A systematic review of circular economy research in the construction industry.

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Transition towards Circular Economy Implementation in the Construction Industry: A Systematic Review

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Abstract

Purpose – While Circular Economy (CE) is fast becoming a political and economic agenda for global urban development, there are still substantial knowledge gaps in possible strategies to speed up such transition, especially in the construction industry. This study analyses literature surrounding circular economy to unpack current trends possible future research directions to foster CE implementation in the construction industry.

Design/methodology/approach- The study undertakes a systematic review of Circular economy literature published between 1990 and 2019. It adopts a five-stage procedure as a methodological approach for the review: formulation of the research question(s); locating and identifying relevant studies; selection and evaluation of studies; analysis or synthesis; and results reporting.

Findings – The findings on CE research in the construction industry show extensive focus on resource use and waste management. There are limited investigations in other areas of construction such as supply chain integration, building designs, policy, energy efficiency, land use, offsite manufacturing, whole life costing, and risk, cost reduction, cost management, health and safety management. The study findings provide evidence that current CE practice fails to incorporate other areas that would facilitate the network of true circular construction industry.

Originality/value – This research provides a comprehensive overview of research efforts on CE in the construction context, identifying areas of extensive and limited coverage over three decades. Besides, it identifies possible pathways for future research directions on CE implementation, towards the accelerated transition to a true circular construction industry for the benefit of funding bodies and researchers.

Keywords: Circular economy; construction industry; systematic review; waste management; resource reuse; sustainability

1. Introduction

Circular economy (CE), which is perceived to emerge from the field of industrial ecology has recently earned the attention of practitioners, including policymakers and scholars from different field of study and industry (Preston, 2012; Geissdoerfer *et al*., 2017). This can be linked to the fundamental need and desire for an alternative approach to the traditional linear model of growth or linear economy of take - make – dispose of materials (Lieder and Rashid, 2016; Schroeder *et al*., 2019). The concept has been accepted by businesses across different sectors around the world as a solution to promote sustainability (Preston, 2012; Lieder and Rashid, 2016; Ghisellini *et al*., 2018) and the construction industry is not an exception.

The construction industry is said to produce more waste than any other industrial sector (Rose and Stegemann, 2018). Despite the vast amount of waste from construction activities (Clark *et al*., 2006; Lieu *et al*., 2011; Bilal *et al*., 2016), and significant impacts of the construction industry on the environment, society and economy (Gencel *et al*., 2012) limited studies have been conducted on CE application within the construction industry (Lieder and Rashid, 2016). Studies (Tukker, 2015; Pan *et al*., 2015) suggested the need to explore strategies to convert and/ or recover the industry waste for recycling and reuse). This idea is consistent with Smol *et al*. (2015), views, who argued that the construction sector could benefit maximally from CE. Other studies clamouring for sustainability in the construction industry (Lemougna *et al*., 2011; Kylili and Fokaides, 2017; Lai *et al*., 2017; Ghisellini *et al*., 2018) have highlighted the importance of CE in this process. These studies suggest the need to explore the efficacy of CE in the construction industry and to understand the extent to which the principles of CE are applicable in the construction activities. This may necessitate the synthesis of the current knowledge in the literature, especially regarding different research focus/domains, on the implementation of CE in the construction industry. Therefore, exploring viable strategies for accelerating the construction industry's transition CE should fast become the centre of current and further investigations. One such strategy is to identify the extent of research coverage on CE implementation in the construction industry from existing literature. Hence, this study systematically analyses literature surrounding CE in the construction

industry to provide a clear understanding of the research efforts and possible pathways to foster CE implementation in the construction industry.

2. Literature review

2.1 Definition of circular economy (CE)

CE is positioned as an efficient method for resource transformation into valuable materials for other processes and products (Preston, 2012). Similarly, MacArthur (2013) referred to CE as a process aimed at maintaining products, materials and components for maximum value of time performance and utility, with the primary goal of eradicating waste. This thinking is consistent with Mitchell's (2015) assertion that CE emphasizes the efficient utilization of resources by extracting maximum value from materials and products beyond their normal useful life.

Furthermore, Kirchherr *et al*. (2017) defined CE as an approach to replacing the end-of-life concept with an economic system that fosters reuse, alternatively reducing, recovering, and recycling of materials in distribution/ production and consumption processes. Likewise, Geissdoerfer *et al*. (2017) describe CE as a regenerative process, which maximizes the utilization of raw materials, and reduces emissions and waste generation through repair, remanufacture, reuse, recycling and refurbishing. Even though CE lacks a generally acceptable definition among scholars and practitioners, there is a consensus that it promotes longer lifecycle of components, materials and products through reuse, repair, recycling, remanufacture and refurbishing (Zacho *et al.*, 2018).

These views suggest that the concept of CE focuses on material and physical resource aspects of the economy (EEA, 2014), which could nurture a constructive path to sustainable development. Taken together, CE can be construed as a recovery system that can minimize resource consumption, waste production, energy leakage, and emission by closing, narrowing, and slowing material and energy loops (Geissdoerfer *et al*., 2017).

2.2 CE in the construction industry

Despite the economic, social and environmental contribution of the construction industry (Gencel *et al*., 2012), it accounts for the highest amount of total waste

generated globally (Núñez-Cacho *et al*., 2018; van Dijk *et al*., 2014; Clark *et al*., 2006). While the construction industry consumes more resources than any other industry (Pomponi and Moncaster, 2017), it also accounts for over 40% of the world's carbon emission. According to Kibert (2016), over 50% of the entire waste being generated in the construction industry is associated with end-of-life activities and operations, which are primarily from demolition. However, only about 30% of these materials are either reused or recycled (Macarthur, 2013).

The current view suggests that it is likely impossible to reuse materials within the construction industry considering that buildings are often disposed of at the end of their useful life. For example, demolition and construction waste in the UK is at an annual average of 45.8 million tons (Akanbi *et al*., 2018). In response to Nuñez-Cacho *et al*.'s (2018) observation that the construction industry requires a closer attention due to its environmental impact, the industry should improve its resource consumption (Smol *et al*., 2015). The current trends and practices in the construction industry suggest that CE can facilitate the sustainability of the industry. The starting point is to understand how CE could contribute to the construction industry, given that CE can be instrumental in reducing the environmental impact of the construction activities (Ghisellini *et al.*, 2018). This is in line with van Stijn and Gruis (2019, p.1) assertion that "the transition to a circular economy in the built environment is key to achieving a resource-effective society". As a result, this study is designed to assess the current research focus on CE in the construction industry and how the concept has been conceptualized in the academic literature.

3. Material and methods

To understand the focus of research on CE in the construction literature, a systematic review was conducted using relevant and available scholarly studies that were published between 1990 and 2019. The rationale for the year 1990 is due to its importance in popularizing the paradigm of sustainability following the publication of the Brundtland report in 1987. Although literature surrounding CE in construction is still in its infancy, the concept is sustainability from which the principles of CE derives have had its root since the 1980s. Furthermore, there was a need to align the search to the period when CE was formally used (Pearce and Turner, 1990). Similarly, a systematic review was adopted due to its potential in

characterizing the extant studies to identify or argue in support of emerging trends (Jabbour, 2013; Mariano *et al*., 2015). As espoused by Thorley *et al*. (2020), this approach to the review of literature is most efficient to evaluate extensive literature towards high-quality outcomes. This approach to data collection has been successfully applied by many scholars (such as Costa and Godinho Filho, 2016; Fahimnia *et al*, 2015) to summarize research findings of similar themes based on predefined criteria. Denyer and Tranfield's (2009) suggested a five-stage procedure to a systematic literature review. This procedure includes the formulation of question(s); locating and identifying relevant studies; selection and evaluation of studies; analysis or synthesis; and results reporting. Denyer and Tranfield's (2009) procedure has been adopted in this research (Figure 1). This choice is underpinned on its rigour and use by previous studies (Thorley *et al*., 2020) to facilitate easy replication, focus on understanding specific research questions using existing studies and reporting the outcome about what is known and unknown.

Insert Figure 1 here

3.1 Formulation of research questions

Consistent with Figure 1, the following research questions were explored in this study:

1. How has research on CE been conceptualized? What were the main areas investigated?
2. What research method(s) have been used in CE research?
3. What is the current knowledge regarding the application of CE in the construction industry?

Using Figure 1 as a basis, this study adopted the following search criteria to identify and retrieve relevant peer-reviewed studies to answer the identified research questions:

1. The article's title or subject had to do with CE in the construction industry.
2. The journal articles published between 1990 and 2019.
3. The articles were scholarly peer-reviewed journals.

4. Only academic journal articles are considered. Hence, company reports are excluded.
5. The journal articles were published in English language. This gave room for easy review and analysis of included articles.

Articles not written in English were excluded for ease of analysis and understanding (Osobajo and Moore, 2017). Only peer-reviewed articles were considered for this systematic review to ensure that all articles have been subjected to the same analytical and review structure, minimizing bias, and foster a fair representation of articles of interest.

3.2 Data Source

Having designed the research question, the second stage (see Figure 1) that involves the efforts to locate and identify relevant studies was further sub-categorized into different sequential steps (Figure 2) to arrive at the selected relevant articles. The initial search was conducted through electronic databases, such as Scopus and Web of science, for all journal articles that focused on CE within the construction industry. These databases are considered appropriate because they are found to be effective in literature search, include a more expanded spectrum of journals and citation analysis, and cover most scientific fields (Falagas *et al*. 2008). Pelz (2019) added that Scopus is efficient because it allows search results to be directly exported into a spreadsheet. Arguably, this will be useful in organizing a large amount of initial search outcome to identify relevant literature for this study. Using this approach, only peer-reviewed journal articles that are relevant to the theme of this current study were retrieved. Based on the search criteria, a total of 50 peer-reviewed journal articles on CE were found to be relevant to the goal of this study and included for further analysis. The search for relevant peer-reviewed journal articles was conducted in the fourth quarter of 2019.

Insert Figure 2 here

The selected sources based on the inclusion criteria are presented in Table 1, although Appendix A presents detailed information about the selected peer-

reviewed articles. Also, Appendix B present the findings of the journal article reviewed. The result and discussion section explain these findings further.

Insert Table 1 here

4. Results and discussion

As presented in Table 1, only fifty studies were considered relevant for further analysis. The reviewed articles were selected not solely by their quality, but was assessed based on the reliability of its findings (Denyer and Tranfield, 2009) coupled with their relevance to the current study.

4.1 Studies overview

Although, CE was formally used in 1990 by Pearce and Turner (1990) within the economic discipline in support of the claim that "everything is input to everything else", the concept has received little or no scrutiny within the construction industry until about 2007. During the early period of its introduction to the construction industry, an average of two peer-reviewed articles were published yearly. However, CE started gaining momentum among researchers and scholars from the year 2016, during which an average of nine peer-reviewed articles was published annually (see Figure 3). This is consistent with Pomponi and Moncaster (2017) assertion that CE is attracting interest as an emerging paradigm which may be attributed to the publication of the Brundtland report in 1987. On the contrary, early studies conducted on the construction activities concerning resource use before 2016 were underpinned by the linear economy model.

Insert Figure 3 here

4.2 Understanding CE in CI

To understand the extent to which the principles of CE are applicable in the CI, attempt was made to establish the background of CE definition used by journal articles. All the artilcles reviewed agreed that CI needs to be transformed from a linear economy toward a circular approach to achieve a sustainable future. However, only fourteen of the studies reviewed attempt to define CE within the construction industry context as shown in table 2. This finding further strengthens

the argument that CE is a relatively new topic that is gaining momentum within the contruction industry (Pomponi and Moncaster 2017; Leising, Quist and Bocken 2018).

Insert Table 2 here

4.3 Study focus

Figure 4 presents the different areas in which scholars and researchers have concentrated their effort in the last decade. About 64% of the studies reviewed had a link with building materials and resources with 34% and 30% for resources reuse and waste management, respectively. This is consistent with Su *et al*. (2013), who argued that scholars should advance their research activities beyond issues related to material management. Other areas that have been researched into but with a minimal attention are CE model (10%), supply chain (8%), building designs (6%), policy (6%), energy efficiency (4%), and land use (2%).

Insert Figure 4 here

4.3.1 Resources reuse

According to the findings of the review, resource reuse remains a major concern for scholars and practitioners within the construction industry. This is because resource consumption provides the built environment with a basis for outlining the emerging lifecycle issues within the industry (Fernandez, 2007). This is in line with Lemougna *et al*.'s (2011) assertion that an awareness of reuse will foster the attainment of a friendly environment and contribute to solving the problem of affordable housing. Exploring material performance in the construction of new buildings may promote material use and reduce CO2 emissions (Huang *et al*., 2013). These views suggest that an understanding of material reuse is essential for the improvement and success of the construction industry.

While reuse contributes to sustainability in construction (Atolagbe and Fadamiro, 2014; Sfakianaki, 2015), Akanbi *et al*. (2018) argued that materials components should be appraised to encourage the adoption of recoverable materials that are mostly reusable. This is because appropriate management of materials components contribute to sustainable development (de Freitas *et al*., 2018).

Besides, reuse of resources at the end-of-life of a building will yield both economic and environmental benefits (Ghisellini *et al*., 2018). However, an understanding of construction material and how reuse will contribute to sustainability and CE are required (López-Uceda *et al*., 2018). Likewise, Minunno *et al*. (2018) argued the environmental advantages of material reuse should be explored in improving the CE of buildings. Arguably, having an adequate understanding and appropriate use of construction material resources can lead to improved performance as well as increasing the industry sustainability performance (Sierra-Pérez *et al*. 2018; Mobili *et al*., 2018; Corradini *et al*., 2019).

4.3.2 Waste management

The findings of this study show that construction and demolition waste is a major contributor to environmental pollution. It is, therefore, imperative to minimize and/or eliminate waste where possible and feasible in construction activities (Tam *et al.,* 2007; Yuan *et al.*, 2011). Waste prevention through the efficient use of construction materials will benefit the industry environmentally and economically (Smol *et al*. 2015). Esa *et al.* (2017) argued that efficient waste management within the industry could be achieved through the concept of CE. This may involve an inclusive and collaborative effort among different stakeholders within the industry (Tong and Tao, 2016).

Although efficient utilization of construction waste is salient to sustainable development (Karayannis *et al*., 2017; Aneke and Awuzie, 2018), poor waste management monitoring remains a major challenge for the industry according to the reviewed studies. However, it is imperative to comprehensively evaluate the contribution of waste materials at various construction stages to environmental impacts (Hossain *et al.,* 2019).

4.3.3 CE model

The design and application of CE models that are specific to the construction industry are lacking in the construction literature according to our review. However, Dean *et al*. (2014) analyzed four independently operated eco-smart corporate communities in USA and China and proposed an expanded business operations model that can be instrumental in assessing environmental

stewardship within the construction industry. Likewise, Nuñez-Cacho *et al*. (2018) designed a scale that will provide information on the degree of the long-term sustainability of the construction company and the degree of CE implementation. Based on the findings of this study and supported by van Breugel (2018), the industry should emphasise the application of models that may allow for sustainable solutions in the construction industry. Wuyts *et al*. (2019) concluded that the availability of frameworks would be useful in deciding the life expectant of building, i.e. to extended or ended.

4.3.4 Supply chain integration

Another important area that is attracting less attention in the construction literature within the domain of CE is supply chain management. Mohamed Abdul Ghani *et al*. (2017) observed that the understanding of the principles of CE within the context of sustainable development is essential in combating the emissions of greenhouse gases (GHG) across the construction supply chain. Besides, Nasir *et al*. (2017) argued that the integration of CE principles within sustainable supply chain management could provide clear advantages for the construction industry. Also, Leising *et al.* (2018) concluded that developing circular buildings requires a new process design where a variety of disciplines in the supply chain is integrated upfront. The lack of interest in the supply chain as revealed by this systematic review serves as a pointer for scholars to explore this area in more depth in understanding how the construction industry can embed CE across its supply chains.

4.3.5 Other focus areas

Another important area of interest is adaptive reuse which can contribute to CE in the construction industry. According to Sanchez *et al*. (2019), adaptive reuse of building structures produce a considerable decrease in the environmental impacts and the construction building cost. Besides, studies (such as Almirall *et al*. 2019; Lai *et al*. 2017) argued for more focus on policies and regulations in the sustainability of construction assets.

Considering the issues of climate change, studies should focus on identifying relevant driving forces of low carbon technology innovation and their interaction

in the construction industry. Also, Hong *et al*. (2014) explored the re-adjustment and optimization of land use patterns and came to a conclusion that pursuing sustainable development and building an ecological civilization is imperative for the future of the construction industry.

While it is evident from the studies reviewed, that researchers continue to strive toward advancing CE within the construction industry, WRAP (2013) asserted that best practice guidance such as offsite construction, design for deconstruction, sustainable procurement, IBM and design out waste should be addressed to promote CE. The concept of circularity is considered to be an instrument for mitigating the environmental footprint of the construction industry (van Breugel, 2018).

4.4 Data collection tool

As shown in figure 5, of the 50 peer-reviewed journal articles identified for the current study, 16 articles (32%) make use of solely secondary data that are readily available from the other sources, while 68% of the articles reviewed used primary data. According to this review, the prominent data collection methods include case study, experiment, interview, questionnaire, field visit, workshop and observation are the different sources of primary methods of data collection used. Twelve articles (24%) employed case study, eight articles (16%) utilized experiment, three articles (6%) utilized interview, two articles (4%) used questionnaire, one article (2%) utilized workshop, one article (2%) utilized observation, and another seven articles (14%) employed more than one method of data collection. Furthermore, 2 articles (4%) of the journal articles reviewed utilised a mixed-method approach. In summary, 92% (46 articles) of the articles reviewed employed qualitative method while little attention has been accorded to quantitative (2 articles (4%)) and mixed-method (2 articles (4%)).

In spite of Pelz (2019) argument that qualitative studies could help to sharpen current theoretical understanding and point to new ones, not enough information about the validity and reliability of the qualitative instruments employed were provided by studies reviewed. Also, considering the different understanding of CE in the construction industry, there is clearly a need for further research on CE from

a quantitative and mixed-method perspective. Such a perspective may allow for more objective measures with an opportunity to generalize the research findings.

Insert Figure 5 here

4.5 Type of study

As shown in figure 6, thirty-five (70%) of the articles analyzed are classified as empirical studies, while fifteen (30%) of the journal articles are classified as theoretical studies, which establishes what theories already exist, and to develop new hypotheses to be tested.

Insert Figure 6 here

Sample size and characteristics were assessed to determine if any pattern existed among the reviewed articles and the extent to which these are generalizable. It was observed that empirical studies that focused on material reuse included researchers, architects, consultants and other construction practitioners as the study participants. Also, building types and building materials are used as a case study. Likewise, studies that focused on waste management considered construction experts and various construction stakeholders for their sample study. Also, different construction and building materials are used as a case study. Furthermore, studies that focused on models considered eco-smart buildings as case study. Studies that focused on supply chain considered different building types and construction materials in their study. Studies that focused on Building designs considered public sector clients, value managers and VM facilitators as sample. Studies that focused on policy considered building material as case study. It was clear from the studies reviewed that building types and building materials remain a key focus for many researchers.

4.6 Study context

All peer-reviewed journal articles (N = 50) selected for this study were conducted in one of 23 different countries. 24 studies (48%) were conducted in developed countries, while 20 studies (40%) were conducted in developing countries, as shown in Figure 7. Only 6 of the studies (12%) reviewed considered both developed and developing countries. Of the studies conducted in developed

countries, the United Kingdom was the dominant country that attracted the attention of scholars, while studies on China was dominant among developing countries. Arguably, studies on circular economy within the construction industry has caught both the attention of scholars in both developed and developing countries. However, lesser attention has been given to comparative studies (i.e. studies involving both developed and developing countries).

Insert Figure 7 here

4.7 Study Continent

Figure 8 revealed that the peer-reviewed journal articles considered for this study had been carried out in 6 different continents. However, Europe and Asia with 20 studies (40%) and 17 studies (34%) respectively dominated the review. Only 3 studies, 2 studies, 1 study and I 1study were conducted in Africa, North America, South America and Australia respectively. Furthermore, 4 studies and 1 study were conducted in 2 continents and 3 continents, respectively. These findings suggested that the circular economy has received more attention from scholars within Europe and Asia. Hence, more research activities are required in other continents such as Africa, North America, South America and Australia. Also, researchers should look into studies that will cut across two or more continents. This will allow and support cross-cultural awareness across continents.

Insert Figure 8 here

5 Gaps in the literature and Future Research Agenda

The review showed different research focus as well as the application of CE in the construction industry. However, the key findings from the reviewed papers (Figure 9) suggest the gaps in the literature and allow for the identification of the direction for future research on CE within the construction industry. For sustainability to be achieved within the construction industry through the CE principles, it is intuitive for research efforts to address and further explore the utility of the CE framework, as presented in Figure 9. The knowledge would allow for the design of new innovative process models and also provide an opportunity for the construction industry to integrate the identified dimensions into its current activities.

Insert Figure 9 here

5.1 Offsite construction

Apart from Elmualim *et al*. (2018) study on how smart and industrialised prefabrication can be used for CE, there is no other research on the construction industry on how CE can influence offsite manufacturing. Offsite manufacturing in the construction industry span from simple precast beams and columns to prefabricated walls and building elements before modular houses. Arguably, researchers should investigate further the application of circularity in the offsite manufacturing process. The investigation could focus on the plausibility of material and resource reuse during design and deconstruction. Furthermore, research and models must be designed to harness limited material and financial resources in offsite construction through CE.

5.2 Cost reduction and management

Studies (such as Omotayo and Kulatunga, 2015; Omotayo *et al*., 2019; Arif *et al.,* 2015) have discussed the cost management concept in the domain of construction waste reduction. The peculiarity of cost reduction is evident and more practical in offsite construction. For instance, Kaizen costing, lean construction and other forms of cost management techniques can be used in the construction industry, especially in offsite construction, to reduce waste. Although construction waste can be tangible and intangible, the principles of CE may increase material reuse in the construction process, which may feed into effective cost models to achieve cost reduction. According to the findings of this study, cost modelling through material reuse and activity feedback loops using kaizen costing may be a potential research area in the field of construction management. This study further argues that any attempts to enhance the productivity of construction activities through CE should consider the propensity for construction cost reduction through many approaches, such as value management systems and value engineering, that could be integrated into CE models in the construction industry.

5.3 Whole life cycle costing

To achieve circularity in the construction industry, the whole life cycle costing is another approach that can be adopted and integrated into CE models. According to Albuquerque *et al*. (2019), the rationale is to address the issues of sustainability that are associated with business operations by integrating externalities into life cycle costing models. This assertion is supported by Harts *et al*. (2019) who identified whole life cycle costing as an enabler for the implementation of a CE in the built environment. Also, Chen and Huang (2019) observed that the application of life cycle assessment is of significant importance to circular economy for products services.

Since whole life cycle costing adopts costing from social, environment and governance perspectives, its contribution in reducing construction cost cannot be underestimated. Although circularity is still emerging in the construction industry, whole life cycle costing is an essential approach that can be implemented and integrated to achieve circularity. Therefore, research into the application of whole life cycle, costing in achieving a circular economy will provide a more in-depth insight into how construction costs can be reduced or maintained throughout a built asset. While Albuquerque *et al*. (2019) studied whole life cycle costing and CE in the food and beverages industry, we proposed that future research in the construction industry should assess the utility of whole life cycle costing when designing circular economy models for the construction operations.

5.4 Risk, health and safety management

Another potential area for future CE research in the construction industry is issues of risk, health and safety management considering the number fatalities in the industry. This research area is necessary considering that risk, health and safety issues have not been sufficiently addressed, especially in the CE literature. Hence, the need for the construction industry to be more effective in evaluating and managing different uncertainties confronting its operations, particularly to achieve sustainability and in creating sustainable values for stakeholders/shareholders is on the increase. For instance, future research should consider the possibility of preparing risk registers in CE when assessing health and safety-related issues in construction projects. Also, material consumption (such as reuse or recycling) mitigating measures should focus on CE by incorporating risk, health and safety

identification approaches, particularly during the construction and prefabrication processes.

6. Conclusion and recommendation

In this paper, we extend the present understanding of CE studies reported in the construction industry based on peer-reviewed journal articles published between 1990 and 2019 through a systematic literature review. In total 50 articles were included in the review.

According to the findings of the study, extensive studies on CE in the construction industry have focused on resource use and waste management. It is clear from the research in CE in the construction industry that research focuses on CE impacts in areas of supply chain integration, building designs, policy, energy efficiency, land use, offsite manufacturing, cost reduction and cost management, whole life costing, and risk, health and safety is limited. These are key areas influencing construction decisions and activities to foster a rapid transition to CE in the construction industry hence possible areas for further research. There must be more research into policy interventions to support CE transition in the construction industry. Research on CE impact on offsite manufacturing, whole life cycle costing and building designs will influence sustainable strategic decisions to support resource use and waste reduction. There must be research identifying influences of supply chain integration and risk management frameworks to enable supply chain organisations to reevaluate their processes and towards accelerated transition into CE practices. Research on cost optimization and health and safety within the CE context in terms of the productivity and investment benefits will enable guidance necessary for a paradigm shift from conventional business models. Focusing on these areas will play a significant role in moving the construction industry further towards creating a novel sustainable future.

Also, the findings showed the dominance of the qualitative research approach in existing CE research. This suggests that future research should endeavour to adopt quantitative method or mixed-method to provide a more objective stance regarding the utility of CE in the industry. Using either of these methods will create more avenues that can facilitate the implementation and application of CE models that are specific to the construction industry. In addition, there is a fair balance in

the studies conducted in both developed and developing countries, although this discovery is not unexpected, given the fact that CE can be instrumental in promoting the sustainability agenda. However, it is observed that comparative studies, using different countries and/or construction activities as a unit of analysis, have not been appropriately considered. One possible future research agenda could involve two or more countries, especially from developing and developed countries and across different continents.

While this study identified different studies on CE in the construction industry, the selection parameters that restricted the retrieved studies to only published peer-reviewed articles are considered as the main limitation of this study. Future study may consider published books, conference papers and grey articles that may provide further insights into the application of CE in the construction industry.

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Table 1: Reviewed Journal

No	Journal Name	2007	2011	2013	2014	2015	2016	2017	2018	2019	Total
1	Journal of Industrial Ecology	1						1			2
2	Resources, Conservation and Recycling	1		1			1		3	1	7
3	Sustainability		1					1	1	1	4
4	Waste management		1						1		2
5	Environment, development and sustainability				1						1
6	Ecological indicators				1	1					2
7	Technology in Society				1						1
8	Ambio				1						1
9	World Journal of Science, Technology and Sustainable Development					1					1
10	Journal of Cleaner Production					1	1	1	2	3	8
11	Energy procedia						1				1
12	Journal of Material Cycles and Waste Management							1			1
13	Management of Environmental Quality: An International Journal							1			1

14	Advances in Materials Science and Engineering	1			1
15	Sustainable Cities and Society	1	1		2
16	Renewable and Sustainable Energy Reviews	1			1
17	International Journal of Production Economics	1			1
18	Acta Structilia		1		1
19	Environmental Science and Pollution Research		2		2
20	Clean Technologies and Environmental Policy		1		1
21	Building		1		1
22	Advances in Civil Engineering		1		1
23	Materials and structures		1		1
24	Engineering, Construction and Architectural Management		1		1
25	Engineering structures			1	1
26	Construction and Building Materials			1	1
27	The International Journal of Life			1	1

	Cycle Assessment		
28	Architectural Engineering and Design Management	**1**	1
29	Environment Systems and Decisions	**1**	1
	Total		**50**

Table 2:

Authors	CE Definition
Fernandez (2007)	It entails activities that both supports economic growth and facilitates the closing of material loops and the overall promotion of resource efficiency.
Yuan *et al.* (2011)	Is the flow of raw material to product, then not to waste in the environment but to regenerated product
Dean *et al.* (2014)	It is aimed at improving the efficiency of materials and energy use.
Smol et al. (2015)	It is keeping the added value in products to eliminate waste.
Wang *et al*. (2015)	Is the transformation of resources to products to regenerated resources mode.
Esa *et al.* (2017)	It is an approach for waste minimization throughout the overall construction cycle.
Nasir *et al*. (2017)	It pushes for a closed-loop supply chain design, enabling any products at the end of their life cycle to re-enter the supply chain as a production input.
Ghisellini *et al.* (2018)	Is a new model of economic development that promotes the maximum reuse/recycling of materials, goods and components in order to decrease waste generation to the largest possible extent.
Akanbi *et al*. (2018); Huang *et al*. (2018); Minunno *et al*. (2018)	Is reducing, reuse and recycling of materials.
Leising *et al.* (2018)	Is a system where material loops are closed and slowed and value creation is aimed for at every chain in the system
Mahpour (2018)	A system that is restorative or regenerative by intention and design to replace the end-of-life concept with restoration.
Sierra-Pérez *et al*. (2018)	It optimises raw material use to minimise environmental impacts.

Appendices

Appendix 1: List of academic peer-reviewed journal articles

Author(s)	Journal Title	Study Focus	Type of Study	Method of Data Collection	Study Context
Fernandez (2007)	Journal of Industrial Ecology	Material reuse	Empirical	Questionnaire	China
Tam, Tam and Le (2007)	Resources, Conservation and Recycling	Waste management	Empirical	Experiment	Australia and China
Lemougna et al. (2011)	Sustainability	Material reuse	Theoretical	Literature review	Cameroon
Yuan, Shen and Li (2011)	Waste management	Waste management	Empirical	Case study	China
Huang et al. (2013)	Resources, Conservation and Recycling	Material reuse	Theoretical	Literature review	China
Atolagbe and Fadamiro (2014)	Environment, development and sustainability	Material reuse	Theoretical	Literature review	Nigeria
Dean, Fath and Chen, (2014)	Ecological indicators	CE model	Empirical	Case study	USA and China
He et al. (2014)	Technology in Society	Energy efficiency	Theoretical	Literature review	China
Hong et al. (2014)	Ambio	Land use	Theoretical	Literature review	China
Sfakianaki (2015)	World Journal of Science, Technology and Sustainable Development	Material reuse	Theoretical	Literature review	Greece
Smol et al. (2015)	Journal of Cleaner Production	Waste management	Theoretical	Literature review	Poland
Wang et al. (2015)	Ecological indicators	CE model	Empirical	Case study	China
Chang et al. (2016)	Journal of Cleaner Production	Policy	Theoretical	Literature review	China
Geldermans (2016)	Energy procedia	Material reuse	Empirical	Workshops	Netherlands
Tong and Tao (2016)	Resources, Conservation and Recycling	Waste management	Theoretical	Literature review	China
Esa, Halog and Rigamonti (2017)	Journal of Material Cycles and Waste Management	Waste management	Theoretical	Literature review	Malaysia
Mohamed Abdul Ghani *et al*. (2017)	Management of Environmental Quality: An International Journal	Supply chain	Empirical	Case study	USA
Jiménez-Rivero, de Guzmán-Báez and García-Navarro (2017)	Suatainability	Waste management	Empirical	Case study and face-to-face structured interviews	Spain
Karayannis et al. (2017)	Advances in Materials Science and Engineering	Waste management	Empirical	Experiment	Greece
Kylili and Fokaides (2017)	Sustainable Cities and Society	Policy	Theoretical	Literature review	Europe

Lai et al. (2017)	Renewable and Sustainable Energy Reviews	Energy efficiency	Empirical	Questionnaire and telephone interview	China
Schiller Gruhler and Ortlepp (2017)	Journal of Industrial Ecology	Supply chain	Empirical	Case study	Germany
Tingley, Cooper and Cullen (2017)	Journal of Cleaner Production	Material reuse	Empirical	Semi-structured interview	UK
Nasir et al. (2017)	International Journal of Production Economics	Supply chain	Empirical	Casse study and interview	UK
Akanbi et al. (2018)	Resources, Conservation and Recycling	Material reuse	Empirical	Case study	UK
Aneke and Awuzie (2018)	Acta Structilia	Waste management	Empirical	Case study and experiment	South Africa
de Freitas et al. (2018)	Clean Technologies and Environmental Policy	Material reuse	Empirical	Experiment	Brazil
Ghisellini, Ripa and Ulgiati (2018)	Journal of Cleaner production	Material reuse	Theoretical	Literature review	Italy, Spain and China
Huang et al. (2018)	Resources, Conservation and Recycling	Waste management	Empirical	Interview	China
Leising, Quist and Bocken (2018)	Journal of Cleaner production	Supply chain	Empirical	Case study	Netherlands
López-Uceda et al. (2018)	Environmental Science and Pollution Research	Material reuse	Empirical	Experiment	Spain
Mahpour (2018)	Resources, Conservation and Recycling	Waste management	Empirical	Semi-structured interview	Iran
Minunno et al. (2018)	Building	Material reuse	Theoretical	Literature review	Australia
Mobili, Giosuè and Tittarelli (2018)	Advances in Civil Engineering	Material reuse	Empirical	Experiment	Italy
Nuñez-Cacho et al. (2018)	Sustainability	CE model	Empirical	Questionnaire	Germany, Spain, Poland, China, Great Britain, USA, Italy and the Netherlands
Sierra-Pérez et al. (2018)	Sustainable cities and society	Material use	Empirical	Experiment	Spain
van Breugel (2018)	Materials and structures	CE model	Theoretical	Literature review	Netherlands
Van Praagh et al. (2018)	Waste Management	Waste management	Empirical	Experiment	Sweden
Yu et al (2018)	Engineering, Construction and Architectural Management	Building designs	Empirical	Questionnaire and semi-structured interviews	Hong Kong
Akinade and Oyedele (2019)	Journal of Cleaner production	Waste management	Empirical	Case study and experiment	UK
Almirall et al. (2019)	Engineering structures	Policy	Empirical	Case study	Spain
Chen et al. (2019)	Construction and Building Materials	Material reuse	Theoretical	Literature review	China, UK and Germany

Chiang, Yen and Lu (2019)	Environmental Science and Pollution Research	Waste management	Empirical	Experiment	Taiwan
Corradini, Pierobon and Zanetti (2019)	The International Journal of Life Cycle Assessment	Material reuse	Empirical	Case study	Italy
Hossain *et al.* (2019)	Resources, Conservation and Recycling	Waste management	Empirical	Literature review	Hong Kong
Mihai (2019)	Sustainability	Waste management	Empirical	Observation	Romania
Raouf and Al-Ghamdi (2019)	Architectural Engineering and Design Management	Building designs	Theoretical	Literature review	Qatar
Sanchez, Esfahani and Haas (2019)	Environment Systems and Decisions	Building designs	Empirical	Case study	Canada
Silva, de Brito and Dhir (2019)	Journal of Cleaner production	Material reuse	Empirical	Case study	Developed and Developing
Wuyts et al. (2019)	Journal of Cleaner production	CE model	Empirical	Field visit and expert interviews	Japan

Appendix 2: Reviewed Journal Findings

Author(s)	Contribution
Fernandez (2007)	Examined the consumption of material resources and concluded that there is a need to formulate strategies for a circular economy that include a resource-efficient.
Tam, Tam and Le (2007)	The authors proposed that the values of water absorption of the pre-treated recycled aggregate in construction have to be significantly reduced with improved mechanical properties to be recyclable.
Lemougna et al. (2011)	The authors concluded that laterite can contribute to solving the problem of affordable housing and providing environmentally-friendly.
Yuan, Shen and Li (2011)	In an attempt to evaluate the efficiency of recycling construction and demolition waste, the study demonstrated that the close-loop recycling option is better than the open-loop recycling option for construction and demolition waste.
Huang et al. (2013)	The outcome of the study indicated effective material reuse influences materials demand and related CO2 emissions for new buildings construction
Atolagbe and Fadamiro (2014)	The authors proposed five major factors of sustainability to justify the use of sustainable material of both housing and environmental developments.
Dean, Fath and Chen, (2014)	The authors concluded that an expanded business operations model (EBOM) is essential assessing an a company's goal of environmental stewardship.
He et al. (2014)	While assessing the overall context of energy efficiency in rural China, the authors concluded that a new theoretical framework is required to assist decision-makers in achieving energy efficiency.
Hong et al. (2014)	Pursuing sustainable development and building an ecological civilization is imperative for the optimization of land use patterns.
Sfakianaki (2015)	Examined the impact of material reuse on sustainable construction to identify its importance and current thinking of the concept.
Smol et al. (2015)	The authors affirmed that the construction industry will benefit both economicallly and environmentally in the efficient use of waste such as sewage sludge.
Wang et al. (2015)	The authors found that eco-efficiency indicators are essential for ecological province contruction as the pre-set indicators are inadequate.
Chang et al. (2016)	The authors identify strengthening technology innovation, improving standards and evaluation, establishing demonstration projects, and publicity are the key supporting activities for sustainable construction.
Geldermans (2016)	Result shows that circularity-values emerge at the intersection of specific intrinsic properties (material and product characteristics) and relational properties (building design and use characteristics), whilst combining multiple parameters for reuseable materials.
Tong and Tao (2016)	It is impeartive to foster collaborative initiatives at the community level to build an inclusive space for recycling activities and promote waste management.

Esa, Halog and Rigamonti (2017)	Proposed a waste management framework based on the concept of circular economy for minimizing construction and demolition wastes.
Mohamed Abdul Ghani *et al*. (2017)	Concluded that "ready-mix concrete manufacturing", "electric power generation, transmission and distribution" and "lighting fixture manufacturing" sectors were found to be the main culprits in the GHG emissions' stock. Hence, understanding the principles of "circular economy" within the context of sustainable development is necessary
Jiménez-Rivero, de Guzmán-Báez and García-Navarro (2017)	Result identified the management stages affecting the on-site production and management of plasterboard in a construction work and proposed best practices for an enhanced on-site waste management.
Karayannis et al. (2017)	The study produced sustainable ceramic materials derived from100% industrial waste by-product mixtures based on circular economy concept.
Kylili and Fokaides (2017)	Concuded that the sustainability of the built environment will come through the increased use of alternative, recycled, natural and unconventional construction materials and thermal insulation materials.
Lai et al. (2017)	Result revealed that system integration plays a crucial role in achieving low carbon development in the construction industry.
Schiller Gruhler and Ortlepp (2017)	The authors concluded that a comprehensive concept for the CE should not be limited to maximum rates of closed-loop circulation within specific products or sectors.
Tingley, Cooper and Cullen (2017)	The study outcome suggests four mechanisms to overcome the systemic barriers to reusing structural steel within the UK construction supply chain.
Nasir et al. (2017)	The authors concluded that an integration of circular economy principles within sustainable supply chain management can provide clear advantages.
Akanbi et al. (2018)	Study outcome revealed that building design with steel structure, demountable connections, and prefabricated assemblies produce recoverable materials that are mostly reusable.
Aneke and Awuzie (2018)	Concluded that the utilization of industrial wastes in the production of FA bricks did not only portray some outstanding characteristics but also showed potential to make salient contributions to society's sustainable aspirations.
Chiang, Yen and Lu (2018)	Concluded that the feasibility of recycled gypsum board used as a swelling agent and good potential for construction works in green lightweight building materials.
de Freitas et al. (2018)	The authors affirms that the management of solid waste contribute to sustainable development.
Ghisellini, Ripa and Ulgiati (2018)	The study revealed that in most cases the circular econmy principle of reuse/recycling of construction and demolition waste at the end-of-life of a building as well as the production of recycled products provide environmental and economic benefits.
Huang et al. (2018)	The study revealed that primary barriers to reducing construction and demolition waste (CDW) in China are lack of building design standard for reducing CDW, low cost for CDW disposal and inappropriate urban planning.
Leising, Quist and Bocken (2018)	The authors affirms that developing circular buildings requires a new process design where a variety of disciplines in the supply chain is integrated upfront.

López-Uceda et al. (2018)	The study revealed that releasing levels of polluting elements in leachates have an important environmental-friendly potential in the extensive green roof market, contributing to the circular economy and urban sustainability.
Mahpour (2018)	Concluded that from behavioral, technical, and legal perspectives, using finitely recyclable construction materials; ineffective construction and demolition wastes dismantling, sorting, transporting, and recovering processes; and using finitely recyclable construction materials are the major barriers to circular econmy transition.
Minunno et al. (2018)	The study revealed the potential of improving the circular economy of buildings through prefabrication reduction, reusability, adaptability and components recyclability.
Mobili, Giosuè and Tittarelli (2018)	Demonstrated that glass reinforced plastic dust (GRPd) addition in FCBs production not only valorises GRPd waste and increases sustainability of FCBs, but can also lead to an improvement of some final performances of brick.
Nuñez-Cacho et al. (2018)	The authors designed a scale that will provide information on the degree of long-term sustainability of the construction company, and the degree of implementation of circular economy.
Sierra-Pérez et al. (2018)	The study result demonstrated a high potential of retrofit buildings with resusing cork insulation boards from an environmental and economic perspective.
van Breugel (2018)	The authors emphasised on the application of models for sustainable solutions in the field of cementitious materials and sustainable construction.
Van Praagh et al. (2018)	The study concluded that pre-treated municipal solid waste incineration (MSWI) could be recycled in Sweden in asphalt paved constructions with acceptable risks to environment.
Yu et al (2018)	The authors concluded that the value management of building designs does provide opportunities to focus on issues relating to sustainable society and environment.
Akinade and Oyedele (2019)	Using BIM principles, the authors developed a computational approach to construction waste measurement.
Almirall et al. (2019)	The study outcome revealed that policy and regulations play a key role in the sustainability of construction assets.
Chen et al. (2019)	The study summarized the existing research topics focusing on recycled aggregate (RA), gaps of current research, suggestions for promoting RA usage, and research directions for future work.
Hossain *et al.* (2019)	The study concluded that adopting resource recovery principle can lead to 37% GHGs reduction from building.
Corradini, Pierobon and Zanetti (2019)	The authors stated that the product environmental footprint (PEF) methodology allows the identification of the main hotspots and actions for reducing environmental impacts in existing buidings.
Mihai (2019)	The study revealed that poor monitoring of construction and demolition waste flows across Romanian counties and the geographical dimension of this waste stream collected by waste operators.
Raouf and Al-Ghamdi (2019)	The authors identified the main obstacles and limitations to BIM implementation in the green building industry.
Sanchez, Esfahani and Haas (2019)	The study revealed that the adaptive reuse of the building structure produces a considerable decrease in the environmental impacts and the construction building cost.

Silva, de Brito and Dhir (2019)	The study highlighted the technical viability and appropriateness of using recycled aggregates in a broad range of construction applications.
Wuyts et al. (2019)	The authors presented a framework for the identification of delayed, justified, or premature obsolescence. This framework can be used to decide whether the life of a residential building should be extended or ended.

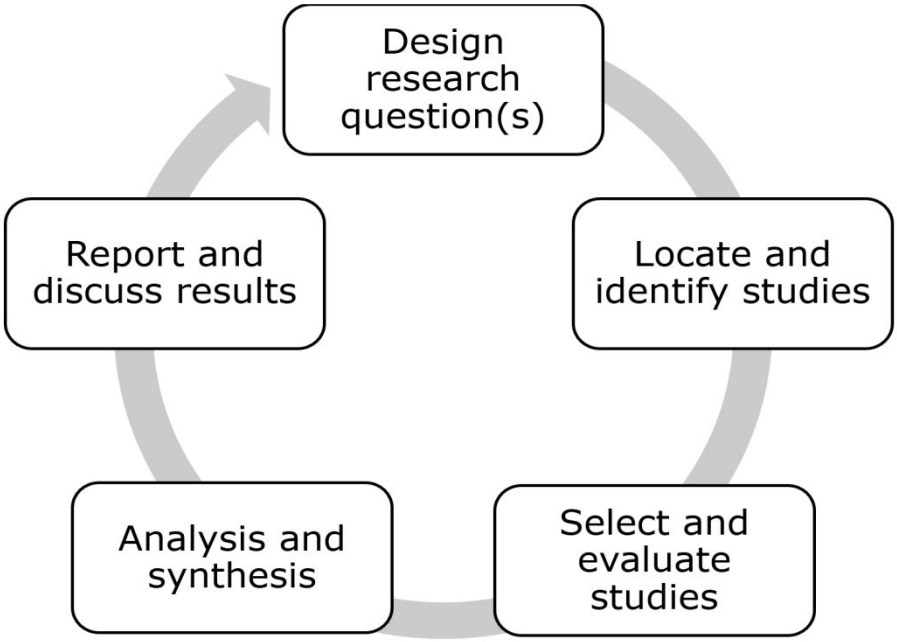

Figure 1: Systematic Review Process Model (Denyer and Tranfield, 2009)

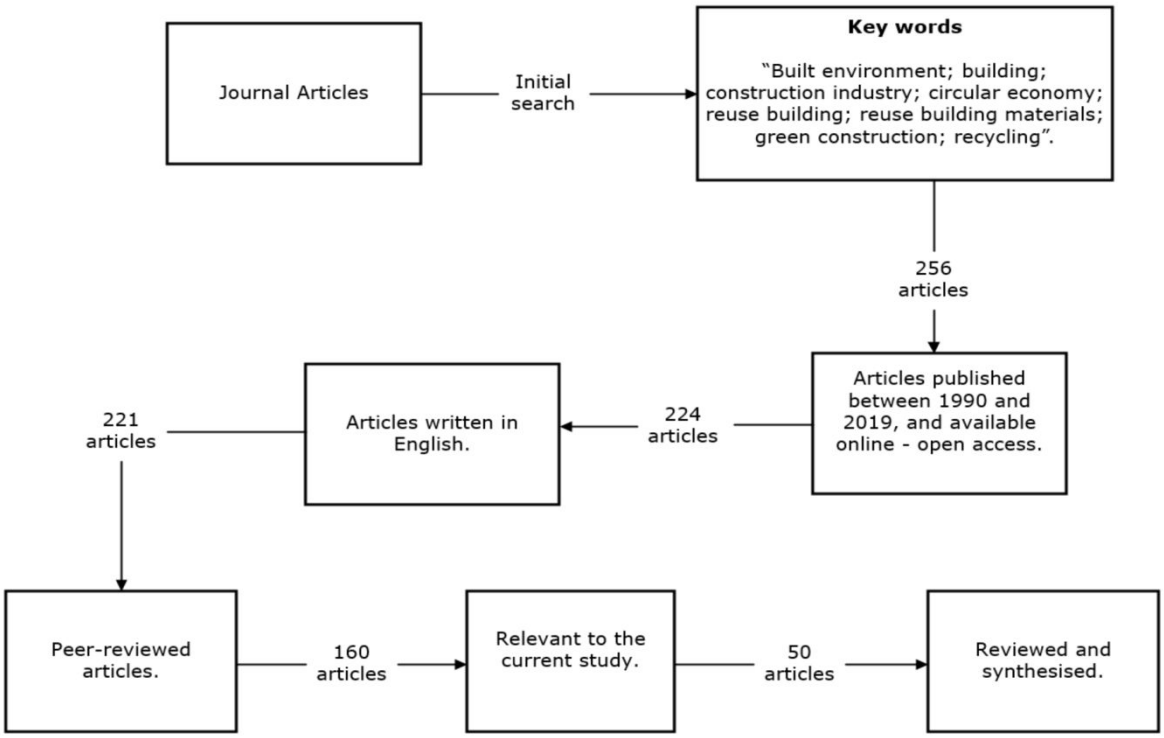

Figure 2: Steps employed for peer-reviewed journal article selection.

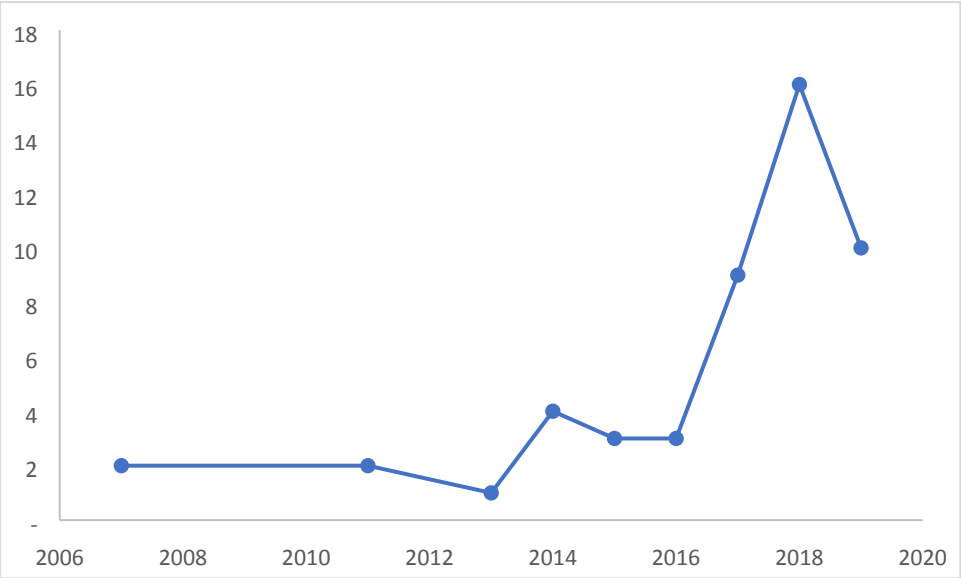

Figure 3: Peer-reviewed journal articles published by year (authors generated).

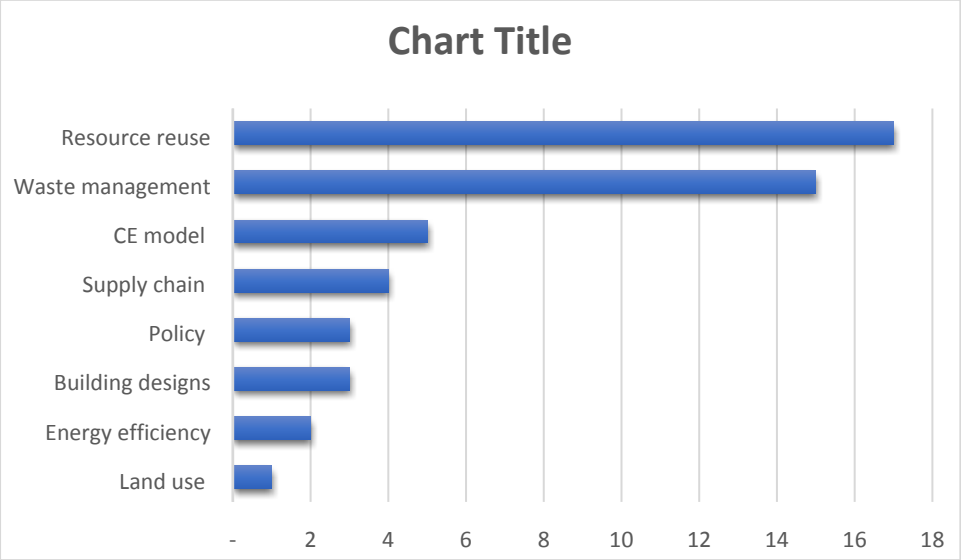

Figure 4: Research concentration (authors generated)

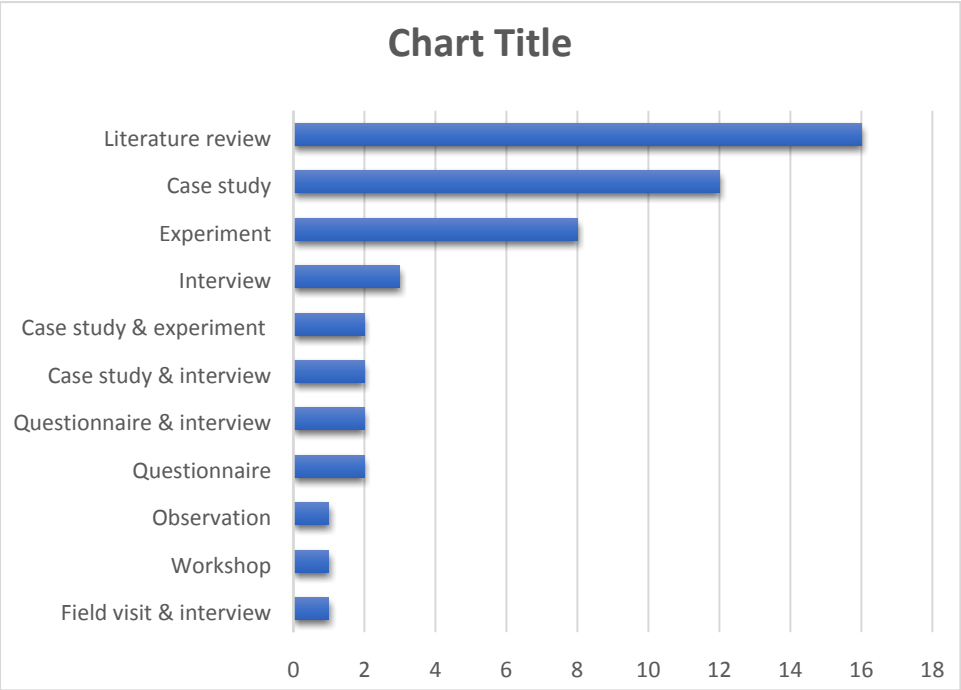

Figure 5: Data collection method

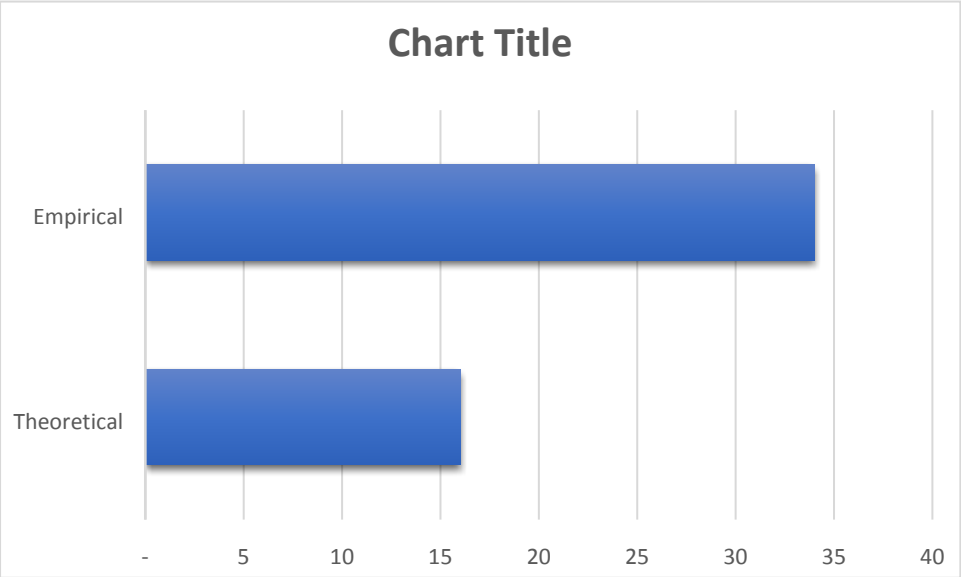

Figure 6: Article classification by research method

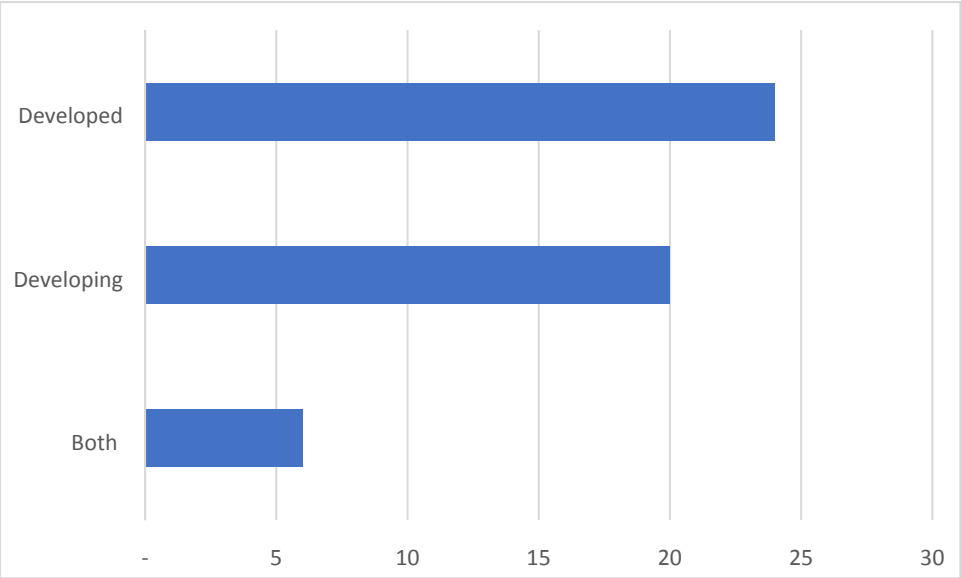

Figure 7: Article segregation by economy

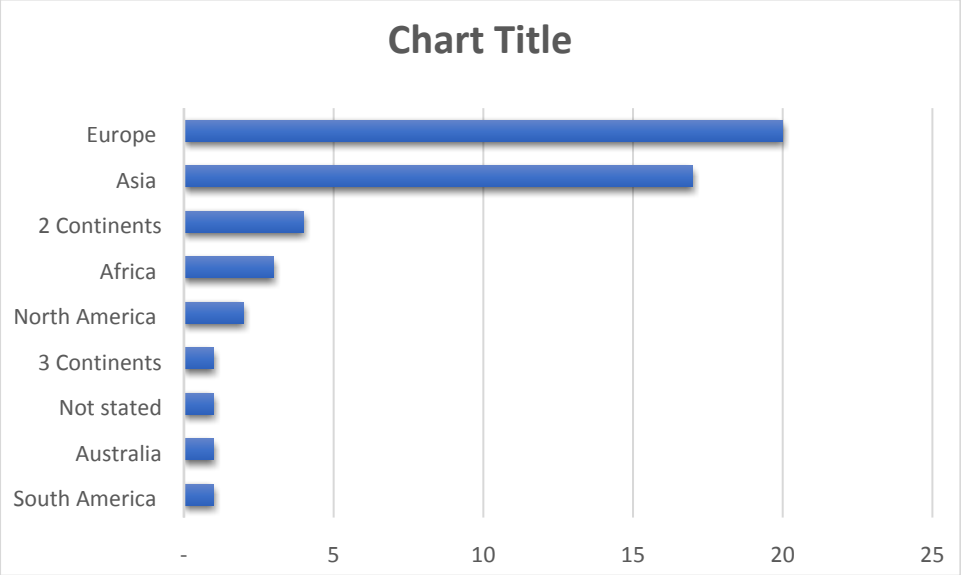

Figure 8: Article segregation by continent

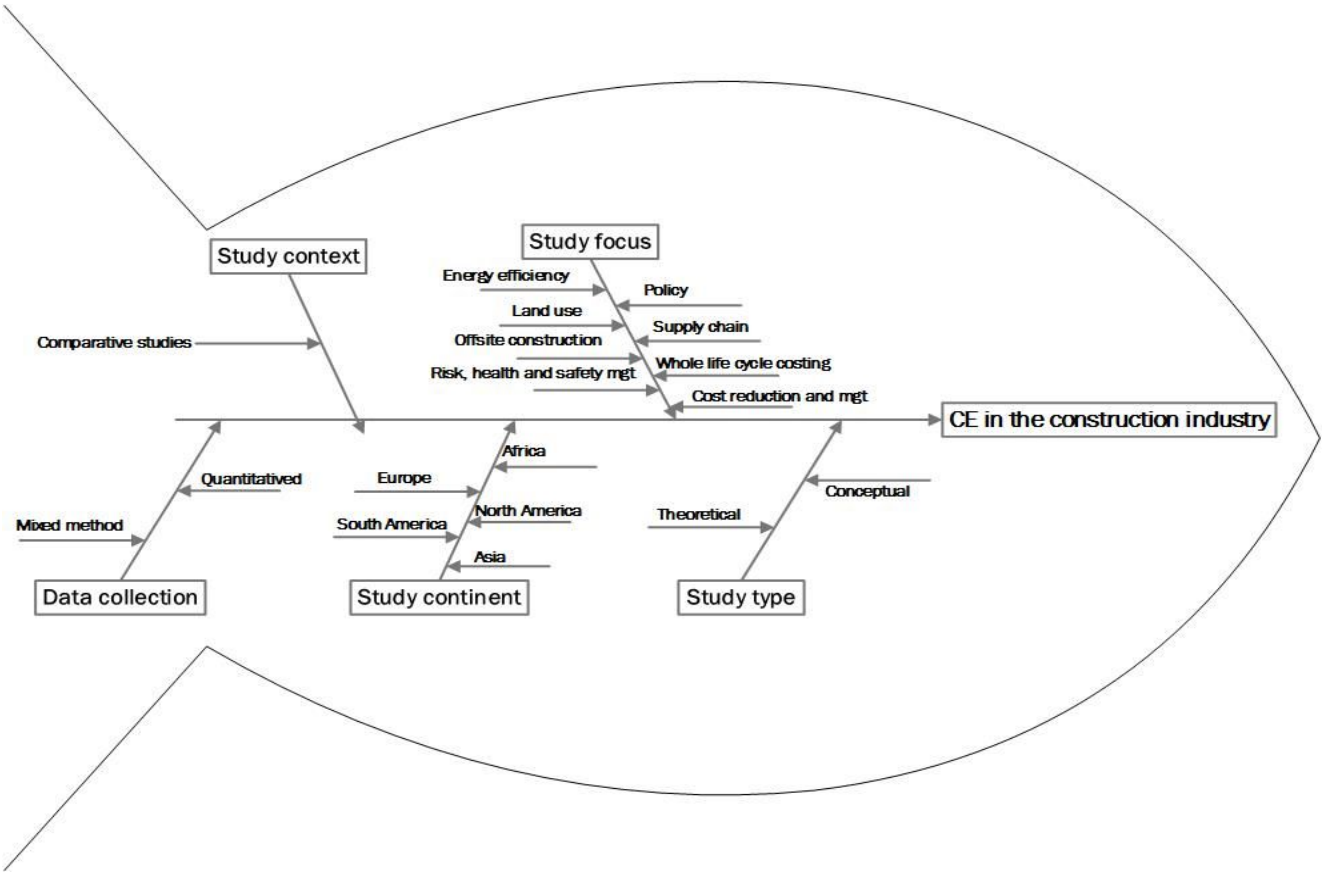

Figure 9: Framework for the future research agenda.