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Conceptual Criteria of Circular Economy (CE) for Green Building Materials (GBM) in Construction and Built Environment Sector

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Abstract: *The global construction industry is experiencing a paradigm shift toward sustainability, yet the adoption of green building materials (GBM) remains limited due to the premium costs associated with procurement. Although GBMs offer significant environmental and operational benefits, their higher upfront costs discourage developers and contractors, particularly in emerging economies, from embracing sustainable practices. This study aims to bridge the gap between circular economy (CE) principles and the premium cost variables that currently hinder the procurement of GBM. Integrative review techniques is used based on final screening articles in Google Scholar and Web of Science using "Circular Economy" AND "Model" AND Built environment OR "Construction" from 2016 to 2025. The study uncovers five (5) main CE criteria for GBM consists of design, production, construction, consumption, and waste management. The CE has covered extensively the life cycle of the materials compared to GBM. Despite having separate guiding principles, CE and GBM's respective focuses must be integrated for comprehensive sustainable implementation.*

Keywords: Green Building Materials, Circular Economy, Construction, Built Environment, Sustainable Procurement

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1. Introduction to the Research Background and Issues

The global construction industry is undergoing a transformative shift toward sustainable practices towards escalating climate challenges, resource depletion, and environmental degradation. In response to this, green building development is one of the strategy to overcome problems related to environmental issues. Despite its lower ownership cost during the maintenance and operation period, the construction cost is about 29% higher, and the life-cycle costs are 17% lower than those of conventional buildings (Meena et al., 2022). To increase stakeholder's interest towards green building development, it is crucial to reduce the building premium costs. The benefits of green buildings such as reduced resource use, lower carbon footprint, and improved long-term efficiency are closely linked to green building materials that minimize waste and environmental impact. This can be strengthened through a circular economy (CE) approach strengthens both by promoting material reuse, recycling, and closed-loop systems that further reduce resource extraction and enhance sustainability.

However, Ha et al. (2023) in their studies revealed that the green building development and usage of green building materials (GBM) are still low. The widespread application of GBM continues to face resistance, largely due to the premium costs associated with procurement, certification, supply chain limitations, and lack of market maturity. For developers and contractors, especially in emerging economies, these higher upfront costs often outweigh long-term operational savings, creating a financial disincentive for adoption.

Construction sustainability emphasizes resource efficiency, reuse, and recyclable resources, environmental protection, prevent toxins, life-cycle costing, and focus on quality (Ogunmakinde et al., 2022). Malaysia has focused on sustainability and resilience in implementing a low-carbon, clean, and resilient development, managing natural resources, and strengthening the enabling environment for effective governance (Twelfth Malaysian Plan 2021-2025). In this context, the circular economy (CE) framework offers a promising pathway to mitigate cost-related barriers. CE is part of achieving sustainability since it creates environmental benefits, economic opportunities, and social equity. Rooted in principles of resource efficiency, waste minimization, and product lifecycle extension, the CE advocates for a shift from the traditional linear "take-make-dispose" model to one where materials are reused, refurbished, or recycled in closed loops " (Hossain et al., 2022; Eberhardt et al., 2019).

CE emphasizes product design that is environmentally friendly, able to be used in the long term, and can be recycled, repurposed, and remanufactured at the end of its life cycle. The concept aims to produce zero waste by implementing appropriate resource-efficient methods to achieve sustainability (Akinade & Oyedele, 2018). According to Cimen (2021), the foundation of CE starts with the 3R principle and further extends to the 4R, 5R, 6R, and 10R principles, which stand for reduce, reuse, recycle, recover, repurpose, remanufacture, refurbish, repair, re-use, and refuse. These principles aim to minimize waste and promote sustainability. The principles and concept of CE were established to cover from the design phase up to the waste management phase.

A CE in the construction sector requires long-term planning and a profit-oriented approach. According to Eberhardt et al. (2019), CE has mostly focused on consumer goods with a short to medium lifespan, but buildings are often different due to their long-lived product and possible changes during their service life, which leads to uncertainty about future conditions. CE is typically proposed for short-term profit and business, while CE for building and construction takes a longer time. The lifespan of a building is long compared to other products such as plastics, electrical and electronic industry, making it difficult for stakeholders and developers to see the long-term benefits of CE. The lifespan of a residential building is typically between 70 and 100 years, while an industrial building lasts between 30 and 40 years (Tirado et al., 2022). In a CE, building materials should be designed for long-term use and be able to be reused and recycled at the end of their cycle.

However, due to the lengthy lifespan of buildings, many business owners find it challenging to predict uncertain future long-term profit benefits. Bilal et al. (2020) state that companies generally prioritize profit over environmental impact and are reluctant to bear upfront costs for the CE system. Referring to Eberhardt et al. (2022), it is argued that there are limited publications specifically addressing the building industry, as it is involved in complex nature due to the CE concept that primarily focuses on short and medium-term consumer goods.

2. Overview of Circular Economy

The CE is being imposed due to rising issues of increasing scarcity of natural resources and environmental concerns. The linear economy (take-make-use-dispose) has caused severe environmental impacts such as waste in landfills, pollution, and greenhouse gas emissions. Myeda et al. (2022) point out that the waste created has an impact on the economic burden, which requires countries to allocate a budget for waste management annually. This inefficient waste management contributes to a huge amount of untreated waste in disposal areas, which not only poses a burden for future generations but also incurs high treatment costs.

CE can benefit from reducing resource consumption, waste generation, energy consumption, and environmental protection while promoting economic development (Agamuthu & Mehran, 2019). The foundation of the CE began in the 1960s and 1970s with the concept of reducing natural resources and waste generation (Velenturf, 2021). In the 2000s, CE started to gain formal recognition, especially in Europe. In 2010, the Ellen MacArthur Foundation was introduced to enhance the CE transition and raise global awareness. Some countries, such as China and Germany, started implementing CE policies even before the concept was formally recognized. China approved the agenda as early as 2002, and Germany enacted a CE law in 1996 (Ogunmakinde, 2019). While the CE has been well-established in European countries, public awareness across the globe is still limited.

2.1 Circular Economy Approach in Malaysia

Developed countries have been actively practicing CE in recent years. However, the implementation of the CE concept in developing countries is still insufficient and faces various obstacles. The adoption of CE practice in some countries has been influenced by the origin year of the theoretical and conceptual framework. Based on history, Winans et al. (2017) stated that the CE concept was established in Germany in the early 1990s to address issues related to the use of raw materials and natural resources in environmental policies. In China, the concept took a turn in 2002 once it was approved by the central government after initially being suggested and presented in 1998 by a scholar (Ogunmakinde, 2019). The CE concept was introduced decades before, followed by raising awareness, policy integration, and global momentum to implement the CE. Bilal et al. (2020) mentioned that developed countries like Japan and Germany have taken the CE initiative. However, according to the National Development and Reform Commission (NDRC) report for 2014, developing countries are lagging. Malaysia, for example, has yet to implement the CE, which raises awareness of the environmental impact on sustainability practices.

Malaysia is one of the developing countries that aims to implement CE as part of its efforts to achieve sustainability. This has been part of the twelfth Malaysian Plan 2021-2025 to reduce environmental impact through CE. However, CE is still a relatively new concept in Malaysia and other developing countries. According to Isa et al (2021), a staggering 90% of solid waste is not properly managed in developing countries. This has caused many developing countries to take the initiative on the CE approach due to the increasing number of waste issues. However, the CE development process is still limited in Malaysia due to a lack of understanding and awareness among stakeholders (Esa et al., 2017). Currently, Malaysia primarily focuses on the waste management phase rather than the complete CE cycle.

Malaysia has established green-related policies as strategies to solve sustainability issues, including the National Biomass Strategy, the Renewable Energy Transition Roadmap (RETR 2020), the Malaysia Roadmap toward Zero Single-use Plastics 2018–2030, and the Sustainable

Development Financing Fund. In addition, acts such as the Environmental Quality Act 1974, the Solid Waste and Public Cleansing Management Act 2007, and Regulation 7 in the Environmental Quality Regulation 2005 have also been established to protect the environment (Agamuthu & Mehran, 2019). These acts and strategies have been developed to protect the environment, but we still lack policies, guidelines, and frameworks specifically focused on CE (Ting et al., 2023). Herrador & Van (2024) find that Malaysia is at a medium level of CE advancement compared to other ASEAN countries. Circularity approaches need extensive initiatives from both the government and stakeholders to collaborate and enhance the practice in Malaysia.

The remanufacturing process is one of the important phases in CE that allows the material to be recycled at the end-of-life usage. Matsumoto et al. (2021) found that Malaysia is one of the major remanufacturing companies in ASEAN. Despite that, researchers point out that implementing the CE business model within the industry is challenging for most stakeholders (Tirado et al., 2022; Cimen, 2021). This is primarily due to uncertain costs associated with developing a new business model, including the cost of virgin material, inadequate market mechanisms, supply and demand for circular material, high upfront investment costs, difficult costing, additional design costs, and an unclear economic financial case (AlJaber et al., 2023). To address these issues, a top-down and bottom-up approach is required to enable successful CE implementation. Unfortunately, Malaysia currently lacks sufficient top-down and bottom-up approaches for CE practices to be implement widely (Agamuthu & Mehran, 2019). Both approaches are crucial for facilitating collaboration between the government and stakeholders to enhance CE implementation.

2.2 Circular Economy in Construction Sector

The construction industry alone has caused depletion in natural resources and creates a large quantity of waste, which increases the problem of environmental degradation, economic development, and harm to society. The total waste generated due to construction industries contributes approximately 30% in Malaysia, while the average waste for construction and demolition (C&D) worldwide contributes about 30 to 40% (Islam et al., 2024; Esa et al., 2021). For that reason, the level of awareness of CE in the construction industry is getting attention worldwide to solve sustainable issues. Agamuthu & Mehran (2019) stated that the Malaysian Construction Industry Development Board (CIDB) has taken the initiative to achieve 20% recycled construction and demolition waste by the year 2020 from the initial baseline of 2016.

According to a study conducted by Esa et al. (2021), contractors have a high level of awareness of CE and familiar with its concept and knowledge. They also recognize the benefits of CE in terms of protecting the environment and promoting sustainability in the future. However, their understanding of CE is limited to waste management rather than considering the full life cycle of CE, which includes design, production, construction, consumption, and waste management. Therefore, it can be argued that contractors are not fully aware of the concept of CE and its implications for environmental degradation. Myeda et al. (2022) found that construction practitioners in Malaysia are least concerned about the environmental impact of construction waste management, but rather worry about the high cost of waste management. Furthermore, the level of awareness and understanding of the CE concept is still low within the industry (Bilal et al., 2020; Munaro et al., 2023; Schraven et al., 2019; Kirchherr et al., 2018).

Cost is a prominent factor considered by developers and contractors when getting involved with green building practices. As supported by Hwang et al. (2017), high premium cost is one of the reasons for the slow development of green buildings. The additional design and construction costs related to specific green components are defined as premium cost (Houghton et al., 2009). According to Russ et al. (2018), premium cost is described as the additional costs in relation to sustainable building elements, that can be divided into hard costs and soft costs. The hard costs refer to the physical components of the construction projects, which include materials, labour, equipment, and overhead costs charged by the contractor or developer. Soft costs encompass non-physical aspects such as fees for green building consultants, green certification, commissioning, marketing, and taxes (Zainul et al., 2016; Hu & Skibniewski, 2021). Hence, it is important to address the high premium cost of green buildings to ensure that sustainability in construction can be achieved. This study is therefore aims to bridge the gap between circular economy (CE) principles and the premium cost variables that currently hinder the procurement of GBM.

3. Methodology

The study primarily aims for identifying Circular Economy (CE) criteria focusing on Green Building Materials (GBM) in construction and built environment sectors, by using qualitative approach via integrative review techniques. The review emphasized on published articles and literature sources as the main instrument. Articles or literature sources were searched through databases from Google Scholar and Web of Science using Boolean string “Circular Economy” AND “Model” AND Built environment OR “Construction”, with the publication ranging from year 2016 to 2025. This range ensure a good pattern of CE evolvement in ten years and ensures updated data for relevancy. The inclusion criteria and exclusions are as follows:

a) Inclusion criteria:
- articles on CE focussing to construction or built environment only.
- CE model and frameworks addressed in articles or developed as blueprint or policies by relevant organization including the World Green Building Council (WGBC), UK Green Building Council (UKGBC), Dutch Green Building Council (DGBC), ARUP, and the European Union (EU)

b) exclusion criteria:
- articles or literature sources on CE that is not related to construction or built environment sectors.

The study has finalised 23 articles for final synthesis of review findings comprise of five (5) journal articles, five (5) organisational reports, as shown in Table 1.

Table 1: Literature sources as final qualitative review and synthesis

Item	Article Title	Journal/Source Details	Author(s)
1	The Circular Economy in the Built Environment	ARUP Report	ARUP (2016)
2	A framework for circular buildings. Dutch Green Building Society (DGBC)	Dutch Green Building Society (DGBC)	Kubbinga et al. (2018)
3	Circular economy strategies in eight historic port cities: Criteria and indicators towards a circular city assessment framework	Sustainability (MDPI)	Gravagnuolo et al. (2019)
4	Circular economy guidance for construction clients: How to practically apply circular economy principles at the project brief stage	UK Green Building Council (UKGBC)	UKGBC (2019)
5	Application of circular economy principles in buildings: A systematic review.	Journal of Building Engineering	Akhimien et al., 2020

6	Integrated model and index for circular economy in the built environment in the indian context	Construction Economics and Building	Smitha & Thomas (2021)
7	Developing Regenerate: A circular economy engagement tool for the assessment of new and existing buildings	Journal of Industrial Ecology	Gillott et al. (2023)
8	The circular built environment playbook	World Green Building Council (WGBC) Report	WGBC (2023)
9	Study on measuring the application of circular approaches in the construction industry ecosystem	European Innovation Council and SMEs Executive Agency (EISMEA) Report	Brincat et al. (2023)
10	Design Frameworks for Circular Buildings: Circular Principles, Building Lifecycle Phases and Design Strategies	Springer Tracts in Civil Engineering	Marchesi & Taveres (2025)

The review analysis and discussion from these literature sources are delineated to two main aspects:

i) CE Criteria and Sub-Criteria in construction and built environment sector.
ii) CE Phases, GBM Criteria and its indicators

4. Analysis of Findings and Discussions

4.1 Analysis of CE Criteria and Sub-Criteria in construction and built environment sector

The review analysis from the ten (10) sources found that the criteria of CE are basically focussing to the life-cycle of materials production and consumption, until it reach to it ends of life. Table 2 extracted the criteria of CE from the ten sources, and narrow down to its sub-criteria under each criterion. This helps to understand the context of CE towards the construction and built environment sectors.

Table 2: Extract of CE Criteria and Sub-Criteria in construction and built environment sector

Author's	CE in Construction and Built Environment Sector	
	Criteria	Sub-Criteria
Arup, 2016	Design	Remodelling, expansion, disassembly, passive design
	Sourcing	Material extraction, modularity and adaptability, construct for flexible, durable, reused and reusable parts.
	Construction	Construction techniques and assembly process, prefabrication and off-site manufacturing, design for reduce material use
	Operation	Minimise environmental impacts, lease components, maintenance
	Renewal	Adaptation and flexibility, easy access to building services, easy for renovation, policies and industry standards on interchangeable component
	Disassembly	BIM application model on dismantling, reverse logistics
	Repurpose	Reuse and recycling, upcycling possibilities
Kubbinga et al., 2018	Optimal material use	Reduce number of materials used, design for flexibility, design for resilience, design for reassembly
	Reutilisation of products	Maximise number of reused materials, maximise number of reused components, maximise number of reused elements, material for future use
	Circular materials	Maximise use of renewable materials, minimise use of scarce/ critical materials, reduce social and environmental impacts on materials

	Knowledge and development and sharing	Availability or accessibility of material information
Gravagnuolo et al., 2019	Raw material extraction & transport	Circular design, circular business and models
	Production process	Waste reduction, renewable energy and retrofitting
	Use and operation of building	Greenhouse gas emissions avoided, water consumption avoided and energy efficiency
	End of life	Reuse of old buildings and redevelopment of degraded areas
UK Green Building Council (UKGBC), 2019	Reuse	Reuse the existing asset, recover materials and products on site or from another site, share materials or products for onward reuse
	Design buildings for optimisation	Design for longevity, design for flexibility, design for adaptability, design for assembly, disassembly and reversibility
	Standardisation or modularisation	Reduction in construction waste, easier to reuse, disassembly features
	Servitisation and leasing	Efficient maintenance, maximum equipment lifespan, data recorded and monitored, minimise waste
	Design and construct responsibly	Use low impact new materials, use recycled content or secondary material, design out waste reduce construction impacts.
Akhimien et al., 2020	Product manufacture	Design for disassembly, design for recycling, material selection
	Construction	Building construction method
	Operation	Operation and optimization, repair, upgrades, component exchange, building durability and performance
	End of Life	Restore, reuse, recycle
Smitha & Thomas, 2021	Design phase	Design for adaptability, design for disassembly, design for deconstruction, design for reuse, design for manufacture and assembly and material passport
	Material manufacture phase	Waste as raw material, recycled content, cleaner production, pollution prevention, avoid toxic content, renewable energy use
	Construction phase	Refuse, reuse, rethink, reduce, building in layers, zero waste, optimisation and lean principles
	Operation phase	Reuse, repair, refurbish, remanufacture, renewable-energy use
	End of Life phase	Repurpose, adapt for change and disassemble
	Demolition	Deconstruction, recover and recycle
Gillott et al., 2023	Design phase	Design for adaptability, design for deconstruction, circular material selection, resource efficiency.
World Green Building Council (WGBC), 2023	Manufacturing	Material selection using bio-based, renewable materials, reduce raw material extraction. Manufacture provides material passports, product assemblies and fabricated elements, business models, take back system.
	Design	Flexibility, adaptability, disassembly and continuous lifecycles, passive design, renewable energy and water harvesting
	Construction	Standard and modular elements, construction techniques
	Operation	Technology in operational
	Retrofit	Reuse is prioritised over demolition and disassembly and deconstruction part of building practices
	Deconstruction	Disassembly and deconstruction, continuously reused
	Reuse and Recycling	Upcycling opportunities
Brincat et al., 2023. (European Comission)	Concept	Reused or recycled content, average age at demolition
	Procurement	Conduct LCA for comparison during the concept stage. End of life consideration

	Design	Design for disassembly or deconstruction, Minimal content on reused and recycled in new buildings/ infrastructure
	Manufacture	Manufacturing and remanufacturing products Involved in reused, recycled and secondary content input
	Demolition of existing building	Hazardous waste generated at demolition, Prediction on the age of the building
	Construction	Wastage rate at installation, Construction waste generated on and off site
	Handover	Effective utilisation of building or asset intensiveness of use Predicted service life of buildings/infrastructure portfolio
	Refurbishment	Construction related waste generated through refurbishment cycles Refurbishment/ transformation rate of buildings/infrastructure portfolio
	End of life	Residual value per unit product/material at end of life.
Marchesi & Taveres, 2025	Strategic stage (concept and procurement),	Concept and procurement
	Design	Design for longevity, design for flexibility, design for adaptability, design for recycling, design for deconstruction, design for disassembly, design for recoverability, prolong the material lifetime
	Manufacturing	Material extraction and supply, material transportation to manufacturing, manufacturing and fabrication, material processing, energy, waste and water consume in factory
	Demolition and construction	Logistics transportation to site, construction installation process,
	Use and refurbishment	Maintenance, repair, replacement, refurbishment, renovation, energy and water consumption use
	End of life	Deconstruction, demolition, reverse logistic, waste processing, reuse, recovery, recycling, disposal.

4.2 Analysis of CE Phases Circular Economy (CE) Phases, GBM Criteria and its indicators

The review analysis found that there are five (5) phases of circular economy: i) design, ii) production, iii) construction, iv) consumption, and v) waste management, as summarised in Table 3. Each phase plays a critical role in enabling circularity within a closed-loop system. The analysis of models and frameworks from ten (10) sources, shows that CE criteria are integral to GBM across all stages. Among these, the design phase is particularly significant, as it establishes the foundation for efficient material flow throughout the subsequent phases. CE principles at this stage prioritize resource efficiency, waste reduction, and the selection of materials that can be recycled or reused. Therefore, strategies like design for deconstruction and reuse, along with design for flexibility and adaptability, are fundamental because they significantly improve opportunities for material recovery, reuse, and long-term recyclability.

Table 3: Summary of Circular Economy (CE) Phases, GBM Criteria and its indicators

CE Phases	GBM Criteria in the CE Phase	Indicators	Author's
Design	Flexible & Adaptive Design	Remodelling, expansion, adaptability, flexibility, passive design	(Arup, 2016; UKGBC, 2019; WGBC, 2023)
	Design for Deconstruction & Reuse	Design for deconstruction, disassembly, assembly, reassembly	(Smitha & Thomas, 2021; Gillott et al., 2023)
	Material Optimization	Reduce number of materials, modularity, resource efficiency	(Kubbinga et al., 2018; WGBC, 2023)
	Design for Longevity & Durability	Design for longevity, resilience, recoverability	(Marchesi & Taveres, 2025)

	Digital Tools for Circularity	BIM for dismantling, material passports	(Arup, 2016; WGBC, 2023)
Production	Material Selection & Sourcing	Use bio-based, renewable, low-impact, or secondary materials	(WGBC, 2023; Brincat et al., 2023)
	Resource Efficiency	Reduce material extraction, minimise waste, cleaner production	(Kubbinga et al., 2018; Smitha & Thomas, 2021)
	Circularity Assessment Tool	LCA for material selection and environmental impact assessment	(Brincat et al., 2023)
	Circular Production Processes	Remanufacturing, fabrication efficiency, energy and water reduction in production	(Marchesi & Taveres, 2025)
	Distribution	Environmental impact and carbon footprints	Marchesi & Taveres, 2025
Construction	Modular & Prefabricated Construction	Prefabrication, off-site manufacturing, standardisation, modular elements	(Arup, 2016; WGBC, 2023)
	Minimizing Construction Waste	Lean construction, material optimization, zero waste, reuse of site materials	(Smitha & Thomas, 2021; UKGBC, 2019)
	Circular Construction Techniques	Circular construction techniques, low-impact assembly, efficient logistics	(Marchesi & Taveres, 2025)
	Contract and procurement	Concept and procurement	Marchesi & Taveres, 2025
	Resource Recovery	Recovery of materials/products on-site or from another site	(UKGBC, 2019)
Consumption (Use & Operation)	Efficient Building Use & Performance	Reduce environmental impact, operational efficiency, maintenance strategies	(Arup, 2016; Gravagnuolo et al., 2019)
	Leasing & Servitisation	Lease components, maximize equipment lifespan, monitor data	(UKGBC, 2019)
	Technology Integration for Circularity	Smart technology, energy efficiency, water harvesting	(WGBC, 2023)
	Retrofitting & Renovation	Adaptive reuse, refurbishments to prolong building life	(Arup, 2016; Gravagnuolo et al., 2019)
Waste Management (End-of-Life & Circularity)	Disassembly and Deconstruction	Design for easy dismantling, BIM for disassembly,	(Arup, 2016; WGBC, 2023)
	Material Recovery, Reuse & Recycling	Upcycling, reuse of old buildings, modular repurposing, Maximise reused/recycled components, recovery of valuable materials	(UKGBC, 2019; WBGC, 2023) (Kubbinga et al., 2018; Brincat et al., 2023)
	End-of-Life Residual Value	Evaluate building/material value at demolition, waste processing, and disposal impact	(Brincat et al., 2023)
	Reverse Logistics	logistics for reuse and recycle	Arup, 2016; Marchesi & Taveres, 2025

4.3 Discussion of Findings

Based on the findings above, the discussions on CE criteria towards GBM in construction and built environment sectors are entailed as follows:

4.3.1 Design Phase

The design phase is the most crucial in the early stages of CE in the built environment. This phase determines material efficiency, cost optimization, and environmental impact throughout the building lifecycle. Based on Table 2, design phase criteria for CE implementation include design for flexibility, adaptability, design for deconstruction, design for reuse, longevity, durability, material optimization, and digital tools for circularity. Additionally, modular construction and prefabrication are the enablers of circular materials in implementing CE (Ho et al., 2024; Jayawardana et al., 2023). This method enables design for deconstruction, disassembly, and reassembly, supporting the CE principles.

The manufacturing designer's role is crucial in producing circular building materials (Quashie et al., 2024). Designers need to be equipped with knowledge of CE principles and practices in CE frameworks, understanding their roles in circular construction for sustainable objectives and CBMs (Quashie et al., 2024). The design process requires technology application, such as Building Information Modelling (BIM), to create effective designs. Won and Cheng (2017) found that digital technology usage in software solutions such as BIM provides a potential solution for design errors, limits unexpected variations, reduces costs, and leads to waste reduction of 4.3% to 15.2% during construction. The utilization of technological advancements in producing circular products helps designers create effective designs throughout the CE cycle.

4.3.2 Production Phase

The manufacturing phase closely followed the initial plan outlined during the design phase, with a strong emphasize on producing circular materials in alignment with circular design principles. As shown in Table 2, several key criteria must be fulfilled during this stage, including material selection and sourcing, resource efficiency, the use of circularity assessment tools, circular production processes, and sustainable distribution. Material sourcing should prioritize the use of recycled materials and responsible extraction and processing of raw materials to support resource conservation (Amarasinghe et al., 2024; UKGBC, 2019).

Unlike linear manufacturing, which often prioritizes profit over environmental considerations, circular manufacturing emphasizes sustainable practices that reduce environmental impact. This can be achieved through the use of advanced technologies and machinery that lower carbon emissions and enhance energy efficiency (Iwuanyanwu et al., 2024). Additionally, distribution and logistics play a critical role in supporting sustainability efforts. Efficient transportation systems that minimize travel distances are essential for maintaining CE principles (Shaari et al., 2021). Collaboration among stakeholders, including industry leaders and government bodies, is vital to overcoming logistical challenges and successfully implementing sustainable circular construction hubs and cities.

4.3.3 Construction Phase

The construction process consists of several key stages, ranging from initial design to final building completion. At each stage, a comprehensive assessment of criteria is necessary to effectively support CE practices. As outlined in Table 2, the critical criteria during construction include minimizing waste, adopting circular construction techniques, enabling resource recovery, and implementing sustainable procurement and contracting practices. Circular building design emphasizes not only efficient construction but also the potential for future deconstruction. This requires active involvement from both manufacturing and construction designers in selecting appropriate techniques and materials. The roles of architects and engineers are particularly vital in ensuring buildings are planned and constructed in alignment with CE principles (Quashie et al., 2024). Their expertise is crucial not only in selecting circular materials but also in designing for ease of assembly and disassembly. Therefore, their knowledge, experience, and awareness are fundamental to successful CE implementation.

In addition to design considerations, procurement and contracting processes must be adapted to support circular goals (Kwasafo et al., 2024). This includes incorporating guidelines such as material passports and leasing agreements into construction contracts. Circular procurement strategies have already been implemented in cities like Helsinki, Zurich, Rotterdam, and Amsterdam, where procurement criteria specifically promote the use of circular construction materials (Big Buyers Initiative Report, 2020). Furthermore, leasing and servitization models have emerged as effective strategies to support closed loops and increase resource productivity (Cruz Rios et al., 2019). Ultimately, contracts serve as the most enforceable tools to guarantee the delivery of circular outcomes throughout the construction process.

4.3.4 Consumption Phase

The consumption phase includes terms such as use phase, product as a service, and building operation and optimization. This phase involves retrofitting and renovation, technology integration for circularity, leasing and servitization, and efficient building use and performance (Table 2). The operation period must align with CE principles by prolonging the lifespan of building materials and aiming for recycling in renovation and refurbishment processes (WGBC, 2023). During this phase, the building must be well maintained to ensure the safety and health of occupants. CE introduces a leasing method for building components and materials to reduce waste by allowing manufacturers to implement a take-back system. The leasing method holds manufacturers responsible for maintenance, repair, replacement, upgrades, and remanufacture (Intlekofer et al., 2009). Demolition is usually a last resort in CE due to its higher environmental impact (Greater London Authority, 2019). Therefore, it is recommended to consider renovation or refurbishment as alternatives to demolition.

4.3.5 Waste Management Phase

Waste management at the end of a building's lifecycle is particularly challenging in the absence of proper planning. This lack of planning often results in missed opportunities for material recovery, higher costs, increased waste production, and greater environmental impacts (Saarani et al., 2022). It hampers the ability to meet sustainability pillars, leading to negative social, economic, and environmental consequences. The study indicates that demolition and deconstruction costs are high without prior preparation. Insufficient design for disassembly complicates component separation, making it more labor-intensive and reducing opportunities for recycling and reuse, which in turn raises waste management and disposal costs (Balogun et al., 2023). Therefore, initial planning is crucial for efficient waste management. According to Table 2, the waste management criteria include disassembly and deconstruction, material recovery, reuse and recycling, end-of-life residual value, and reverse logistics. When a building reaches the end of its lifespan, initial design for deconstruction, design for disassembly, and design for waste minimization take place. The implementation of Extended Producer Responsibility (EPR), along with innovative business models, revised frameworks, and enacted policies, drives progress toward achieving a CE. This approach reduces waste production by allowing materials to be recycled back to the original manufacturer.

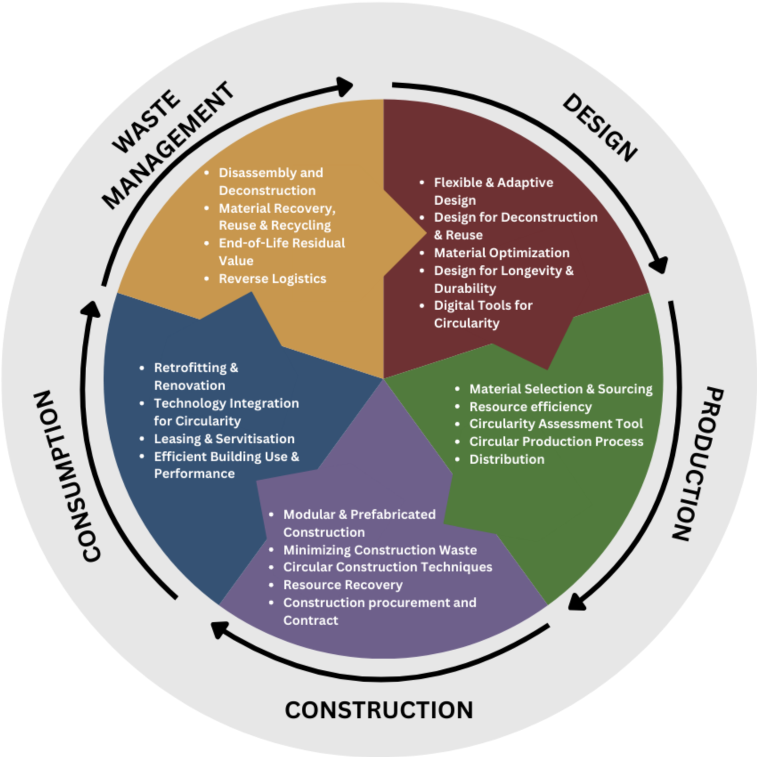

Figure 1: Conceptual Criteria of CE to Green Building Materials in Construction and Built Environment Sector

The adoption of CE has gained traction over the years, while the GBM market is still expanding. The CE and GBM have overlapping criteria in minimizing environmental impact, carbon emission reduction, and the performance and composition of materials (Ekwuno, 2023; Kumar, 2020). The CE has comprehensively covered the life cycle of the materials compared to GBM. In the future, manufacturing companies, including stakeholders, have to practice and consider the full life cycle of the GBM rather than focusing on only a few phases. As the CE covers a broader approach than GBM, both methods aim to reduce environmental impacts, which need integration for a more sustainable future. Despite of having separate guiding principles, CE and GBM's respective focusses must be integrated for comprehensive sustainable implementation.

Figure 1 shows the criteria of CE focusing on GBM in a flow diagram starting from design, production, construction, consumption, and lastly waste management before it turns into a closed-loop system where the recycled materials re-enter the design phase. Construction is an additional main component in CE compared to other sectors to cover the comprehensive flow in the built environment, since the complex nature of the project and the long building lifespan. This model aims to emphasize the importance of criteria to fulfill CE principles during implementation. The CE criteria involve various stakeholders in ensuring that the GBM can be produced, constructed, utilized, and managed throughout the cycle. Incorporating CE criteria helps achieve a holistic approach across the entire lifecycle while enhancing sustainable green practices

5. Conclusion

In conclusion, each CE lifecycle phase is interconnected to support the closed-loop system. The five main phases of CE include design, production, construction, consumption, and waste management. Design is a critical phase in determining the other cycle processes that fulfill CE criteria in other stages. The production phase is conducted based on design considerations to fulfill CE principles. Construction is an additional phase specifically in the built environment due to the complex nature of the project, requiring collaboration among stakeholders. The absence of construction phases could impact on non-enforceable binding agreements between stakeholders, resulting in a failure to comply with CE criteria. Additionally, leasing and servitization are important criteria during consumption to reduce waste by allowing product repair, maintenance, and upgrades. Finally, waste management is an important aspect of CE, allowing materials to be recycled and minimizing waste in landfills. These five phases of the CE cycle could have implications for procurement costs when integrated with GBM. the relationship strength between the criteria of CE and GBM procurement is suggested as a future research.

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