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# A REVIEW ON CIRCULAR ECONOMY AND ITS SYNERGY WITH INDUSTRIAL SYMBIOSIS

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## *ABSTRACT*

*The construction industry, a major contributor to global material consumption and environmental impact is also pivotal for economic growth and job creation. Hence, transitioning to concepts like Circular Economy (CE) and Industrial Symbiosis (IS) offers a sustainable pathway in reinforcing the industry by mitigating the negative impacts. CE emphasizes principles like reduce, reuse and recycling to close loops, while IS fosters this through cross-industry collaboration by repurposing waste and by-products. This study explores synergies between CE and IS in the context of the construction industry to address the implementation gaps of the two concepts. Through a narrative literature review, this study analyses definitions, and principles to CE adoption in construction sector, such as fragmented regulations, high costs, technical limitations. Moreover, findings reveal that IS is a critical enabler for CE in bridging implementation gaps. This is by facilitating material exchanges between different industries This study also explored current practices of these concepts in various regions. Though the studies prove this synergy, between CE and IS, it was also highlighted that practical challenges persist, at the same time underscoring role of the IS concept due to the lack of trust and systemic linkage. In concluding the research, it was emphasized that policymakers and industries must prioritize in creating and working on collaborative frameworks, standardising regulations while ensuring the construction sector aligns with sustainable development goals.*

**Keywords:** *Circular Economy; Construction Industry; Industrial Symbiosis; Sustainability; Waste Management.*

## 1. INTRODUCTION

Construction industry with its special features offers unique opportunities to a country, significantly contributing to the economic growth, creating job opportunities, and simulating development processes through projects such as infrastructures. However, the construction industry is known to be among the most material-intensive sectors globally, consuming massive amounts of raw material and generating massive amounts of waste. In the European Union, for instance, the construction industry consumes 1.2 to 1.8 million tons of raw material annually. In Netherlands, constructions industry accounts for approximately 50% of the overall material consumption (Yu et al., 2021). The situation

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is not all that different in the Asian region as well. Even though compared to Northern Europe and North America, many regions of Asia have a low material consumption, it still accounts for a considerable amount (Schiller & Roscher, 2023). Overall, the construction and building sector annually incorporates about 40% of the over 90 billion tonnes of raw materials extracted from the earth (Valentini, 2023). Further, the global consumption of building materials has tripled from 6.7 billion tons to 17.5 billion tons during the period from 2000 to 2017 (Huang et al., 2020). According to the global status report for building and construction, this sector significantly contributes to global climate change while accounting for about 21% of global greenhouse gas emissions. It also states that buildings were accountable for 37% of energy and carbon dioxide ($CO_2$) emission and 34% of global energy demand specifically in 2022 (United Nation Environment Programme, 2024). Most importantly, the process from extraction to manufacturing of these building materials itself has resulted in almost 90% of the life cycle environmental pollution.

These staggering environmental impacts has brought the need for a transformation towards Circular Economy (CE), a principle which the Ellen MacArthur Foundation defines as an industrial system which brings in a transition from linear “take-make-waste” model into a circular approach (Ellen MacArthur Foundation, 2013). One of the main reasons for a major part of waste generation is the linear economy, whereas in a CE, the circular approach can take the role and work in reducing waste generation. As a sustainable concept, CE shows a significant potential in actualization of the sustainable development goals. Therefore, CE was placed as the heart of sustainable development (Ogunmakinde et al., 2022). Hence, CE has the potential to effectively address the aforementioned issues that the construction sector is struggling with due to the environmental, social and economic pillars globally.

However, this transition towards CE requires practical measures. The actions that stand out among the current CE practices used in the industrial sectors are almost limited in aiming at recycling and reusing within a small range, usually within an organisation. In addition, there are number of studies conducted related to the importance of CE concept, even though the practical implementation of it seem to be lacking. However, recently, the necessity for the implementation of cross-cutting intersectoral networks have been raised as a way forward in transitioning towards a CE (Oskam et al., 2021). Therefore, rather than working in isolation, stronger connections and interactions between sectors have been recognized as important to improve the effectiveness of recovering and reusing materials. To ensure this, Industrial Symbiosis (IS), which focuses on intersectoral exchange of waste or by-products, should be uplifted and implemented universally (Castellet-Viciano et al., 2022). While the theoretical knowledge on CE and IS are well-established, and their individual benefits are acknowledged, yet there is notable gap in literature that explicitly addresses their combined potential to overcome the implementation barriers within specific industrial context, particularly the construction sector. Existing studies often discuss and explore these two concepts in isolation or provide a general overview of their synergy in various other context. However, this synergy has not been explored from a construction industry perspective

This study, therefore, aims to explore the CE and IS concepts and their synergy in the construction industry. This includes the lessons learned throughout the past decades by different countries, and both advantages and disadvantages experienced along with studying how to fill in the gaps of CE implementation through IS. Accordingly, to achieve the aim of the research, three objectives were formulated as follows:

1. Objective 01: To explore both CE and IS concepts.
2. Objective 02: To find the similarities and differences between CE and IS.
3. Objective 03: To create synergy in bridging the gaps in implementation of CE through IS in the construction context.

# 2. RESEARCH METHODOLOGY

The research aim was set to explore the concept of CE and its synergy with IS. To fulfil the aim, a narrative literature review was conducted. Selected existing literature sources were use to collect data for this study. Literature sources including journal articles, books and conferences papers were used to gather in-depth knowledge regarding the study area. Moreover, reports, news articles and well-established websites were also used to provide statistics to reinforce the findings. The data was collected by searching key words strings of "Circular Economy", "Industrial Symbiosis" and "Circular Economy" AND "Industrial Symbiosis" in combination. This method made it possible to explore more broadly and openly different sources related to the research topic. The search targeted scientific databases such as Google Scholar, Scopus, and Web of Science with an interest in literature on IS, CE and their integration with specifically focusing on the construction industry. During the process peer-reviewed journal articles, conference papers, and institutional reports were given a priority. Grey literature from Government reports, industry websites, and reputable news sources, gathered through an internet search, were also utilized to ensure that current viewpoints and actual scenarios were captured. This approach which included gathering data from a range of literature sources facilitated producing a wide overview of the field of study, beyond solely academic writing (Snyder, 2019).

# 3. CIRCULAR ECONOMY (CE)

The concept of the CE has been studied over the past decades and is now gaining significant traction among both researchers and practitioners. According to research, there is no specific single originator or an origin for the CE concept. Yet, many has contributed to bringing up this concept. Some of the significant contributors are Michael Braungart, a German chemist; John Lyle, a U.S. professor along with his student William McDonough and Walter Stahel, an economist and an architect, respectively. Later, in the 1990s, the CE concept was popularized, especially in China, as a response to natural resources scarcity and economic growth. Recycling was a noticeable factor within this concept (Winans et al., 2017). The CE practises in China, which were well-recognized with '3R" concept, was originated from Germany and Japan, where there was a greater desire in forming a more closed loop society (Geng & and Doberstein, 2008). Since there have been various countries and various researchers showing interest towards the CE concept with different views, this section intended to explore the concept of CE in detail, including its definitions, principles, benefits and its applicability for the construction industry.

## 3.1 DEFINITIONS AND PRINCIPLES OF CIRCULAR ECONOMY

There are various definitions for CE that can be found in different research papers, and minor changes can be seen based on aspects such as the year of introduction, the researchers, and the study contexts. Some studies have also attempted to collate these different definitions to develop a common definition for CE. Table 1 presents studies identified through an in-depth search of available resources.

*Table 1: Existing studies on different CE definitions*

| Authors | Title | Definition |
|---|---|---|
| Kirchherr et al., (2017) | Conceptualizing the circular economy: An analysis of 114 definitions | Acknowledge that CE understanding can be broader than a definition. They define CE as "an economic system that replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes." It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. |
| Geisendorf & Pietrulla (2018) | The circular economy and circular economic concepts-a literature analysis and redefinition | Stated that "The circularity indicators of the Ellen MacArthur Foundation (2013) only capture the product and company level but fail to provide ideas for the macroeconomic level."<br>They have revised the CE definition with distinguishing between core characteristics of a circular economy and framing conditions enabling its implementation. Their revised distinguish how the most common concepts mentioned by others are situated in different dimensions like efficiency/zero waste target, industry/service oriented, or micro/macro scope. |
| Awan, et al., (2020) | A Literature Analysis of Definitions for a Circular Economy<br>. | Twenty-eight definitions were taken into consideration covering a period from 1999 to 2019. This analysis revealed that up to this period, stakeholder perspective and resilience were not included explicitly in the definitions. Ultimately it stated, "Circular Economy (CE) is an activity, set of process for reducing the material used in production and consumption, promoting material resilience, closing loops and exchange sustainability offering in such a way that maximize the ecological system." |
| Alhawari et al., (2021) | Insights from Circular Economy Literature: A Review of Extant Definitions and Unravelling Paths to Future Research | Study focused on capturing the key aspect from the definitions that varied in their coverage and provide better understanding of the CE concept. The authors have defined CE |

| Authors | Title | Definition |
|---|---|---|
| | | in the following manner considering the organizational perspective - "CE is the set of organizational planning processes for creating and delivering products, components, and materials at their highest utility for customers and society through effective and efficient utilization of ecosystem, economic, and product cycles by closing loops of concerning resource flows." |
| Kirchherr et al., (2023) | Conceptualizing the Circular Economy (Revisited): An Analysis of 221 Definitions | The authors believed a clearer, more practical and relevant CE conceptualization can aid in maintaining proper connection between CE practice and research. Through their framework used to examine 221 definitions they also expected to see whether they are universally or locally tailored. This study focused on contributing an updated systematic analysis of CE definitions, while aiming to illustrate where the academic fields currently sit on its own understanding about this concept. They recognized and stated that final definition may never materialize. Moreover, they stated that depending on the regular shifting state of environmental conditions, technologies and economic and socio-political context the definition of CE is more likely to be on a state of evolution. |
| Sardianou, et al., (2024) | What are the key dimensions that CE emphasizes on? A systematic analysis of circular economy definitions | The authors found that CE definitions have focused on "waste management", "resource scarcity" and "recycling" activities. They also stated that "CE is typically viewed through the lens of waste management, emphasizing the need to reduce unnecessary demand, in addition to promoting efficient resource and product usage." The authors have not provided a specific definition but have analysed several existing definitions. They found and highlighted that "waste" and "recycling" as the central concepts of CE. |

## 3.2 CIRCULAR ECONOMY IN THE CONSTRUCTION INDUSTRY

The concept of CE offers a sustainable solution to the issues created by the linear material consumption trend which is "take, make, dispose" in the construction industry. CE seeks to maintain the material value at the highest point by following practices such as reducing, reusing, and recycling (Andrews, 2015; Lieder & Rashid, 2016). Academic definitions of CE in construction have converged around several key principles like reuse, recycle, recover, and all-together-framework like 3R and 4R (Kirchherr et al., 2023). Over the past decades, a significant transferring has been occurring in the industry, with the CE model adoption. It made a huge change in providing greater potential to reduce both resource extraction and waste generation for the construction industry. However, as stated by Benachio et al., (2020), there is a greater level of awareness which has been found within CE in the built environment research area about the need of change to a CE from the traditional linear economy concept. Yet, the real-world practitioners argue on the lack of standardized practices and methods to aid in proper implementation of CE in construction industry.

## 4. INDUSTRIAL SYMBIOSIS AS A SYSTEMIC ENABLER FOR CIRCULAR ECONOMY

The transformation from linear to circular economy needs efforts from everyone and especially from industries, as they play a vital role in transformative consumption and production patterns. European Commission being one of the practitioners had put their focus on different recommendations with measures for the transformation of the industrial sector to maximize recyclability and durability of materials, and through that, ultimately reduce the environmental impact. The initial step of industrial sector in CE strategies is aimed at implementing action plans like using recycled and reused products within production systems (Sardianou et al., 2024). Yet, as the CE concept move further towards seeking advanced criteria, in early 2000s they implemented an action plan transversally rather than vertically along the supply chain (Neves et al., 2020).

Hence, the need of cross-cutting intersectoral networks had arisen to ensure the sustainability of the industrial sector. IS is a subsector within industrial ecology that studies the flows of energy and materials. It has now evolved to an extent where it is viewed in broader terms rather than in isolation. As a result, it tries to interconnect the industries and their process in maximizing the use of energy and materials (Wadström et al., 2021). On the other hand, with the CE concept remarkably being more conceptualized and defined, IS also had started gaining more attention by companies to reduce waste emissions along with an urge to find alternatives for primary resource consumption. Thereby, IS was considered as one of the effective solutions that brings down the primary input consumption and environmental impact of waste emissions (Yazan et al., 2016). Chertow (2007) defined IS as “engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and byproducts. The keys to IS are collaboration and the synergistic possibilities offered by geographic proximity” (Chertow, 2007). According to the location and the case, the specificity of IS may change. Most importantly, IS only succeeds if companies are willing to take a risk and at the same it lasts only if both the waste supplier and waste user has build-up trust among them (Yap, 2005). Regardless of individual efforts, companies and industries must get together and interact to receive the maximum results of their actions and guarantee a smooth, effective and efficient flow of recovered and reused materials. To achieve this, IS, which is being practiced in some of the European countries must be universally implemented (Castellet-Viciano et al., 2022). According to Martin et al., (2015), IS can be identified as an effective enabler in accomplishing the principles of the CE.

### 4.1 DEFINITIONS AND PRINCIPLES OF INDUSTRIAL SYMBIOSIS

IS promotes physical exchanges of wastes, energy, and by-products among traditionally separated industries in a collective manner (Chertow, 2007). It is a sub-field of industrial ecology, which is now gaining attention through literature as a key strategy being supportive for the transition towards CE (Fraccascia & Giannoccaro, 2020). The main principle here is that two parties in particular, identified as waste producer and waste user, get together to establish a relationship where one would exploit the waste of the other party to make a new product or to replace an input in the production process (Patricio et al., 2022; Chertow, 2000). Chertow (2000) had defined the IS as "engaging traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity". This definition is widely being disseminated (Neves et al., 2020). A more recent definition by Haq et al. (2021) defines IS as "a collaboration scheme for competitive advantage where industrial trade is essential to developing a sustainable future because it involves resources, energy, water, and/or by-products being exchanged among various industries".

## 4.2 SYNERGIES BETWEEN CIRCULAR ECONOMY AND INDUSTRIAL SYMBIOSIS

CE concept's first roots run back to almost sixty years early consists of a fundamental part similar to Green Economy and industrial ecology, where IS is a sub-field of the industrial ecology. According to Andersen, (2007), IS seeks to optimize the management of the flow of materials, energy, water by-product, and ultimately to enhance the linear chain of consumption and production just as the CE concept. IS in particular, having a string to the CE, focus on operating at the inter-firm level (Yazan et al., 2016). As a result, IS has been identified as great potential component in facilitating CE by the European Commission (Álvarez & Ruiz-Puente, 2017).

### 4.2.1 Similarities and Comparative Analysis between Circular Economy and Industrial Symbiosis

Further to above findings from various literature, this section provides an overview of the most relevant similarities and differences between the two concepts, CE and IS, as depicted in Table 2.

*Table 2: Similarities between circular economy and industrial symbiosis*

| Similarities between CE and IS |
|---|
| Aims to integrate the principles of environmental sustainability. |
| Foster material circularity to ensure more efficient usage. |
| The idea of waste can be repurposed is central in both. |
| Thrives to build linkage and relationships in different level of degree. |
| Contribute and encourage in local collaboration, job creation and cost saving. |

The following Table 3 further provides a comparison on the key aspects of CE and IS concept.

*Table 3: Comparative analysis between CE and IS*
*Source: Adapted from Vargas-Merino et al., (2022), Chertow & Park (2016) and Neves et al., (2020).*

| Factor | Circular Economy | Industrial Symbiosis |
|---|---|---|
| Main Goal | Slow down the scarcity of natural resources while minimizing environmental | Collaboration between industries to exchange materials, waste, |

| Factor | Circular Economy | Industrial Symbiosis |
|---|---|---|
| | damage through reducing pollutions. | energy and by-products to reduce environmental impact. |
| Research area | A wider range of recovery system | Generally, the direct physical exchange of materials, energy and by-product through pipelines system |
| Focus/Emphasizes on | Materials and products of all kinds | Largely industrial waste and by-product |
| Bottomline of the Term | Encourage resource efficiency and reduce waste through recycling | Enhance industrial collaboration and facilitates resource sharing. |
| Mainstream | Minimization of resource extraction; minimize waste | Waste-to-Resource, Inter-industry collaboration |
| Fundamental Principles | Developing imperative of sustainable development R; 3Rs improved to 9Rs | Cross-Sector collaboration, Sharing among waste producer and waste user |

### 4.2.2 Industrial Symbiosis to Address Gaps in Circular Economy Implementation

CE is well-known to be a broader concept that tries to bring out the sustainability. In fact, the system-level approach of CE has been organized into three levels, named as the macro, meso and micro level. Each level has gaps which are needed and are being address. As the Figure 1 below elaborates, along with our key consideration on both levels of CE and IS, has been found go to hand in hand. In fact, IS has the potential to fill the gap within a wider approach to fill the one of the gaps of CE in practical implementation (Palagonia et al., 2025).

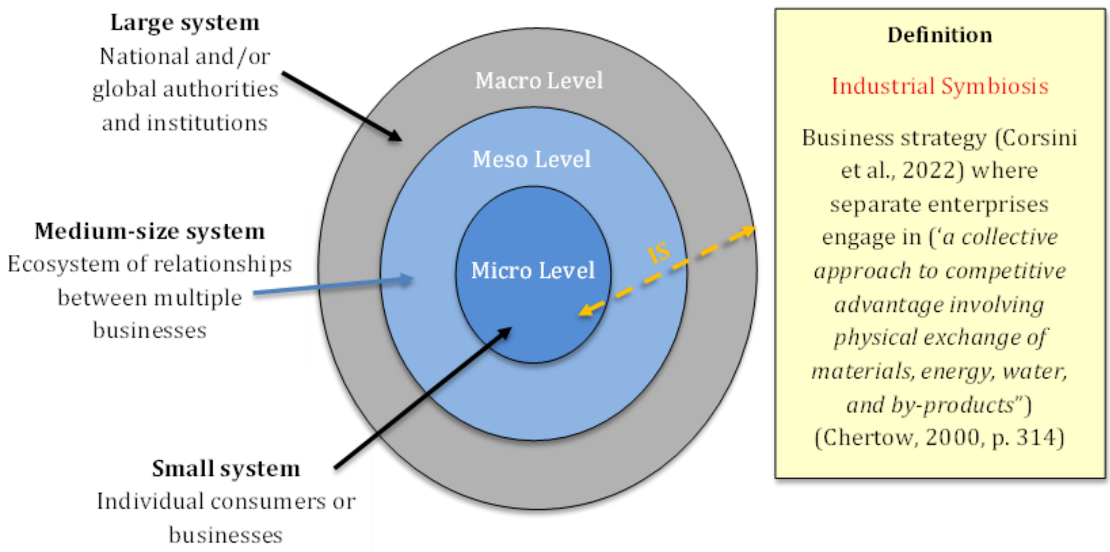


*Figure 1: The industrial symbiosis within circular economy system level*
*Source: (Palagonia et al., 2025)*

#### 4.2.3 Collaborative Opportunities between Construction and other Industries

Park et al. (2015), had studied nine case resources circulating under IS development, where those projects delivered major benefits in Korea without a requirement of any investments. For instance, heat transfer salt which has reach the end-of-life stage in petrochemical process was repurposed in an easy manner as descaling salt for stainless steel. In another case, a waste organic solvent was directly used as a paint ingredient. For this no extra process was needed. Moreover, there have been IS activities seen in Europe as well regardless less attention in the literature related to this area. The European commission had introduced a revised CE package as an action plan for the CE where they refer the role of IS in focusing on the concept where "*waste or by-products of one industry to become inputs for another"* (Domenech et al., 2019). There has been waste recovery practice through IS found in two construction projects in Brazil. Through this it was found that those two project had 9% and 30% of waste was recovered through IS (Freitas & Magrini, 2017).

#### 4.2.4 Conceptual Framework for Bridging Circular Economy Gaps through Industrial Symbiosis in the Construction Sector

According to the findings, a conceptual framework is proposed in Figure 2 which illustrates how the IS enables the implementation of CE principles within the construction sector by bridging the gap.

At the base of the framework, lies the construction industry which is traditionally resource-intensive and operates under a largely linear model of "take-make-dispose". Regardless, the increasing recognition of CE principles like reuse, recycling, and resource efficiency, there is a clear and greater implementation gap that hinders their full adoption in practice. Hence, the "gap" has been positioned at the centre of the framework representing the disconnection caused by barriers such as fragmented regulations, limited collaboration, technical challenges and high cost. The framework highlights that IS can effectively address this gap along with the proper contribution from Strategic/Policy Layer and Industry Actors. Through encouraging collaboration between different industries, IS facilitates the exchanges and repurposing of material, energy, and by-product transforming waste from one process into valuable input of another.

Finally, the goal is presented on top of the framework, which is an improved CE in the construction industry. As a result, the construction industry can move beyond isolated efforts and adopt more systemic, sustainable practices that align with the broader goals of environmental and sustainable development.

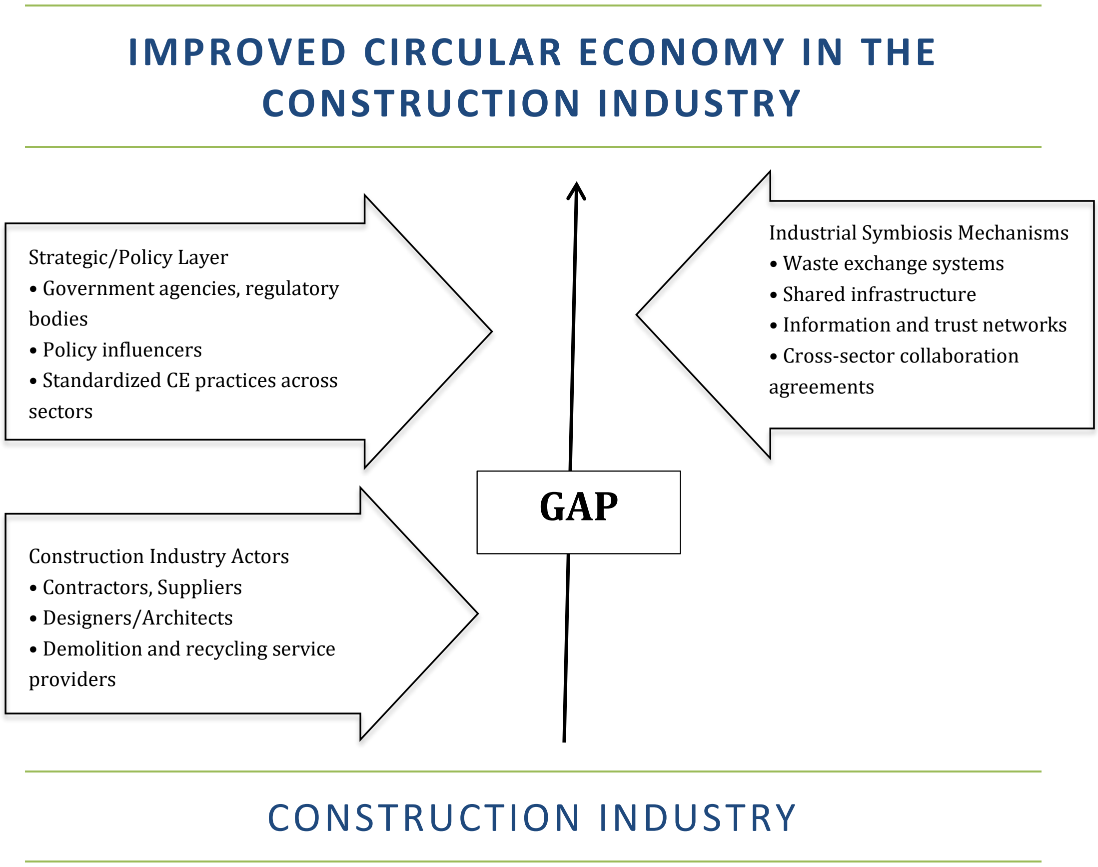


*Figure 2: Conceptual framework for bridging circular economy gaps through industrial symbiosis in the construction sector*

## 5. CONCLUSION

At present, CE is gaining attention increasingly as one of the promising solutions to address the environmental issues and the challenges of resource depletion. It was also found that even though CE has the potential to deliver significant environmental, economic and social benefits, it also includes gaps that has impacted on the proper and effective implementation of the concept in terms of all three levels (macro, meso, and micro). IS has the potential to connect within wider approach of CE and shift towards a multilevel framework. Studying about the synergies between CE and IS can help in better understanding the concepts and their effective implementation for beginners. Among the many definitions, understanding the concepts in an analytical manner and comparing the two concepts based on their similarities and differences, this study aimed at building awareness about the linkage between the two concepts. Through this narrative literature review, the authors presented various definitions on the concepts and similarities of both the concepts, where it was clear that CE and IS has goals in-line, except that CE is a broader concept than IS. The findings of this study highlights that IS directly addresses several crucial implementation gaps in CE, such as lack of systemic linkages, fragmented material flows and challenges faced in establishing cross-sectorial collaboration. Considering that this study provides evidence for the potential of IS in filling implementation gaps within CE, it would be a great contribution to study on the mechanism to initiate this and recommend frameworks for better progression. The construction industry must see to it that they are actively seeking and establishing collaborative partnerships for material and energy exchange. This can be achieved through fostering trust and investing in infrastructure that supports inter-firm resource flows. Policymakers may boost this process through developing and enforcing regulatory frameworks and incentives that may specifically promote IS networks within the construction industry. It could include tax breaks while researchers focus on developing practical tools and guidelines to facilitate the formation and management of IS networks.

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