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APPLICATION OF CIRCULAR ECONOMY PRINCIPLES INTO TROPICAL BUILDING DESIGNS: A LITERATURE REVIEW

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ABSTRACT

The increasing intensity of global population growth has heightened the demand for buildings in tropical zones. Consequently, meeting this burgeoning demand poses a significant challenge to the construction sector, compounded by resource scarcity. As a result, there is mounting pressure on construction building designs to transition towards more sustainable practices. In response, Circular Economy (CE) principles are being considered for incorporation into tropical building designs to enhance sustainability. Thus, this research endeavours to assess the feasibility of integrating CE principles into building designs as a means of advancing sustainability. Adopting content analysis collected data were analysed. The study revealed that tropical building designs offer a sustainable method well-suited to address the growing demand for buildings. Furthermore, it was identified ten enabling factors, thirty-five barriers, and twenty-four strategies in relation to the application of CE principles to building designs. It was revealed that the findings of the study will drive the convergence of CE principles with tropical building designs. Consequently, this research contributes to the theory by bridging the gap in utilising CE principles within building designs to enhance sustainability in the construction industry.

Keywords: *Barriers; Circular Economy; Enablers; Strategies; Tropical Building Design.*

1. INTRODUCTION

As a cornerstone of modern development (Ferdous et al., 2019), the construction industry is attributed between 35% to 40% of global energy consumption and energy-related carbon emissions (Chen et al., 2023). Further, the authors highlighted that the production of building materials and products alone accounts for 10% of energy-related carbon emissions which are reflecting the industry's reliance on resource-intensive processes. These figures underscore the urgent need for transformative solutions to lessen the

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negative environmental impact of construction activities (Vita et al., 2019). Moreover, the rapid growth of the world population has brought the construction sector to a more difficult phase (Avtar et al., 2019). With an estimated 8.0 billion people in 2022 and projected long-range will lie between 9.4 to 10.0 billion people by 2050, the demand for construction is set to intensify (Gu et al., 2021). The aforementioned surge will undoubtedly amplify carbon emissions and strain natural resources (Shang et al., 2022). Further, Eberhardt et al. (2020) predicted that buildings will become major temporary material stock because of the greater amount of inefficient material usage in the building sector.

According to Verma et al. (2023), there are currently 3.3 billion people living in tropical zones, and by 2050, it is predicted that this number will rise to 6.3 billion. The climate in tropical regions is hot and muggy (Al-Obaidi et al., 2014). The unique climatic context of tropical regions demands specialised design strategies that take high temperatures, humidity, and extreme weather patterns into account (Emmanuel, 2012). Hence, along with population growth, urbanisation, and material depletion, Iyer-Raniga (2019) emphasised that buildings in tropical zones need to consider regenerating energy where possible and it may include the use of energy-efficient designs.

Over the past decade, the concept of Circular Economy (CE) has gained attention due to growing environmental concerns and risks associated with resource shortages (Guerra & Leite, 2021). CE is a regenerative system that minimises resource intake and waste, emissions, and energy leaks by slowing down, closing, and tightening the cycles of materials and energy (Geissdoerfer et al., 2017). Accordingly, CE principles offer a roadmap for resource optimisation, waste reduction, and environmentally responsible construction methods, aligning with the industry's need for innovative and sustainable solutions (Guerra & Leite, 2021). Kara et al. (2022) declared that by embracing circularity, the construction field can transition towards closed-loop systems, minimising waste and promoting a more sustainable life cycle for buildings.

In the built environment, implementation of CE can mainly deal with building design and adopting CE principles in building designs can minimise resource consumption and waste production, prolong the useful life of resources to a great extent, and bring resources back into use (Rahla et al., 2021). Akhimien et al. (2021) declared that integrating CE principles into building designs in tropical regions can address these challenges by promoting sustainable material choices, energy-efficient building techniques, and adaptive strategies. In addition, the authors highlighted that the construction industry can navigate the complexities of tropical climates while contributing to more sustainable and resilient built environments by synergising circular practices with building designs.

However, the CE is relatively new for architecture, engineering, and construction (Charef et al., 2021). Although CE building design and construction strategies are increasingly being developed and implemented, the process has not yet reached a consensus or defined direction in the building sector (Eberhardt et al., 2020). Ghufran et al. (2022) have proposed a paradigm shift towards CE-based sustainability. Accordingly, Ababio and Lu (2022), Guerra and Leite (2021), Oluleye et al. (2023), have extensively discussed and studied on enablers and barriers of applying CE in the construction industry to enhance the sustainability of the buildings. On the other hand, Bulbaai and Halman (2021), Kerdan (2016), and Xianlin (2018) have primarily investigated on energy-efficient building design strategies and approaches in tropical regions to meet sustainability. Eberhardt et al., (2020) assessed which construction and design approaches are connected to the notion of CE for new buildings. Accordingly, numerous previous research focused on application of CE principles into general building designs. Nevertheless, there is a dearth of literature on application of CE principles into building designs in the tropical region to ameliorate sustainability through addressing the challenges of global population growth, material depletion and environmental impact. Hence, this research attempted to develop a conceptual framework to explore the adaptability of CE principles into building designs in tropical regions to improve sustainability through literature review. The following objectives were achieved:

1. to investigate the enablers of implementing CE principles into building designs,
2. to identify the barriers of implementing CE principles into building designs,
3. to propose suitable strategies to integrate CE principles with building designs.

Therefore, this study was undertaken to explore the potential for further study on the adaptability of CE principles into topical building designs to improve sustainability .

2. RESEARCH METHODOLOGY

Research methodology is a systematic way to solve a problem (Tan, 2022). An orderly, clear, and repeatable research process for the examination of the body of existing literature is called a literature review (Mio et al., 2020). A literature serves as the foundation for developing new conceptual frameworks or theories (Snyder, 2019). Journal articles, books, and conference proceedings with properly cited references are regarded as high-quality sources, therefore the identified literature must be of a high calibre and reliable (Xiao & Watson, 2019). Accordingly, for this study, journal papers, conference proceedings and books were referred to ensure the quality and reliability of the findings.

This study was conducted by reviewing the existing literature focusing on the integration of the concepts of Circular Economy (CE), building design, and sustainability in order to pave the road map for applying CE principles to tropical building designs. Figure 1 delineates the process adopted in conducting the literature review.

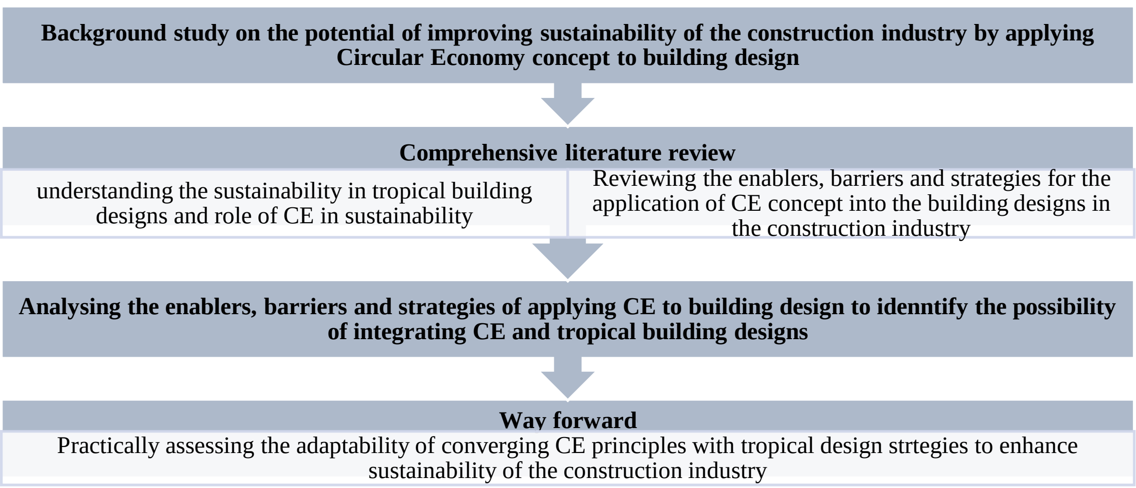

Figure 1: Research process

As shown in Figure 1, a background study was conducted followed by a literature study to understand the necessity of applying CE principles to tropical building designs to ameliorate the sustainability in the built environment. Subsequently, a comprehensive literature review was conducted on the research area by analysing and synthesising a group of related literature in developing new theories (Xiao & Watson, 2019). Content analysis is a flexible method to analyse text data (Hsieh & Shannon, 2005). Hence, adopting content analysis, gathered data through literature study was analysed. Subsequently, a conceptual framework was developed using the literature findings, as this framework will provide direction for further research on the investigated topic (Martín et al., 2019). Moreover, the aforementioned framework will guide researchers in investigating the adaptability of CE principles to tropical building designs, going beyond general building designs.

3. RESEARCH FINDINGS

3.1 SUSTAINABILITY IN DESIGN

The building industry notably impacts energy consumption and the environment through resource use and waste generation (Eberhardt et al., 2019). In order to address these obstacles, the building sector is prioritising sustainable designs, which aim to mitigate environmental impacts, promote economic viability and prioritise occupant well-being (Mirabella et al., 2018). Sustainable designs incorporate principles such as optimising insulation, using high-performance windows, and incorporating renewable energy sources like solar panels to minimise energy consumption and carbon footprint (Eberhardt et al., 2019). Eco-friendly materials that are durable and responsibly sourced reduce waste and resource depletion. Additionally, sustainable buildings enhance occupant well-being by maximising natural light, providing adequate ventilation, and using non-toxic materials (Negi, 2021). This holistic approach considers the entire lifecycle of a building, from design and construction to operation and demolition, contributing to the resilience and sustainability of communities (Fithian et al., 2017).

3.1.1 Tropical Building Design as a Sustainable Building Design Approach

Tropical design is defined as a sustainable building design approach which embraces the unique climatic and environmental conditions of tropical regions to create buildings that are not only harmonious with their surroundings but also environmentally responsible (Agbete & Frank, 2020). The key to tropical design's sustainability lies in its ability to naturally regulate temperature and minimise energy consumption. Thus, tropical design as a sustainable approach takes full advantage of the tropical climate and the available resources to create eco-friendly, energy-efficient, and culturally sensitive architectural solutions (Yusuf, 2021). By harmonising with the environment, utilising natural ventilation, and incorporating indigenous materials, tropical design offers a compelling model for sustainable architecture that not only respects the local ecosystem but also responds to the challenges of climate change and resource conservation (Seddon et al., 2021). Despite growing pressure to shift towards more sustainable practices, the building construction sector in developing countries continues to rely on a non-sustainable, linear economic model (Castell-Rüdenhausen et al., 2021). The linear approach fails to facilitate material reuse and results in obsolete buildings at the end of their lifespan (Ghufran et al., 2022). Therefore, CE building designs have been increasingly developed and implemented (Eberhardt et al., 2020).

3.2 CIRCULAR ECONOMY AND BUILDING DESIGNS

Currently, building designs have extensively made negative impacts on the environment through immense resource consumption and greater waste generation (Utrilla et al., 2018). Furthermore, CE techniques are anticipated to yield economic benefits by raising net material savings, preventing pollution and safeguarding the environment. R imperatives of CE are used to explain the strategies of the CE concept, where 9R principles are the widely used R imperatives within the construction sector (Stoiljković et al., 2023). The “9Rs” principles consist of Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle and Recover construction waste, resources and products (Ruiz et al., 2020). In order to minimise the aforementioned unresolved issues in building designs, Suárez-Eiroa et al. (2019) emphasised the necessity of applying CE principles to building designs. Nevertheless, implementing CE strategies in building design is hindered by the ambiguity surrounding the concept (Rahla et al., 2021). Hence, it is crucial to assess the enablers of implementing CE into building designs and the strategies to overcome its obstacles and improve the enablers as well (Guerra & Leite, 2021).

3.2.1 Enablers of Implementing Circular Economy Principles into Building Designs

Despite the Circular Economy's apparent simplicity, applying circular thinking to buildings may prove challenging (Rahla et al., 2021). Then, it is possible to identify the CE enablers as the drivers propelling this shift in the direction of more sustainable development (Santolin et al., 2023). Table 1 summarises enablers of implementing CE principles into building designs.

Table 1: Enablers of implementing CE principles into building designs

Enablers	Authors										
	A	B	C	D	E	F	G	H	I	J	K
Green building design	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Advanced design software	✓					✓		✓	✓		
Renewable construction material	✓	✓		✓		✓		✓	✓	✓	✓
Recycled construction material	✓	✓		✓		✓	✓	✓	✓		✓
Resource efficient construction	✓	✓		✓		✓	✓			✓	
Excess material recycling (Designing out waste)	✓	✓	✓	✓				✓			✓
Energy efficient services	✓					✓	✓	✓		✓	✓
Building life extension	✓					✓	✓	✓	✓		
EOL material upcycling	✓	✓							✓	✓	✓
Foment greater maturity in quality	✓				✓		✓		✓		✓

[A] Barros et al. (2021); [B] Çetin et al. (2021); [C] Guerra & Leite (2021); [D] Antwi-Afari et al. (2022); [E] Anastasiades et al. (2021); [F] Rios et al. (2021); [G] AlJaber et al. (2023); [H] Hart et al. (2019); [I] Ababio & Lu (2022); [J] Zaman et al. (2023); [K] Oluleye et al. (2023)

As presented in Table 1, it was apparent that green building design, recycled construction materials and renewable construction materials are the most proposed enablers to encourage building designers to apply CE principles. CE is a cutting-edge approach that encourages green building design ideas within the construction sector (Rahla et al., 2021).

Moreover, applying CE principles to building design has the potential to mitigate adverse environmental effects and resource depletion by ensuring that materials are reused once the building reaches its end-of-life and by keeping resources in use (Rahla et al., 2021). On the other hand, for EOL material upcycling, there was limited literature as an enabler.

3.2.2 Barriers of Implementing Circular Economy Principles into Building Designs

Beyond the enablers of implementing CE principles into building designs, there is no review of the literature that encompasses a large range of sustainable designs in the current CE context (Charef et al., 2021). Gillott et al. (2023) also stated that the CE philosophies remain limited within the construction industry. As emphasised by Urbinati et al. (2021), despite the enormous potential and benefits of CE, application of the CE in the construction industry has been hampered by several barriers. Therefore, it is apparent that there is no exception in the case of applying CE principles to building designs. Accordingly, Table 2 indicates the potential barriers to implementing CE principles into building designs that were identified by previous studies.

Table 2: Barriers of implementing CE principles into building designs

Barriers of implementing CE principles into building designs	Authors												
	A	B	C	D	E	F	G	H	I	J	K	L	M
Economical													
1. New approach adoption cost	✓												
2. Initial cost for principle adoption	✓						✓			✓	✓	✓	✓
3. Additional cost for design phase	✓				✓						✓		
4. Lack of client demand							✓					✓	
5. Risk of client's readiness to pay the new concept	✓							✓			✓		
6. Underdeveloped market for salvaged components						✓					✓		
Sociological													
7. Resistance to change	✓									✓	✓		✓
8. Lack of trust	✓					✓							
9. Lack of concern and awareness	✓				✓	✓		✓	✓	✓	✓	✓	✓
10. Bad image of salvaged materials	✓					✓							
11. Ignorance of long-term benefits	✓					✓		✓			✓		✓
12. Impatience to get a return on investment quickly	✓					✓					✓		
Environmental													
13. Environmental benefits of reuse are not guaranteed						✓							
14. Not all materials can be environmentally effectively recycled						✓							
15. Use of virgin stock	✓												
16. Lack of incentives on environmental assessment methods											✓		✓
17. Emissions from transport	✓										✓		
Technical													
18. Construction method adoption	✓												

Barriers of implementing CE principles into building designs	Authors												
	A	B	C	D	E	F	G	H	I	J	K	L	M
19. Uncertain product composition	✓										✓	✓	
20. Lack of appropriate technology	✓										✓	✓	✓
21. Complexity of building design		✓				✓		✓					
Organisational													
22. Lack of staff	✓									✓			
23. Architect incompetence	✓									✓			
24. Lack of experienced, skilled workers	✓			✓					✓	✓	✓	✓	✓
25. Multiple stakeholders needed	✓				✓								✓
26. Lack of support from the top management team	✓			✓									
27. Complexity to implement new approaches	✓	✓											
28. Lack of certification and recertification	✓						✓						
29. Lack of recovered material standards	✓					✓						✓	
30. Lack of building standard guidance	✓										✓	✓	
Political													
31. Lack of policies and regulations	✓	✓	✓			✓	✓		✓	✓	✓	✓	✓
32. Regulation absurdity and failures	✓	✓				✓				✓			
33. Regulation complexity and strictness	✓												
34. Lack of specific constructability requirements	✓					✓							
35. Lack of fiscal incentives or support	✓			✓	✓		✓	✓	✓	✓	✓	✓	✓

[A] Charef et al. (2021); [B] Gillott et al. (2023); [C] Moscati et al. (2023); [D] Rahla et al. (2021); [E] Çimen (2021); [F] Rios et al. (2021); [G] Rizos et al. (2016); [H] Adams et al. (2017); [I] Shooshtarian et al. (2022); [J] Tambovceva & Titko (n.d.); [K] Osei-Tutu et al. (2022); [L] Springvloed (2021); [M] Kanters (2020)

As indicated in Table 2, there are six (6) main categories and subcategories of barriers to implementing CE principles into building designs. According to Charef et al. (2021) and Osei-Tutu et al. (2022), the barriers linked to the economy are mainly dealt with initial cost of principle adoption and the socioeconomic barriers are mainly related to people's behaviour and the seeking of profit first. Further, technical barriers are related to the construction materials and others to the building scale such as construction methods, project phase adoption and building lifespan. Failures of enacted rules and regulations, lack of experience and knowledge of the staff are identified as political barriers and organisational barriers respectively for implementing CE principles into building designs (Rios et al., 2021). Osei-Tutu et al. (2022) stated that complexities in building design and lack of technological advancement have become obstacles to implementing CE concept. Considering all the above, lack of fiscal support or incentives, lack of awareness and lack of policies are the barriers for which the highest literature was found.

3.2.3 Strategies to Integrate Circular Economy Principles with Building Designs

In the path of the transition to a CE, it is required a range of specific strategies for the aforementioned barriers (Dokter et al., 2021). Table 3 indicates strategies of integrating CE principles into building designs that were identified by previous studies. Following the listed below strategies enables construction designers to adopt CE principles to building designs to ensure the sustainability of the building construction.

Table 3: Strategies of implementing CE principles into building designs

Strategies to integrate CE principles with building designs	Authors												
	A	B	C	D	E	F	G	H	I	J	K	L	M
1. Exercising leadership and educating stakeholders	✓	✓		✓	✓		✓	✓	✓	✓		✓	✓
2. Integrating CE in contractual requirements for design	✓						✓	✓					
3. Assigning CE consultants to assist design	✓						✓	✓			✓		
4. Creating databases for reusable components	✓					✓					✓		✓
5. Enforcing sustainable procurement aligned with CE	✓						✓						
6. Creating tax deductions for CE design strategies	✓						✓						
7. Establishing targets for salvaged components	✓					✓	✓			✓			✓
8. Establishing targets for reducing building embodied energy	✓								✓	✓		✓	
9. Increasing demolition taxes	✓					✓							
10. Promoting carbon taxes	✓					✓							✓
11. Incorporating CE in building codes	✓					✓				✓	✓		
12. Educating designers and building owners on life cycle cost	✓			✓	✓								✓
13. Integrating client demands into architecture education	✓			✓	✓								✓
14. Integrating CE into university curricula in all sectors	✓					✓		✓					✓
15. Raising public awareness of CE through public campaigns	✓		✓										
16. Incorporating CE training into the professional license renovation requirements for architects, engineers, and contractors	✓						✓		✓	✓		✓	
17. Raising awareness of construction stakeholders about successful examples of CBMs in the sector	✓	✓	✓			✓	✓	✓			✓		
18. Allocating public funding to offer financial aid to people who want to engage in circular design and construction	✓	✓	✓		✓	✓			✓	✓	✓		✓
19. Offering subsidies, tax credits, and low-interest loans for	✓	✓	✓		✓	✓			✓	✓	✓		✓

Strategies to integrate CE principles with building designs	Authors												
	A	B	C	D	E	F	G	H	I	J	K	L	M
companies that want to engage in CE practices													
20. Developing standards and improving current methodologies for environmental assessments of CE strategies	✓						✓			✓	✓		
21. Developing and enhancing technologies to assess the quality and safety of salvaged components	✓				✓		✓						✓
22. Increasing taxes on new construction and reducing taxes for building adaptive reuse	✓						✓	✓	✓		✓		
23. Creating national and regional CE action plans	✓						✓					✓	✓
24. Integrating CE strategies to ICT	✓				✓				✓	✓			✓

[A] Rios et al. (2021); [B] Rizos et al. (2016); [C] Adams et al. (2017); [D] Shooshtarian et al. (2022); [E] Springvloed (2021); [F] Eberhardt et al. (2020); [G] Hossain et al. (2020); [H] Dokter et al. (2021); [I] Foster (2020); [J] Utrilla et al. (2018); [K] Norouzi et al. (2021); [L] Leising et al. (2018); [M] Kalmykova et al. (2018)

As per Table 3, integrating CE principles into building designs requires multifaceted strategies. In this sense, the concept of CE can advocate building designs resulting in more sustainable, efficient, and adaptable structures for the future. Empowering leadership skills of the practitioners in building designs enables professional's awareness and keen to follow CE principles (Rios et al., 2021). Allocating public funds as financial support encourages designers to study and apply CE principles (Norouzi et al., 2021). In addition to that, the government could take the initiatives to introduce new taxes and loan rates for construction organisations to facilitate the implementation of CE in the design (Hossain et al., 2020).

3.3 THE POTENTIAL FOR FURTHER STUDY ON ADAPTABILITY OF CE PRINCIPLES INTO TOPICAL BUILDING DESIGNS TO IMPROVE SUSTAINABILITY

As established in Section 3.1.1, tropical building design is a sustainable approach. Additionally, it was revealed that by creating circularity within the industry, CE fosters sustainability. It clearly indicates the potential for further enhancing sustainability in the building sector by integrating CE principles into tropical building designs. Previous studies have shown a growing demand for buildings in tropical zones, making it crucial to incorporate circularity in these designs to address resource scarcity. However, previous research has primarily focused on the general application of CE principles to building designs, identifying 10 enablers, 35 barriers, and 24 strategies. Neither in-depth research has been conducted on the specific application of each R principle of the 9R principles to building designs. Therefore, to assess the feasibility of applying CE principles to tropical buildings, it is essential to investigate the enablers, barriers, and strategies for each R principle in the 9R framework within the tropical building design approach. This will provide valuable insights to building designers and stakeholders, enhancing the sustainability of the construction sector. Hence, the findings of the study could be adopted as a baseline for investigating the enablers, barriers, and strategies in applying each R principle of 9R CE principles to tropical building designs. Furthermore, by collecting empirical data, the extent to which the findings of this research study are applicable to the tropical building design context could be further evaluated. In addition to that, further investigation could be conducted to determine which of the 9R CE principles have the most impact on achieving sustainability when applied to tropical building designs.

3.4 CONCEPTUAL FRAMEWORK

One or more formal and empirical findings from the literature are included in a conceptual framework. It serves to illustrate the connections between these concepts and how the research study relates to them (Academic Guides: Theories and Frameworks: Introduction, n.d.). The conceptual framework answers questions of "Why is this research important?" and "How does it contribute new knowledge?" (Varpio et al., 2019).

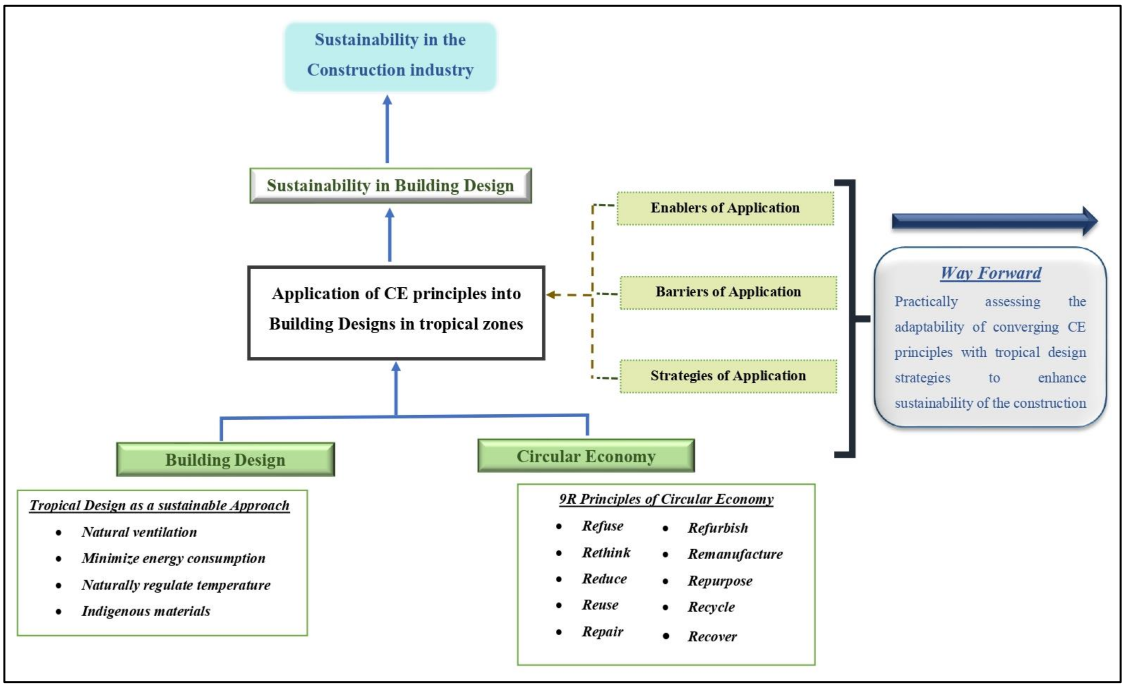

Figure 2: Conceptual framework

The conceptual framework illustrated in Figure 2 serves as a roadmap to address the identified literature gap. Sustainable strategies in tropical designs hold the potential to alleviate resource scarcity, while the 9R principles of CE steer the construction industry towards more sustainable practices. The application of CE principles in tropical building designs could accommodate the growing demand for buildings in tropical zones while enhancing sustainability practices within the construction industry. Hence, it could be further investigated the enablers, barriers, and strategies of integrating CE principles with tropical building design for each R principle of the 9R CE principles, based on the findings of this study.

4. CONCLUSIONS

Urbanisation, intensive growth of global population and material depletion have become greater concerns for the sustainability of the construction sector. Moreover, facilitating for growing population is a major difficulty faced by the building construction in tropical zones. Therefore, building design strategies should be advanced more through application of sustainable principles. Tropical designs were found as a method of sustainable building design solution and applying 9R CE principles to the tropical building designs would enhance the sustainability of the construction industry while facilitating the aforementioned surge in demand for buildings. Accordingly, it was investigated enablers, barriers and strategies for application of 9R principles to building designs. As a result, ten enablers were found, among which green buildings, renewable construction materials and recycled construction materials are the enablers for which the majority of literature was there. Moreover, under six subcategories of technological, economical, political, social, environmental and organisational, altogether 35 number of barriers were found. Subsequently, it was investigated strategies that could be adopted to manage and overcome the challenges. Establishing leadership skills, providing financial facilities, and rising awareness of the practitioners are mostly proposed strategies. It was concluded emphasising the cruciality of studying the enablers, barriers and strategies of applying CE principles to building designs for future researchers because based on the findings of this study forthcoming researchers could evaluate the integration of CE principles with tropical building designs to address the aforementioned issues. It is further recommended for building designers and architects to widen the application of CE principles into building designs and other construction practices to ensure circularity within the construction industry. Moreover, it is strongly recommended to conduct further research on the applicability of converging CE principles with energy-efficient building design strategies such as net zero energy building design strategies and tropical passive design strategies.

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