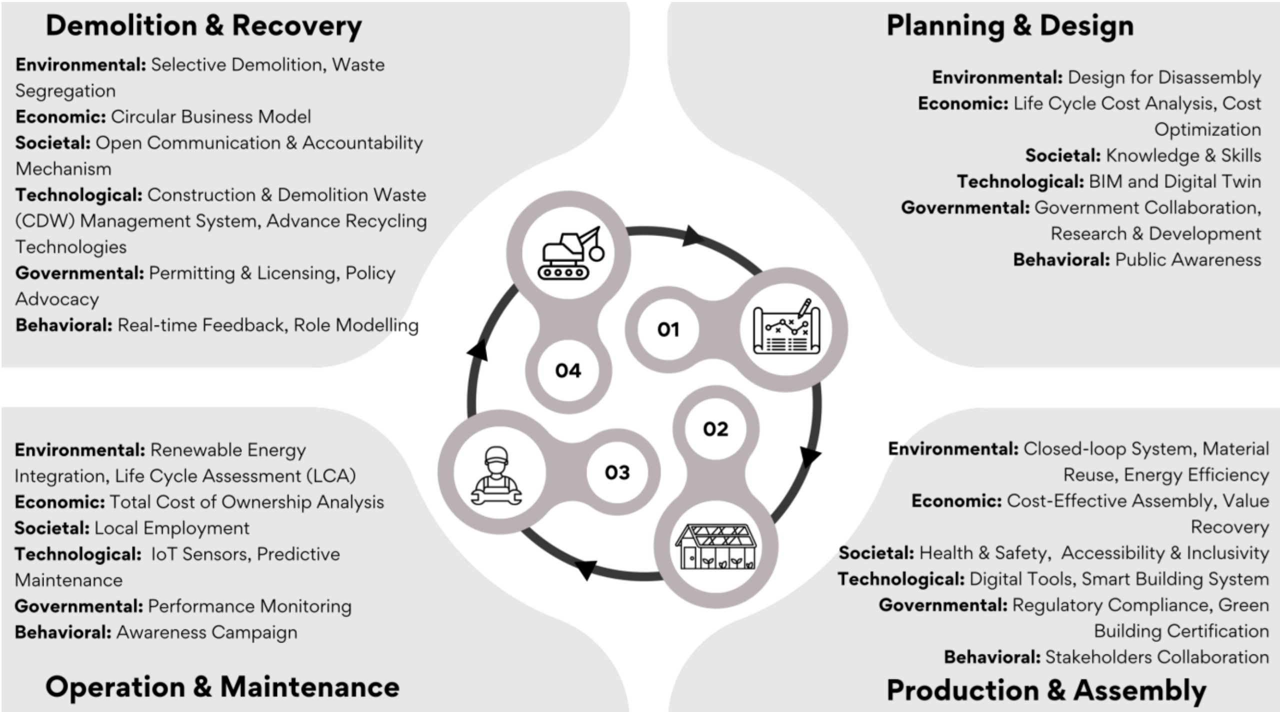

Fig. 1 *Framework for integration of circular economy in the Industrialised Building System (IBS)*

The proposed six-dimension framework offers a holistic approach to addressing real-life challenges in construction and demolition (C&D) waste management. By integrating environmental, technological, economic, societal, governmental, and behavioural dimensions, the framework provides actionable strategies tailored to diverse stakeholders. For example, developers can apply environmental and technological strategies to reduce material waste during IBS construction, while policymakers could implement governmental and economic measures to incentivise recycling and reuse. Furthermore, the framework's emphasis on behavioural shifts ensures sustainable practices are embedded across the industry.

The framework's impact goes beyond waste reduction, contributing to economic growth through material recovery while supporting Malaysia's sustainability goals. These strengths highlight its practical value in addressing real-world challenges in construction and demolition (C&D) waste management. To refine the framework into a practical guideline for designers and manufacturers, questionnaire surveys and interviews would be conducted. These insights would help improve decision-making in implementing Circular Economy principles within IBS applications. Evaluating real construction projects is essential to identifying viable solutions, and active participation from industry practitioners is crucial to addressing on-site challenges effectively.

6. Conclusion

The integration of Circular Economy (CE) principles within Industrialised Building Systems (IBS) represents a transformative approach to advancing sustainability in the construction industry. This research critically examined the synergy between CE and IBS, proposing a comprehensive framework that categorises essential attributes across environmental, technological, economic, societal, governmental, and behavioural dimensions.

The findings highlight the critical importance of coordinated efforts among stakeholders including designers, manufacturers, and policymakers to drive sustainable practices across all stages of construction projects. By aligning IBS with Circular Economy (CE) standards, the framework identifies key Circular Economy attributes that stakeholders recognise as essential. These attributes are organised into key dimensions, such as lifecycle cost analysis for economic viability, advanced material recovery strategies for environmental sustainability, and deconstruction for material reuse within technological considerations.

Future research should focus on testing the proposed framework in real IBS projects to assess its impact on reducing material waste, improving cost efficiency, and enhancing circularity across various project stages. Additionally, further studies are needed to explore how digital tracking tools, policy interventions, and financial incentives can accelerate the adoption of Circular Economy (CE) principles within Malaysia's regulatory framework. By fostering collaboration and sharing knowledge, this research aims to establish IBS as a key driver of sustainable construction, setting a benchmark for CE integration in Malaysia and beyond.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Riduan Yunus, Eizzad Amirul Arash Mohd Nizam;* ***data collection:*** *Ezhwan Nur Arshad, Eizzad Amirul Arash Mohd Nizam;* ***analysis and interpretation of results:*** *Riduan Yunus, Syed Burhanuddin Syed Mohamad;* ***draft manuscript preparation:*** *Riduan Yunus, Eizzad Amirul Arash Mohd Nizam. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Shareh Musa, S. M., Md Yassin, A., Zainal, R., Shafii, H., and Yeo, P.Y. (2019). Comparison of Construction Waste Generation Between Industrial Building Systems (IBS) With Conventional Systems, *Journal of Information System and Technology Management*, *4(14),* 72–83, https://doi.org/10.35631/jistm.414007

[2] Muhaidin, N. H. M., & Chan, H. B. (2018). The comparison of construction waste produced by conventional method against IBS: A case study in Pulau Pinang, *AIP Conference Proceedings*, *2020(1),* https://doi.org/10.1063/1.5062681

[3] Rahaman, F. A. A., & Taib, N. (2019). A Review On The Construction Method In Minimising Construction Waste In Malaysia. *European Proceedings of Multidisciplinary Sciences*, 215–223, https://doi.org/10.15405/epms.2019.12.21

[4] Maniam, H., Nagapan, S., Abdullah, A. H., Subramaniam, S., and Sohu, S. (2018). A Comparative Study of Construction Waste Generation Rate Based on Different Construction Methods on Construction Project in Malaysia, *Engineering, Technology & Applied Science Research*, *8(5),* 3488–3491, https://doi.org/10.48084/etasr.2340

[5] Abd Shukor, A. S., Bakri, A. S., and Idris, N. H. (2021). Assessing Site Waste Management Practices and Cost Between Conventional and Industrialised Building System (IBS) Projects in Malaysia, *Int. J. Sustain. Constr. Eng. Technol.*, *12(5),* 156–163, https://doi.org/10.30880/ijscet.2021.12.05.016

[6] Zairul, M. (2021). The recent trends on prefabricated buildings with circular economy (CE) approach, *Clean. Eng. Technol.*, *4,* https://doi.org/10.1016/J.CLET.2021.100239

[7] MacArthur, E. (2020). What is a circular economy? | Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

[8] Musa, M. F., Mohammad, M. F., Mahbub, R., and Yusof, M. R. (2018). Adopting Modular Construction in the Malaysian Construction Industry, *Asian J. Environ. Stud.*, *3(10),* 1–9, https://doi.org/10.21834/aje-bs.v3i10.307

[9] Rahimah Mohd Noor, S., Yunus, R., Halid Abdullah, A., Nagapan, S., and Mohamad Syahir Syed Mazlan, S. (2018). Insights into The Adoption of Lean Management in Industrialised Building System (IBS) Implementation: The Drivers and Challenges, *Int. J. Eng. Technol.*, *7(3.23),* 22, https://doi.org/10.14419/ijet.v7i3.23.17253

[10] Othman, M. Z., *et al.* (2018). Intergration of Islamic Value (Work Ethics) in Construction Projects: The Malaysian Industrialised Building System (IBS) Case, *J. Soc. Sci. Res.*, *6*, 189–195, https://doi.org/10.32861/jssr.spi6.189.195

[11] Nawi, M. N. M., Mydin, M. A. O., Nursal, A. T., Nifa, F. A. A., and Hanafi, M. H. (2015). Payment issues in Malaysia industrialised building system (IBS): A research framework, *Adv. Environ. Biol.*, *9(4),* 88–91, https://repo.uum.edu.my/id/eprint/13878/1/Pay.pdf

[12] Shamsuddin, S. M., Zakaria, R., Abidin, N. I., Hashim, N., and Yusuwan, N. M. (2021). Confirmatory factor analysis of the life cycle costing sub-cost distribution for industrialised building system using sem-pls, *Eng. J.*, *25(1),* 287–296, https://doi.org/10.4186/ej.2021.25.1.287

[13] Ginga, C. P., Ongpeng, J. M. C., and Daly, M. K. M. (2020). Circular Economy on Construction and Demolition Waste: A Literature Review on Material Recovery and Production, *Materials (Basel).*, *13(13),* 2970, https://doi.org/10.3390/ma13132970

[14] Ly, D. H., Le, Q. H., Hoang Nhat Nguyen, T. D., Ahn, Y., Kim, K., & Kwon, N. (2024). Advancing modular construction through circular economy: Insights from semi-automated PRISMA analysis and topic modeling. *Journal of Building Engineering*, *98*(October), 111232. https://doi.org/10.1016/j.jobe.2024.111232

[15] Wuni, I. Y., & Shen, G. Q. (2022). Developing critical success factors for integrating circular economy into modular construction projects in Hong Kong. *Sustainable Production and Consumption*, *29*, 574–587. https://doi.org/10.1016/j.spc.2021.11.010

[16] Kabirifar, K., Mojtahedi, M., Wang, C., & Tam, V. W. Y. (2020). Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *Journal of Cleaner Production*, *263*, 121265. https://doi.org/10.1016/j.jclepro.2020.121265

[17] Singh, J., & Ordoñez, I. (2016). Resource recovery from post-consumer waste: important lessons for the upcoming circular economy. *Journal of Cleaner Production*, *134*, 342–353. https://doi.org/10.1016/j.jclepro.2015.12.020

[18] Wuni, I. Y. (2023). A systematic review of the critical success factors for implementing circular economy in construction projects, *Sustain. Dev.*, *31(3),* 1195–1213, https://doi.org/10.1002/sd.2449

[19] Sinxadi, L., Ngowi, A. B., Ramakrishna, S., and Awuzie, B. (2021). Toward a Dynamic Capabilities Framework for Engendering 4IR-Enabled Circular Economy in a University of Technology, *Front. Sustain.*, *2*, 1–13, https://doi.org/10.3389/frsus.2021.718723

[20] Leising, E., Quist, J., and Bocken, N. (2018). Circular Economy in the building sector: Three cases and a collaboration tool, *J. Clean. Prod.*, *176*, 976–989, https://doi.org/10.1016/J.JCLEPRO.2017.12.010

[21] Sanchez-Lite, A., Zulueta, P., Sampaio, A. Z., and Gonzalez-Gaya, C. (2022). BIM for the Realization of Sustainable Digital Models in a University-Business Collaborative Learning Environment: Assessment of Use and Students' Perception, *Buildings*, *12(7),* https://doi.org/10.3390/buildings12070971

[22] Wang, Y., Chong, D., and Liu, X. (2021). Evaluating the critical barriers to green construction technologies adoption in china, *Sustain.*, *13(12),* 1–14, https://doi.org/10.3390/su13126510

[23] Tirado, R., Aublet, A., Laurenceau, S., and Habert, G. (2022). Challenges and Opportunities for Circular Economy Promotion in the Building Sector, *Sustain.*, *14(3),* https://doi.org/10.3390/su14031569

[24] Ghisellini, P., Cialani, C., and Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems, *J. Clean. Prod.*, *114*, 11–32, https://doi.org/10.1016/J.JCLEPRO.2015.09.007

[25] Papamichael, I., Voukkali, I., Loizia, P., and Zorpas, A. A. (2023). Construction and demolition waste framework of circular economy: A mini review, *Waste Manag. Res.*, *41(12),* 1728–1740, https://doi.org/10.1177/0734242X231190804

[26] Urbinati, A., Chiaroni, D., and Chiesa, V. (2017). Towards a new taxonomy of circular economy business models, *J. Clean. Prod.*, *168*, 487–498, https://doi.org/10.1016/j.jclepro.2017.09.047

[27] Charef, R., Ganjian, E., and Emmitt, S. (2021). Socio-economic and environmental barriers for a holistic asset lifecycle approach to achieve circular economy: A pattern-matching method, *Technol. Forecast. Soc. Change*, *170*, https://doi.org/10.1016/J.TECHFORE.2021.120798

[28] Ababio, B. K. and Lu, W. (2022). Barriers and enablers of circular economy in construction: a multi-system perspective towards the development of a practical framework, *Constr. Manag. Econ., 41(1),* 3–21, https://doi.org/10.1080/01446193.2022.2135750

[29] Charef, R. *et al.* (2021). Barriers to implementing the circular economy in the construction industry: A critical review, *Sustain.*, *13(23),* 12989, https://doi.org/10.3390/su132312989

[30] Osei-Tutu, S., Ayarkwa, J., Osei-Asibey, D., Nani, G., and Afful, A. E. (2022). Barriers impeding circular economy (CE) uptake in the construction industry, *Smart Sustain. Built Environ.*, *12(4),* 892-918, https://doi.org/10.1108/SASBE-03-2022-0049/FULL/XML

[31] Bertino, G., Kisser, J., Zeilinger, J., Langergraber, G., Fischer, T., and Österreicher, D. (2021). Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials, *Applied Sciences (Switzerland)*, *11(3),* 1–31, https://doi.org/10.3390/app11030939

[32] Schuster, S. and Geier, S. (2022). CircularWOOD - Towards Circularity in Timber Construction in the German Context, *IOP Conf. Ser. Earth Environ. Sci.*, *1078(1),* https://doi.org/10.1088/1755-1315/1078/1/012030

[33] Minunno, R., O'Grady, T., Morrison, G. M., Gruner, R. L., and Colling, M. (2018). Strategies for applying the circular economy to prefabricated buildings, *Buildings*, *8(9),* 125, https://doi.org/10.3390/buildings8090125

[34] Maury-Ramírez, A., Illera-Perozo, D., and Mesa, J. A. (2022). Circular Economy in the Construction Sector: A Case Study of Santiago de Cali (Colombia), *Sustain.*, *14(3),* 1923, https://doi.org/10.3390/su14031923

[35] Wijewansha, A. S., Tennakoon, G. A., Waidyasekara, K. G. A. S., and Ekanayake, B. J. (2021). Implementation of circular economy principles during pre-construction stage: the case of Sri Lanka, *Built Environ. Proj. Asset Manag.*, *11(4),* 750–766, https://doi.org/10.1108/BEPAM-04-2020-0072

[36] Adams, K., Osmani, M., Thorpe, T., and Thornback, J. (2017). Circular economy in construction: current awareness, challenges and enablers, *170(1),* 15-24, https://doi.org/10.1680/JWARM.16.00011

[37] Nandha Gopan, S. and Balaji, M. (2023). Indian automotive supply chains: barriers to circular economy for sustainable development, *Manag. Decis.*, *61(11),* 3589–3609, https://doi.org/10.1108/MD-03-2023-0435

[38] Santos, M. C., Veiga, C., Dantas, S. S., Águas, P., and Santos, J. A. C. (2023). Key drivers for the adoption of circular economy practices in the tourist accommodation sector, *Worldw. Hosp. Tour. Themes*, *15(6),* 633–655, https://doi.org/10.1108/WHATT-09-2023-0112

[39] Guarnieri, P., Cerqueira-Streit, J. A., and Batista, L. C. (2020). Reverse logistics and the sectoral agreement of packaging industry in Brazil towards a transition to circular economy, *Resour. Conserv. Recycl.*, *153*, 104541, https://doi.org/10.1016/j.resconrec.2019.104541

[40] Tabatabaee, S., Mahdiyar, A., & Ismail, S. (2021). Towards the success of Building Information Modelling implementation: A fuzzy-based MCDM risk assessment tool. *Journal of Building Engineering*, *43*(July), 103117. https://doi.org/10.1016/j.jobe.2021.103117

[41] Abkar, M. M. A., Yunus, R., Gamil, Y., & Albaom, M. A. (2024). Enhancing construction site performance through technology and management practices as material waste mitigation in the Malaysian construction industry. *Heliyon*, *10*(7), e28721. https://doi.org/10.1016/j.heliyon.2024.e28721

[42] Maurya, N., Srivastav, Y., Rawat, S., Ranjan, Y., Srivastava, R., Shukla, B. K., & Varadharajan, S. (2023). Reinforcing civil infrastructure with waste glass-enhanced concrete: A comprehensive review of properties, performance and applications. *Materials Today: Proceedings*, *93*, 239–248. https://doi.org/10.1016/j.matpr.2023.07.177

[43] Maurya, N., Srivastav, Y., Rawat, S., Sharma, M., Srivastava, R., Sihag, P., & Shukla, B. K. (2024). Augmenting Concrete Performance and Sustainability with Recycled Glass: A Critical Examination of Material Characteristics and Construction Applications. *AIP Conference Proceedings*, *3050*(1). https://doi.org/10.1063/5.0193663

[44] Shukla, B. K., Bharti, G., Sharma, P. K., Sharma, M., Rawat, S., Maurya, N., Srivastava, R., & Srivastav, Y. (2024). Sustainable construction practices with recycled and waste materials for a circular economy. *Asian Journal of Civil Engineering*, *July*. https://doi.org/10.1007/s42107-024-01111-y

[45] Shukla, B. K., Gupta, A., Gowda, S., & Srivastav, Y. (2023). Constructing a greener future: A comprehensive review on the sustainable use of fly ash in the construction industry and beyond. *Materials Today: Proceedings*, *93*, 257–264. https://doi.org/10.1016/j.matpr.2023.07.179

[46] Saad, S., Rasheed, K., Ammad, S., Hasnain, M., Ullah, H., Hannan Qureshi, A., Mohsen Alawag, A., Altaf, M., & Sadiq, T. (2025). Offsite modular construction adoption in developing countries: Partial least square approach for sustainable future. *Ain Shams Engineering Journal*, *16*(1), 103228. https://doi.org/10.1016/j.asej.2024.103228

[47] Pomponi, F. and Moncaster, A. (2017). Circular economy for the built environment: A research framework, *J. Clean. Prod.*, *143*, 710–718, https://doi.org/10.1016/J.JCLEPRO.2016.12.055

[48] Yunus, R. and Yang, J. (2014). Improving ecological performance of industrialized building systems in Malaysia, *Constr. Manag. Econ.*, *32(1–2),* 183–195, https://doi.org/10.1080/01446193.2013.825373

[49] Melella, R., Di Ruocco, G., and Sorvillo, A. (2021). Circular construction process: Method for developing a selective, low co2eq disassembly and demolition plan, *Sustain.*, *13(16),* 8815, https://doi.org/10.3390/su13168815

[50] Primasetra, A., Larasati, D., and Wonorahardjo, S. (2022). BIM Utilization in Improving Energy Efficiency Performance on Architectural Design Process: Challenges and Opportunities, *IOP Conf. Ser. Earth Environ. Sci.*, *1058(1),* https://doi.org/10.1088/1755-1315/1058/1/012018

[51] Eickhoff, T., Forte, S., and Göbel, J. C. (2022). Approach for Developing Digital Twins of Smart Products Based on Linked Lifecycle Information, *Proc. Des. Soc.*, *2*, 1559–1568, https://doi.org/10.1017/pds.2022.158

[52] Farooque, M., Zhang, A., Thürer, M., Qu, T., and Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review, *J. Clean. Prod.*, *228*, 882–900, https://doi.org/10.1016/j.jclepro.2019.04.303

[53] Genovese, A., Acquaye, A. A., Figueroa, A., and Koh, S. C. L. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications, *Omega (United Kingdom)*, *66*, 344–357, https://doi.org/10.1016/j.omega.2015.05.015

[54] Sutan, A. and Vranceanu, R. (2021). Who should pay the bill for employee upskilling?, *SSRN Electron. J.*, https://doi.org/10.2139/ssrn.3843614

[55] Samarakoon, S. M. S. M. K. and Ratnayake, R. M. C. (2023). End-of-life solution prioritization for pre-cast concrete components aligning with circular economy targets, *Struct. Concr.*, *24(2),* 1751–1765, https://doi.org/10.1002/suco.202200572

[56] Liu, J., Gong, E., and Wang, X. (2022). Economic benefits of construction waste recycling enterprises under tax incentive policies, *Environ. Sci. Pollut. Res.*, *29(9),* 12574–12588, https://doi.org/10.1007/s11356-021-13831-8

[57] Gutberlet, J. (2021). Grassroots waste picker organizations addressing the UN sustainable development goals, *World Dev.*, *138*, 105195, https://doi.org/10.1016/j.worlddev.2020.105195

[58] Kakkos, E. and Hischier, R. (2022). Paving the way towards circularity in the building sector. Empa's Sprint Unit as a beacon of swift and circular construction, *IOP Conf. Ser. Earth Environ. Sci.*, *1078(1),* https://doi.org/10.1088/1755-1315/1078/1/012009

[59] Finch, G., Marriage, G., Pelosi, A., and Gjerde, M. (2021). Building envelope systems for the circular economy; Evaluation parameters, current performance and key challenges, *Sustain. Cities Soc.*, *64*, 102561, https://doi.org/10.1016/j.scs.2020.102561

[60] Ju, L., Tan, Z., Li, H., Tan, Q., Yu, X., and Song, X. (2016). Multi-objective operation optimization and evaluation model for CCHP and renewable energy based hybrid energy system driven by distributed energy resources in China, *Energy*, *111*, 322–340, https://doi.org/10.1016/j.energy.2016.05.085

[61] Luo, Y., Zou, J., and Gu, G. (2021). Multimaterial Pneumatic Soft Actuators and Robots through a Planar Laser Cutting and Stacking Approach, *Adv. Intell. Syst.*, *3(10),* https://doi.org/10.1002/aisy.202000257

[62] Çetin, S., De Wolf, C., and Bocken, N. (2021). Circular Digital Built Environment: An Emerging Framework, *Sustainability*, *13(11),* 6348, https://doi.org/10.3390/su13116348

[63] Geissdoerfer, M., Pieroni, M. P. P., Pigosso, D. C. A., and Soufani, K. (2020). Circular business models: A review, *J. Clean. Prod.*, *277*, 123741, https://doi.org/10.1016/j.jclepro.2020.123741

[64] Davila Delgado, J. M. and Oyedele, L. O. (2020). BIM data model requirements for asset monitoring and the circular economy, *J. Eng. Des. Technol.*, *18(5),* 1269–1285, https://doi.org/10.1108/JEDT-10-2019-0284

[65] Luscuere, L. M. (2017). Materials Passports: Optimising value recovery from materials, *Proc. Inst. Civ. Eng. - Waste Resour. Manag.*, *170(1),* 25–28, https://doi.org/10.1680/jwarm.16.00016

[66] Ismail, Z. A. (2019). Optimising the safety of road transport workers on IBS building construction projects: a review, *Soc. Responsib. J.*, *15(6),* 837–851, https://doi.org/10.1108/SRJ-09-2018-0240

[67] Stawiarska, E., Szwajca, D., Matusek, M., and Wolniak, R. (2021). Diagnosis of the maturity level of implementing industry 4.0 solutions in selected functional areas of management of automotive companies in poland, *Sustain.*, *13(9),* https://doi.org/10.3390/su13094867

[68] Simpson, E., Bradley, D., Palfreyman, J., and White, R. (2022). Sustainable Society: Wellbeing and Technology—3 Case Studies in Decision Making, *Sustain.*, *14(20),* https://doi.org/10.3390/su142013566

[69] Heesbeen, C. and Prieto, A. (2020). Archetypical CBMs in construction and a translation to industrialized manufacture, *Sustainability (Switzerland)*, *12(4),* https://doi.org/10.3390/su12041572

[70] Wu, Z., Jiang, M., Cai, Y., Wang, H., and Li, S. (2019). What hinders the development of green building? An investigation of China, *Int. J. Environ. Res. Public Health*, *16(17),* https://doi.org/10.3390/ijerph16173140

[71] Jadhav, N. Y. (2016). Renewable Energy Integration in Buildings, in *Green and Smart Buildings. Green Energy and Technology*, 109–122. https://doi.org/10.1007/978-981-10-1002-6_7

[72] Geissdoerfer, M., Savaget, P., Bocken, N., and Hultink, E. (2017). The Circular Economy - A New Sustainability Paradigm?, *Journal of cleaner production, 143,* 757-768, https://doi.org/10.1016/J.JCLEPRO.2016.12.048

[73] Marinakis, V. and Doukas, H. (2018). An advanced IoT-based system for intelligent energy management in buildings, *Sensors (Switzerland), 18(2),* https://doi.org/10.3390/s18020610

[74] Wu, M., Wu, Y., Liu, X., Ma, M., Liu, A., and Zhao, M. (2018). Learning-based synchronous approach from forwarding nodes to reduce the delay for Industrial Internet of Things, *Eurasip J. Wirel. Commun. Netw., 2018(1),* 1-22, https://doi.org/10.1186/s13638-017-1015-z

[75] Bhutta, K. S. and Huq, F. (2002). Supplier selection problem: A comparison of the total cost of ownership and analytic hierarchy process approaches, *Supply Chain Manag., 7(3),* 126–135, https://doi.org/10.1108/13598540210436586

[76] Ferrin, B. G. and Plank, R. E. (2002). Total Cost of Ownership Models: An Exploratory Study, *J. Supply Chain Manag., 38(2),* 18–29, https://doi.org/10.1111/j.1745-493X.2002.tb00132.x

[77] Eikelenboom, M. and Long, T. B. (2023). Breaking the Cycle of Marginalization: How to Involve Local Communities in Multi-stakeholder Initiatives?, *Journal of Business Ethics, 186(1),* 31-62, https://doi.org/10.1007/s10551-022-05252-5

[78] Kazancoglu, I., Sagnak, M., Kumar Mangla, S., and Kazancoglu, Y. (2021). Circular economy and the policy: A framework for improving the corporate environmental management in supply chains, *Bus. Strateg. Environ., 30(1),* 590–608, https://doi.org/10.1002/bse.2641

[79] Gálvez-Martos, J. L., Styles, D., Schoenberger, H., and Zeschmar-Lahl, B. (2018). Construction and demolition waste best management practice in Europe, *Resour. Conserv. Recycl., 136*, 166–178, https://doi.org/10.1016/j.resconrec.2018.04.016

[80] Bocken, N., Pauw, I. D. De, Bakker, C., and van der Grinten, B. (2016). Product design and business model strategies for a circular economy, *J. Ind. Prod. Eng., 33*, 308–320, https://doi.org/10.1080/21681015.2016.1172124

[81] Deniz, D. (2021). Sustainable Design Thinking and Social Innovation for Beating Barriers to Circular Economy, *WIT Trans. Ecol. Environ., 253*, 219–226, https://doi.org/10.2495/SC210191

[82] Shao, J. (2019). Sustainable consumption in China: New trends and research interests, *Bus. Strateg. Environ., 28(8),* 1507–1517, https://doi.org/10.1002/bse.2327

[83] Verhagen, T. J., Sauer, M. L., Voet, E., and Sprecher, B. (2021). Matching demolition and construction material flows, an urban mining case study, *Sustain., 13(2),* 1–14, https://doi.org/10.3390/su13020653

[84] Vargas-Terranova, C. A., Rodrigo-Ilarri, J., Rodrigo-Clavero, M. E., and Rozo-Arango, M. A. (2022). M-GRCT: A Dynamic Circular Economy Model for the Optimal Design of Waste Management Systems in Low-Income Municipalities, *Int. J. Environ. Res. Public Health, 19(5),* https://doi.org/10.3390/ijerph19052681

[85] Huysentruyt, M., Delmas, M., and Barnosky, E. (2020). The Circular Economy: Motivating Recycling Behavior for a More Effective System, *Acad. Manag. Proc., 2020(1),* 21567, https://doi.org/10.5465/AMB2020.21567abstract

[86] Elzinga, R., Reike, D., Negro, S. O., and Boon, W. P. C. (2020). Consumer acceptance of circular business models, *J. Clean. Prod., 254*, 119988, https://doi.org/10.1016/j.jclepro.2020.119988