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From green to regenerative supply chain management in construction: Towards a conceptual framework

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ABSTRACT

Green Supply Chain Management (GSCM) has emerged as a valuable managerial strategy in the construction industry, dedicated to instilling environmental sustainability principles throughout the lifecycle of construction projects. Despite its wide adoption, the built environment continues to generate numerous negative environmental impacts such as significant greenhouse gas emissions, resource depletion, excessive waste production, habitat destruction, and more, thus intensifying climate change. To address this, a shift toward regenerative thinking that goes beyond minimizing negative impacts to actively regenerate ecosystems, restore depleted resources, and regenerate damaged habitats is deemed necessary. This study builds on established GSCM practices and identifies their shortcomings in achieving 'true sustainability'. In response, it introduces a novel Regenerative Supply Chain Management (RSCM) framework that incorporates key regenerative principles: Focus on Place, Harmony with Place, and Co-evolution which offers a more comprehensive approach, facilitating a transition towards regenerative practices. Overall, this framework not only offers insights into advancing green or sustainable thinking in construction but also provides practical implications for the industry. By embracing regenerative practices, the construction sector can actively restore and renew the built environment, fostering a more restorative and resilient future.

1. Introduction

Similar to other sectors, Green Supply Chain Management (GSCM) holds substantial significance within the construction industry as it encompasses a series of steps from the initial planning or design phase to the conclusion of the building's lifecycle. Embedded within the traditional supply chain framework, GSCM prioritizes environmental preservation, economic advantages, and social enhancements, with the ultimate aim of reducing and potentially eliminating the adverse environmental effects of the construction supply chain (Jing et al., 2019; Jum'a, 2023). This concept encompasses green design, manufacturing, purchasing, transportation, and reverse logistics, all integrated into the traditional supply chain networks (Balasubramanian and Shukla, 2017a). Multiple studies have examined the core aims of GSCM in construction. These encompass enhancing a firm's competitive edge (Woo et al., 2016), delivering additional value to stakeholders (Da Rocha and Sattler, 2009), and enhancing the ecological, economic, and operational performance of a supply chain (Balasubramanian, 2014).

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While GSCM presents numerous benefits when applied in the construction sector, its principles often centre on designing and constructing buildings with minimized environmental impact or achieving isolated sustainability gains. However, the prevailing population growth, the need to improve construction techniques, continual resource consumption, environmental deterioration, and the increasing impacts of climate change highlight the imperative for a fundamental transformation in the interaction between humans and the natural environment. (Petrovski et al., 2021). Existing tools and frameworks aimed at assisting building professionals in moving beyond green or sustainable practices lack sufficient acknowledgement of the interconnection between human development and the broader environment, while also failing to comprehensively incorporate elements such as education, community engagement, and socio-economic diversity (Plaut et al., 2012). Hence, there is an urgent call for embracing regenerative thinking (Mang and Reed, 2012) which highlights the significance of actively interacting with the natural world and nurturing a collaborative relationship with nature through adaptive, resilient, and restorative approaches. (Du Plessis, 2012). The emerging concept of regenerative thinking promotes a departure from green or sustainable thinking (Petrovski et al., 2021). While green initiatives or sustainability aim to minimize environmental impact, the regenerative concept focuses on fostering the health and evolution of social and ecological systems (Brown et al., 2018).

This study, therefore, explores the key issues surrounding the prevalent GSCM practices utilized within the construction industry. Although these practices aim at achieving green or sustainable performance outcomes, they fall short of encompassing the comprehensive solution needed to actively restore and improve our built environment over time. In response, this study proposes the integration of the regenerative concept into each GSCM phase in an attempt to develop a novel Regenerative Supply Chain Management (RSCM) for the construction industry. Unlike conventional green or sustainable performance outcomes achieved through the GSCM practices, the RSCM practices emphasize the continuous improvement of our built environment over time, moving beyond mere sustainability.

Drawing from the prevalent overemphasis on green or sustainable construction practices and the limited attention given by researchers (Abdolazimi et al., 2024; Le and Nguyen, 2024; Oyefusi et al., 2024) to improving GSCM practices beyond merely reducing harm or achieving sustainability, the main research question of this study is: How can GSCM shift from a green to a regenerative paradigm in the context of the construction industry? To further explore this main research question, the following sub-question was first developed.

RQ1: What are the dominant forms of GSCM practices used in the construction industry and their performance limitations?

To address this question, this study started with a comprehensive review to understand the current GSCM practices in construction, including their performance limitations. In essence, this phase generated two valuable research outcomes: (i) the main stages of GSCM used in the construction industry and (ii) their performance limitations.

Building upon the research outcomes of the first research question, the following sub-question was further developed.

RQ2: How can regenerative principles be integrated into the current GSCM practices used in construction to enable a transition from simply mitigating environmental impacts or achieving sustainability, towards promoting a more harmonious relationship between humans and the natural world?

To address this question, an extensive literature review was first conducted to establish the foundational principles of the regenerative concept. Based on this foundation, evidence-based regenerative practices were identified. These practices were then strategically integrated into each phase of the construction supply chain management (SCM) process, resulting in the development of a conceptual RSCM framework. The RSCM framework differs from that of GSCM by incorporating unique elements, such as targeted ecosystem restoration, resource replenishment, habitat regeneration, community co-evolution, biodiversity enhancement, and dynamic feedback mechanism, amongst others which are designed to create a net positive environmental impact. As such, the RSCM framework proposed in this study provides a more comprehensive approach that enhances the understanding and practical application of regenerative principles in construction.

The contribution of this study has theoretical, methodological, and practical implications. As such, construction professionals can leverage this knowledge to remain abreast of the most recent developments and approaches in regenerative practices throughout the construction SCM phases.

1.1. Research gaps, novelty, and framework

The construction industry plays a significant role in global environmental deterioration, contributing significantly to resource depletion, waste production, and greenhouse gas emissions (Li et al., 2019; Wu et al., 2019). Efforts to mitigate these impacts have led to the emergence of GSCM practices in the construction industry. However, while GSCM focuses on reducing negative environmental impacts and achieving various sustainability benefits, it falls short in addressing the pressing issues that our built environment faces (Oyefusi et al., 2022). According to (da Costa Gonçalves et al., 2023; Hou et al., 2021), the built environment is currently dealing with climate change, environmental degradation, and a growing need to adapt to the challenges brought about by a changing planet. The shift from sustainability towards a regenerative approach acknowledges the need to address past damages, actively repair and restore, and create a more resilient and adaptive built environment over time (Mang and Reed, 2020).

Fig. 1 illustrates the existing gaps in the established knowledge base concerning GSCM practices in the construction industry, alongside the remedies proposed by this study. Unlike other industries such as agriculture (Okeke et al., 2022; Soto et al., 2021),

manufacturing (Rahimifard et al., 2018), technology (Gulotta et al., 2022; Jayasree et al., 2023), healthcare (Greig et al., 2004; Kim et al., 2016; Pereira et al., 2011), transportation (Clarke et al., 2010; Kebede and Worku, 2021) amongst others, where regenerative principles and practices have gained traction, the construction sector lacks well-defined and conceptualized principles or practices. Understanding if these principles can be integrated into the construction industry or if a need to develop a new set of principles remains unexplored.

To address the aforementioned gaps, it is evident that there is a need to develop a conceptual framework that outlines regenerative principles and practices specifically tailored to the construction SCM. Such a framework would guide construction stakeholders on integrating regenerative practices into their supply chain operations, thereby facilitating the transition towards more resilient construction processes and outcomes.

Overall, the novelty of this study lies in its departure from traditional sustainability practices by proposing a comprehensive shift towards regenerative thinking. Unlike GSCM, which primarily addresses sustainability through reductionist measures, the RSCM framework offers a transformative approach that aligns SCM with broader ecological goals. It facilitates a transition from sustainable to regenerative practices, ensuring that each phase of the construction supply chain contributes to environmental restoration and renewal.

Building upon the aforementioned research gaps and the novelty this study aims to present, the overall research framework for this study is illustrated in Fig. 2, which outlines the paper's organization into four sections. Section 1 presents a comprehensive literature review concerning GSCM and the regenerative concepts, Section 2 elaborates on a conceptual framework underpinned by relevant regenerative principles, Section 3 provides a discussion of this study, and Section 4 concludes the study while addressing its implications and limitations.

2. Literature review

2.1. GSCM in construction: major stages and performance limitations

To fully understand the concept of GSCM in the construction industry, Ming et al. (2019) define GSCM as an innovative approach that integrates environmental concerns involving all stakeholders from design through procurement, materials selection, project completion, handover, and even the end-of-life phase. This integration aims to enhance an organization's competitiveness and long-term profitability. Similarly, Da Rocha and Sattler (2009) proposed that GSCM encompasses managing all supply chain activities to minimize environmental impacts across the final products i.e. buildings or infrastructure, ultimately striving for zero net harm to the environment.

Numerous GSCM practices applicable to the construction industry, along with their respective categorizations, have been identified in extant studies. For instance, Hopkins (2016) highlights the importance of green design as a crucial stage of GSCM, emphasizing its significant impact on quality, time, and cost within construction projects. It encompasses practices such as specifying recyclable materials, integrating solar energy systems, designing with minimal material and energy consumption, and selecting sustainable sites, amongst others (Liu et al., 2012; Wibowo et al., 2018). According to Chowdhury et al. (2016), green design involves integrating environmentally conscious principles into conventional design methods, aiming to mitigate adverse environmental effects. Though Zhang et al. (2011) revealed that green design varies across industries, encompassing activities aimed at minimizing a product's environmental impact throughout its lifecycle, Rostamzadeh et al. (2015), on the other hand, revealed that the green design stage often commences with an environmental impact assessment to understand the building's ecological consequences.

Similar in importance to green design, green purchasing involves integrating environmental considerations into construction

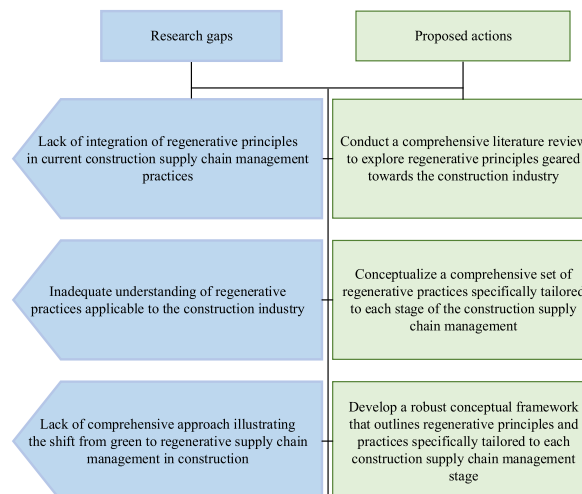


Fig. 1. Research gaps and proposed actions investigated in the study.

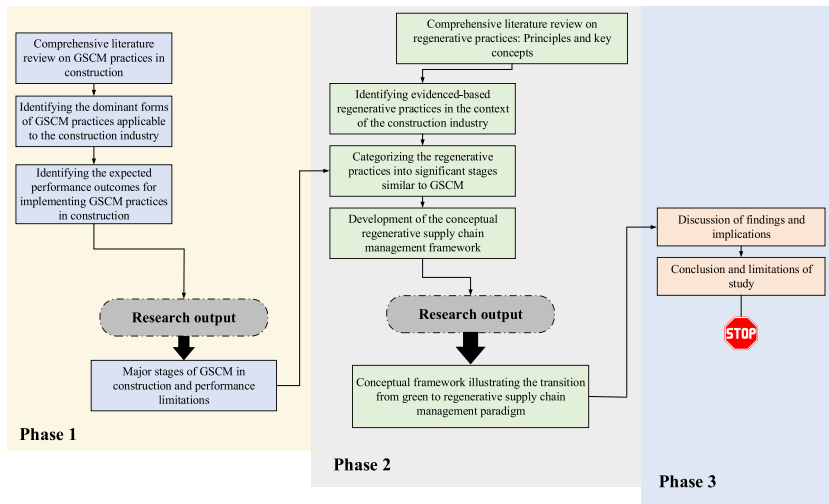


Fig. 2. Research framework.

project procurement processes (Balasubramanian and Shukla, 2016). According to (Rostamzadeh et al., 2015; Wang et al., 2024), green purchasing entails acquiring environmentally friendly materials and products, aiming to ensure they possess the required environmentally friendly features. In construction, Balasubramanian and Shukla (2017b) stressed that the integration of green purchasing should begin during the pre-qualification stage, with suppliers requiring an Environmental Management System (EMS) and ISO 14001 certification. Other examples of green purchasing practices applicable to the construction industry include assessing suppliers’ environmental performance, procuring non-toxic materials, selecting suppliers based on their green initiatives, and more (Ali et al., 2020; Bohari et al., 2024; Esfahbodi et al., 2016; Laosirihongthong et al., 2013).

Green transportation, on the other hand, seeks to mitigate the adverse environmental effects of transportation systems in the context of GSCM in the construction industry. It is worth highlighting that green transportation practices complement other GSCM stages, such as green design and green purchasing (Kazancoglu et al., 2018). Efforts to address the environmental footprint of construction activities during the transportation stage of GSCM include the use of green practices such as stacking vehicles for material transport, using fuel-efficient vehicles, conducting virtual meetings, prioritizing shared and public transport, amongst others (Al-Ma’aitah, 2018; Ng et al., 2012). Additionally, the reviewed literature consistently highlights green construction as a prominent stage of GSCM in the context of construction. According to Seth et al. (2016), green construction encompasses practices that consider energy use, water consumption, and toxicity at construction sites.

Finally, End-of-Life (EoL) Management, also known as Reverse Logistics (RL), is another crucial stage of GSCM in construction. This stage encompasses green practices that serve as a corrective measure for addressing environmental waste in various industries, including construction (de Campos et al., 2017). Implementing EoL Management practices necessitates green practices such as careful planning and the integration of energy-efficient demolition procedures to ensure material recovery (Smol et al., 2015) and extend the

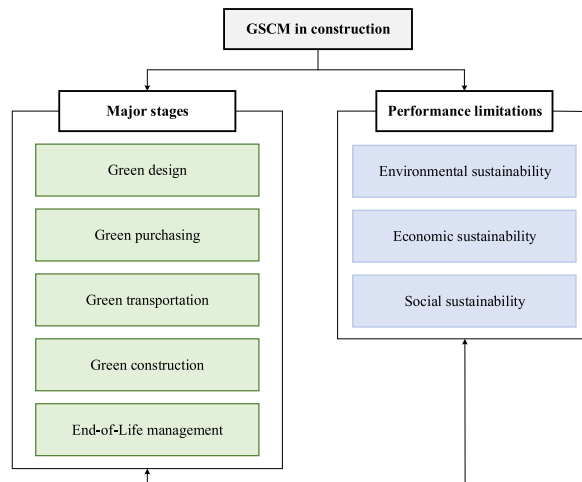


Fig. 3. Major stages of GSCM and their performance limitations.

life of building materials during the deterioration stage (Hosseini et al., 2015).

Furthermore, extant studies reveal a significant set of performance evaluation criteria used in defining how well GSCM practices perform in the construction industry. These studies have demonstrated that GSCM practices primarily aim to achieve environmental sustainability by reducing waste, greenhouse gas emissions, and the harmful consumption of materials and energy (De Giovanni and Vinzi, 2012). More so, Dashore and Sohani (2013) added that GSCM practices offer strategic means to combat environmental issues, such as waste reduction and pollution mitigation.

Beyond environmental sustainability benefits, GSCM practices in construction also yield economic sustainability. Construction companies implementing GSCM practices aim for economic sustainability, alongside environmental objectives (Xie et al., 2022). This involves reducing expenses related to materials, water, energy, waste treatment, and environmental penalties (Al-Ma'aitah, 2018).

Though much of the performance evaluation of GSCM practices has focused on environmental and economic sustainability, social sustainability has begun to receive increasing attention. Researchers are recognizing the importance of evaluating GSCM practices against social criteria, including employee health, client satisfaction, education, community engagement, and more (Balasubramanian and Shukla, 2017b; Gimenez et al., 2012; Zailani et al., 2012). More so, extant studies such as Le (2020)'s comprehensive GSCM practice performance model have shown that GSCM practices, like green design, purchasing, transportation, and construction can improve the social sustainability performance of the built environment.

In conclusion, Fig. 3 illustrates the major stages of GSCM practices currently used in the construction industry and their performance limitations, primarily focused on achieving sustainability alone.

2.2. The regenerative concept

Recently, the definition of sustainability has started changing due to the rising field and the need for the regenerative concept (Mang and Reed, 2020). Several authors have attempted to define the regenerative concept. For example, Jenkin and Zari (2009) define the regenerative approach as a systemic approach that integrates the damages caused by deteriorated sites back to an acceptable healthy state through the intervention of human activities and biophilic designs, thereby fostering a reconnection between people and nature. Mang and Haggard (2016) on the other hand define the regenerative concept as a framework encompassing developmental strategies aimed at enhancing the co-evolutionary relationship between humans and ecosystems, thereby fostering the planet's ongoing expression of diversity, complexity, and inspiration. Furthermore, Cole (2012a, 2012b) defines the regenerative concept as a fundamental approach that reconceptualizes the process of construction to encompass its broader role and impact within a larger context.

Following the numerous definitions of the regenerative concept in extant studies, it is evidenced that the consensus among the researchers is that sustainability is not enough to make the fundamental change we need in our built environment, hence there is a need for the introduction of the regenerative concept that seeks to create a mutually beneficial environment to both human and the ecosystems over time.

The regenerative concept redefines our understanding of the built environment, shifting away from the traditional building-centric definition to encompass the interconnections among buildings, infrastructure, natural systems, and the broader context of communities, including their culture, economy, and politics (Mang and Reed, 2012). To enable the construction industry to shift towards regenerative thinking, Craft et al. (2017) concluded that less emphasis needs to be placed on building elements and more on processes that focus on the co-evolution of the whole system; that is making a case for humans to be equally and part of the built environment.

Furthermore, the emerging concept of regenerative approaches is not solely spearheading the redefinition of sustainability but is also reshaping the parameters of the built environment and its roles (Mang and Reed, 2020). Today's green and sustainability practices tend to fall into the degenerating or zero-impact paradigms which mainly aim to achieve net-zero or carbon-neutral outcomes. Hence, there is a need for a transition towards a living and a whole system of thinking called the regenerative concept. To fully understand the difference between the green, sustainability and regenerative concepts, Fig. 4 presents the positions of each concept within the built

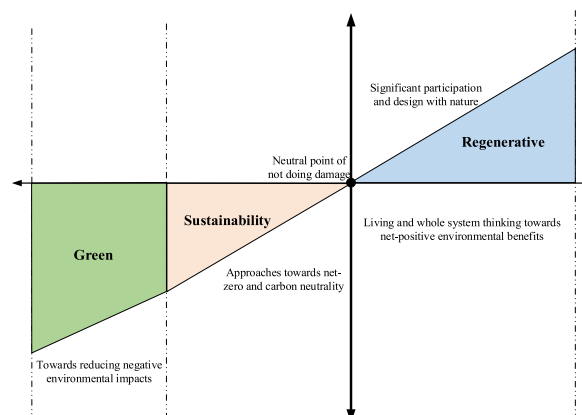


Fig. 4. Positioning green, sustainability and regenerative concepts (Modified from (Reed, 2007)).

environment context.

2.2.1. Principles of the regenerative concept

The first step towards achieving a regenerative built environment is not a change in technique but a change in our mindset (Mang and Reed, 2012). As a result, the following subsections encapsulate the three key principles and evolving processes for framing the approaches of the regenerative concept, as depicted in Fig. 5.

Principle 1. Focus on place. Integrating the regenerative concept in the built environment should begin with understanding the changing dynamics of our place i.e. the human and natural systems to identify the opportunities for realizing better health and capability due to the presence of humans in that environment (Mang, 2017). Moreover, Mang and Reed (2012) reinforced that the principle of focus on place is all about recognizing our built environment as a dynamic entity with its own distinct story and future; continuously influenced by the surrounding ecosystem. In essence, this principle aims to gain an extensive understanding of the unique characteristics that the built environment seeks to possess. This level of understanding is different from the green or sustainable construction process.

While the green or sustainable construction processes start with gathering isolated information from experts regarding the water, energy, soils, and many more required for construction, Mang and Reed (2012) added that the regenerative concept goes beyond this by integrating a systemic approach to understanding on how such information works in connection with the unique characteristics of the built environment.

Critically, the principle of focus on place works at the intersection of developing a strategic process to better understand the right approach to integrate regenerative solutions, thus enabling our built environment to achieve its highest level of potential and make the construction stakeholders become cocreators of such solutions (Cole, 2012b; Du Plessis, 2012).

Principle 2. Harmony with place. The principle of harmony with place emphasizes developing a built environment that also repairs the systems or the world around and within it so that the built environment can become a whole; encompassing all systems (Mang and Reed, 2012). Du Plessis (2012) supports this assertion and as a result, proposes two fundamental questions namely; how can we harmonize ourselves with nature? and how can construction activities improve the overall well-being of the built environment? Many researchers have attempted to respond to these questions through different approaches. For example, Birkeland (2014) suggests that the built environment must develop in harmony with the human and natural systems in terms of increased population, pollution, poverty, biodiversity loss, and more. Furthermore, Sertyesilisik (2017) stressed that the built environment should be developed in harmony with its location and adapt to changes in technology throughout its lifecycle. With this, the needs of the community are kept in harmony with their location. In the same vein, Cole (2012a) pointed out that there is a need to keep a unique identity of our built environment as it provides harmony between the fast-rising and changing components, people and events, thus making our built environment distinctive. The author further concluded that keeping certain unique characteristics of the built environment is essential for conserving historical areas of the built environment to bring harmony to life, nature and spirit.

Principle 3. Co-evolution. The regenerative concept does not end at identifying the potential of the place and incorporating strategies in harmony with the human and natural systems. Co-evolution, the third principle to achieve a regenerative built environment emerges during or from the outputs of the two principles described in the previous subsections. During this phase, the role of a built environment shifts and becomes one that will actively engage individuals who will be responsible for its ongoing sustenance and

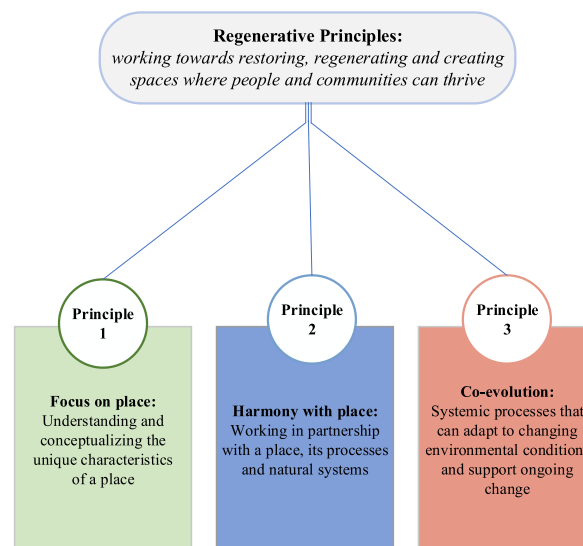


Fig. 5. Principles of the regenerative concept.

development as it progresses (Mang and Haggard, 2016). Since the future of all systems is uncertain, there is a need for a regenerative principle called co-evolution that handles uncertainty, most especially those related to the fact that human systems in the built environment are open to different opportunities (Cole et al., 2013).

Besides, one of the major challenges of today's design or construction practices is to identify and integrate important practices that drive the co-evolution process (Dorst, 2019). Nonetheless, implementing the principle of co-evolution involves a substantial level of systemic intricacy and dynamism, one that incorporates multi-levels of nested systems, and requires the involvement or consideration of the human and natural systems (Marcotullio, 2008).

2.2.2. Regenerative supply chain management practices

The first research output of this study has described the concept of GSCM in construction including its major stages and practices applicable to each stage. However, the following subsections introduce evidence-based regenerative practices, derived from regenerative principles, which are seamlessly incorporated into the major stage of the construction supply chain, mirroring the structure of GSCM. This integration contributes to the development of a novel, RSCM that seeks to answer the second research question.

Regenerative design. Extant studies have been able to reveal several regenerative practices that could be incorporated during the design stage of construction SCM. For example, Craft et al. (2017) proposed a set of regenerative design practices in developing a design model aimed at investigating the fundamental interactions between human and natural systems, thus providing net-positive benefits. Their study revealed that creating a visually engaging entrance that blends natural elements with social interaction spaces such as walkways and integrating a building façade that extends to integrate planter boxes are important regenerative design practices. With this, the entrance helps to strengthen occupants' connection to nature, thus improving their well-being and connection to nature, while the façade on the other hand helps with engaging with the natural system by providing Indigenous wildlife habitat to improve biodiversity, preserving the ecosystem, and increase the building's adaptability to changing climate conditions.

In an attempt to search for the best design approach to solve the current global problems and at the same time evolve with the human and natural systems, Bonyad et al. (2018) utilized the three principles of the regenerative concept to identify and validate the appropriate design practices for achieving regeneration during the design phase of a building project. The results of the findings revealed that designing with nature, encouraging architects or designers to reflect the local context of the building occupants, integral assessment—a whole system that preserves the cultural identity of the occupants, and designing to the energy requirement of the building (such as passive solar designs) rather than just specifying the regular sustainable technologies that might not be able to produce as much energy needed by a building are the most prioritized practices by experts for achieving a regenerative building during the design stage.

Other notable evidenced-based regenerative design practices identified in the literature include the incorporation of public art and design elements solely for human delight (ILFI, 2019; Petrovski et al., 2021), specifying murals inspired by nature intended mainly for human delight and celebration of their culture and place (Williams and Williams, 2019), assessment of site and place as living systems (Mang and Reed, 2020), and integrating public spaces that promote inclusivity and accessibility for all individuals (Attia, 2018; Plaut et al., 2012; Zari, 2010).

Regenerative purchasing. To integrate the regenerative concept during the purchasing stage, Peretti and Druhmman (2019) advised that construction stakeholders should first address all ecosystemic questions related to regenerative design, such as: Will the material last? Will the materials require much energy to produce? How does it contribute to the social needs of the local community and economy? and What role will the materials play in beautifying the built environment? To answer these questions, the researchers adopted the principles of harmony with place and co-evolution to illustrate how construction materials can benefit communities and equity in two distinct ways, all while ensuring the mitigation of adverse impacts during the procurement stage. According to the researchers, the first method involves the specification of local materials to engage local workforce and craftsmanship, thereby supporting local employment and ensuring the utilization of healthier or suitable materials for the construction. The second method is to specify products from manufacturers whose modes of operation and policies encourage gender equality and ethical working conditions. The introduction of the JUST program by The International Living Future is a great example that seeks to guide how purchasing organizations should treat their employees and make important decisions that will be beneficial to the built environment through the regenerative purchasing stage (ILFI, 2019).

Regenerative transportation. As Cervero and Sullivan (2011) have reported, the use of conventional transportation systems such as buses and cars is still prominent in the transportation of construction materials and site workers, thus resulting in little or no improvement in curbing the carbon emissions and wastes generated by the construction sector. Against this backdrop, Tannous et al. (2020) suggested that providing housing close to the site location for the employees will help to minimize commutes, thus resulting in reducing the need for vehicle trips and promoting alternative means of transportation such as cycling and walking within the construction site. Considering this idea, less energy is required and the well-being of the employees on site is improved (Joshi, 2017).

However, there might be a situation where it is impossible to provide accommodation for the site employees near the project site. In this case, the use of the conventional mode of transportation becomes inevitable. Nevertheless, Al-Akkam (2012) revealed the provision of shared transport for the employees and the use of multimodal transportation techniques (i.e using more than one mode of transportation such as a combination of rail and waterways to allow for a single trip of construction materials) will curb the carbon footprint of each worker and the entire transportation duration of construction materials, thus improving the well-being of all living systems and decrease the depletion of natural systems. Another suggestion reported by (Battisti et al., 2021; Tucci, 2021) is to encourage the use of cleaner fuels and electric vehicles for the transportation of resources required for construction. Most of these electric trucks or vehicles use a regenerative braking system that helps produce the electrical energy required by these vehicles just by using the brake pedal (González-Gil et al., 2013). In the conventional vehicle, energy is mostly wasted as it turns into heat and disperses

into the built environment, thus damaging the ecosystems.

Regenerative construction. The effective shift from the reductionist (i.e green or sustainability) to the positivity (i.e regenerative) approach during the construction stage of the supply chain can be achieved by incorporating regenerative practices into the resources (i.e materials and technologies) and other decisions made on the construction site to improve the well-being of workers and provide other net-positive benefits. Emerging research works developed in other industries are now beginning to be integrated into the construction industry. For example, researchers like (Guarino et al., 2015; Jaworski and Trzepieciński, 2016; Van Tittelboom and De Belie, 2013) mainly focus on how to improve the lifespan of materials such as steel, concrete, polymers, gypsum and plasterboards to make them self-healing, improve the thermal storage of buildings and make them capable of repairing any small linear cracks in buildings.

Another method of integrating regenerative practices into the construction stage is to install interpretive signage that teaches visitors and occupants about the project (ILFI, 2019). According to Hughes et al. (2013), interpretive signage uses the principle of focus on place to enhance visitor perceptions about the potential of the site or place. Similarly, Carter (2013) pointed out that these signages help explain the themes and practices of our place and tend to emphasize historical and ecological education. The International Living Future Institute (ILFI) has evaluated the importance of this practice and they revealed that integrating interpretive signage helps to share successful solutions and facilitate extensive modification in a construction project through the provision of informative materials for the occupants (ILFI, 2019).

More so, activities on construction sites can have detrimental effects on wetland functions and services (Abbe et al., 2011). As a result (Cole, 2012a, 2012b), adduced that there is a need to construct water circulation systems and wetlands on the site to collect stormwater or rainwater and replenish underground water sources. Several methods have been well-established to demonstrate how this practice can be effectively achieved. For example, Wallace et al. (2015) proposed a rainwater harvesting system that uses data from a simulated climate forecasting model in an attempt to develop a suitable rooftop design that can capture uncertainty in future climatic conditions. The result of the study yielded a maximum reliability score of 90%.

Regenerative End-of-Life management. Though it might be difficult to ascertain the specific use or status of the future life of a construction project in an attempt to improve the current EoL management practices, emerging knowledge such as the regenerative paradigm is beginning to initiate changes in these norms. By integrating regenerative practices during the EoL management stage of the construction supply chain, the useful life of construction materials will be transformed into new products, design, reduced waste products, recovery/reuse, and reshaping the method of consumption to allow for use by other occupants rather than for individual use only (Foster, 2020). Findings from the literature revealed key regenerative practices that could be incorporated into the EoL management stage. Çimen (2021) emphasized the importance of careful dismantling, disassembly, and recovery rather than complete demolition to reduce waste in landfills and conservation of resources. Though Hopkinson et al. (2018) argued that the additional cost and the data quality assurance of these practices posed a barrier, Tingley et al. (2017) using the principle of focus of place were able to proffer a solution to this by developing a database accessible to associated stakeholders to enable them to extract detailed information about the materials to be dismantled, disassembled and recovered for further resale.

While previous studies have adopted one or two principles of the regenerative concept to develop regenerative EoL management practices, ILFI (2019) on the other hand combined the three principles of the regenerative concept and disclosed that creating a Materials Conservation Management Plan (MCMP) for adaptable reuse and deconstruction is capable of optimizing materials during the EoL management phase and encourage the reuse of salvaged “waste” materials.

3. Conceptual framework development

The previous subsections fully expounded the principles and evidenced-based regenerative practices to help facilitate a shift from GSCM to RSCM in the construction industry. Though few researchers were explicit regarding the principles used in developing the regenerative practices applicable to each construction SCM stage, gaps exist as several of them were silenced with their approach. Hence, there is a need for a conceptual framework to standardize the description of each regenerative practice and to help establish a holistic view of what the novel RSCM entails.

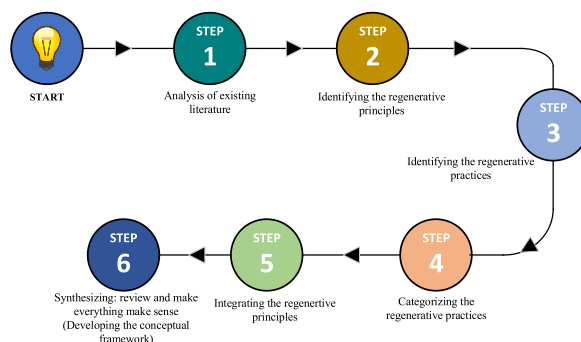


Fig. 6. Methodology for the development of the conceptual framework (Modified from Jabareen (2009)).

In essence, the purpose of this framework is threefold. First, it helps to synthesize over a decade of research on regenerative practices in construction while taking into consideration all relevant principles. Second, it would serve as a tool for researchers to facilitate literature review and further research. Lastly, construction stakeholders such as designers, suppliers, contractors, consultants, clients, and policymakers could consider it as a mechanism for integrating regenerative practices into their supply chains and the built environment in general in an attempt to proffer immediate solutions to rising environmental issues in the built environment. For these reasons, a preliminary conceptual RSCM framework is developed. The methodology used in developing the preliminary conceptual framework follows the approach of Jabareen (2009) and has been illustrated in Fig. 6.

Step 1- Analysis of existing literature:

This is the first task in developing the RSCM framework. The literature review on regenerative practices conducted in the previous subsections was analyzed to identify the strengths and weaknesses of extant studies. The strengths were identified to form the components of the overall framework. The weaknesses, on the other hand, provide insights into areas that need improvement which justifies the need for developing the conceptual framework.

Step 2- Identifying the regenerative principles:

As part of the strengths of the literature review analysis, the regenerative principles were identified and extracted. The result of the analysis revealed the three principles of the regenerative concept i.e. focus on place, harmony with place, and co-evolution.

Step 3- Identifying the regenerative practices

The objective of this step is to identify several regenerative practices following the extensive review of extant studies. This task has already been thoroughly accomplished in the preceding subsections.

Step 4- Categorizing the regenerative practices

This step seeks to categorize the regenerative practices into their respective constructs. Since this study seeks to improve the current GSCM practices and their respective stages, the identified regenerative practices in step 3 were categorized into five major constructs, that is, design stage, purchasing stage, transportation stage, construction stage and End-of-Life (EoL) management stage. It is worthy of note that similar regenerative practices were merged to ensure an even distribution of each practice across the five constructs. All identified regenerative practices (40) and their respective constructs (5) are annotated in Table 1.

Step 5- Integrating the regenerative principles

The categorized regenerative practices were further grouped into their main attributes and characteristics using the regenerative principles. This step shows a reasonable definition of each regenerative practice and demonstrates how it emerged from the regenerative principles.

Step 6- Synthesizing

The objective of this step is to synthesize the overall findings from the literature while following the steps described above. During this stage, the conceptual framework illustrated in Fig. 7 is developed and modified until everything makes sense.

4. Discussions

This study explores how regenerative principles can be integrated throughout the SCM phases to ensure that every member of the supply chain contributes to a restorative and regenerative built environment. To achieve this, the study proposes embedding strategies that promote the restoration of our built environment at each stage of SCM. This approach involves adopting practices that focus on the unique characteristics of local ecosystems (Focus on Place), ensuring that operations harmonize with and enhance the local environment (Harmony with Place), and fostering continuous adaptation and improvement in response to environmental feedback (Co-evolution).

In essence, we addressed several knowledge gaps and present a conceptual framework (see Fig. 7) to clarify how a sequence of SCM practices can be developed based on regenerative concepts. The novel RSCM framework proposed in our study suggests that merely adopting green or sustainable practices is insufficient for the continuous improvement of our built environment over time. This study therefore calls on all members of the construction supply chain to rethink their current practices.

More so, theoretical, methodological, and practical implications were identified through this conceptual paper.

4.1. Theoretical and methodological implications

This study contributes to theory by expanding the scope of SCM within the construction industry to include regenerative principles.

Table 1
Categorization of the regenerative practices into their respective constructs.

Code	Regenerative practices	References	Total citation frequency
Regenerative Design			
RD1	Incorporate natural elements: integrating urban agriculture, elevated green roof platforms, green spaces, gardens, and parks, living walls, trees, ecological networks, permaculture, biophilic design approach, and nature-inspired murals	[1]; [2]; [3]; [4]	4
RD2	Develop a database and materials passport using BIM and base design using KPIs for energy, materials, water, and air	[4]; [1]; [3]	3
RD3	Holistic Evaluation - Thorough examination of a site and its surroundings, encompassing cultural, economic, geographic, climatic, and ecological aspects as interconnected and dynamic living systems	[5]; [6]; [7]	3
RD4	Understand and shape the design to mirror the specific local context, considering both ecological and cultural factors, rather than relying solely on theory	[5]; [6]; [1]; [8]	4
RD5	Incorporate elements of public art and design that aim to enhance human enjoyment and foster meaningful connections with the surrounding environment, in alignment with the project's intended purpose	[7]; [9]	2
RD6	Integrate a building façade and landscape designs to facilitate wildlife connectivity that incorporates native plants, meadows, and other landscape features that support biodiversity, sequester carbon and provide ecosystem services	[3]; [10]; [4]	3
RD7	Designing a visually engaging entrance that integrates natural elements with social interaction in the building	[3]	1
RD8	Integrate public spaces that promote inclusivity and accessibility for all individuals	[4]; [1]; [39]; [8]; [6]	5
Regenerative Purchasing			
RP1	Purchase non-toxic biodegradable materials	[11]	1
RP2	Purchase construction materials that support the local community and equity	[12]; [40]	2
RP3	Select healthy construction materials that support biodiversity and ecosystem services	[12]; [3]	2
RP4	Invest in purchasing or procurement strategies that improve the well-being of the inhabitants and promote social justice by hiring local workforce	[12]	1
RP5	Purchase construction materials that are designed for reusability and recyclability	[4]; [11]	2
RP6	Sourcing materials locally: Purchase locally produced construction materials	[4]	1
RP7	Considering materials with Environmental Product Declaration (EPD) report, Cradle to Cradle (C2C) certified materials or any other eco-certified products	[3]	1
RP8	Prioritizing products sourced from manufacturers committed to ethical and inclusive practices, including gender equality and responsible working conditions	[12]	1
Regenerative Transportation			
RT1	Use cleaner fuels for the transportation of resources required for construction (such as hydrogen fuel cell-powered trucks and delivery vehicles used to transport materials and equipment to and from construction sites)	[13]	1
RT2	Local accessibility: reducing the need to travel by using the lowest possible distance from the project site or purchasing materials from local suppliers	[14]; [16]; [15]	3
RT3	Prioritizing multiple pathways to the site through diverse transportation and access modes to protect damage to the land for other species	[17]; [18]	2
RT4	Provide site accommodation to encourage walking/cycling of workers to the site and promote the use of a shared public transport system	[19]; [22]	2
RT5	Use low-impact transportation methods such as barges and trains to transport heavy materials and equipment to remote sites	[19]	1
RT6	Use a multimodal transportation technique to convey the resources required on the site.	[20]	1
RT7	Preparation of a transport plan for the site as well as impacts on the surrounding road network which forms an important part of a community's cultural heritage	[21]	1
RT8	Use the designated network for motorised vehicles to avoid conflict between pedestrians and cyclists while transporting resources required for construction	[22]	1
Regenerative Construction			
RC1	Preserving important site characteristics during construction	[23]	1
RC2	Incorporating a meticulously organized waste management strategy that addresses all on-site grey and black water	[24]; [7]	2
RC3	Construction of water circulation systems and wetlands on the site to store stormwater and replenish underground water sources	[25]; [2]; [26]	3
RC4	Include diverse stakeholders from vulnerable or disadvantaged populations in the construction phase and safeguard access for people with physical disabilities	[7]	1
RC5	Installation of interpretive signage that teaches visitors and occupants about the project and provides places for the built environment occupants to gather and connect with the community	[7]; [27]	2
RC6	Consider the project's cultural and aesthetic values during construction, while protecting occupants' access to sunlight, fresh air, clean water and soil	[7]; [28]	2
RC7	Using innovative construction techniques such as the modular method of construction and automation and applying efficient maintenance management plans during construction	[7]; [12]; [29]	3
RC8	Promoting awareness regarding the importance of fostering a favorable environmental footprint in construction by prioritizing the health and well-being of workers and regulating the selection of construction materials	[12]; [26]	2
Regenerative EOL Management			

(continued on next page)

Table 1 (continued)

Code	Regenerative practices	References	Total citation frequency
REOL1	Implement dismantling, disassembly, and recovery rather than complete demolition	[30]; [31]	2
REOL2	Integrate waste reduction into the end-of-life management phase and encourage imaginative reuse of salvaged “waste” materials	[7]; [30]; [31]	3
REOL3	Create a Materials Conservation Management Plan (MCMP) and a plan for adaptable reuse and deconstruction that explains how the project optimises materials during the end-of-life management phase	[7]; [32]; [33]	3
REOL4	Include diverse stakeholders from vulnerable or disadvantaged populations in the end-of-life management phase	[7]	1
REOL5	Ensure the efficiency of the end-of-life management stage by consistently taking into account the external impacts on human welfare (such as health and justice) and environmental factors (including pollutants and emissions)	[12]	1
REOL6	Redesigning discarded building components by another user to become adaptable to the changing needs of the community (i.e. human and natural systems)	[34]; [30]; [31]; [35]; [36]	5
REOL7	Considering the impacts of the end-of-life management activities on the natural resources and the ecosystem by implementing the Life Cycle approach during decision-making	[37]; [38]	2
REOL8	Integrate new sources of safe, resilient, and decentralised energy infrastructure powered entirely by renewables to function throughout the year in a resilient manner	[7]; [3]	2

References: 1 = Chidinma and Omoyeni (2019); 2 = Cole et al. (2012); 3 = Craft et al. (2017); 4 = Attia (2018); 5 = Mang and Reed (2020); 6 = (Zari, 2010); 7 = (ILFI, 2019); 8 = Cole (2012a, 2012b); 9 = Petrovski et al. (2021); 10 = Du Plessis (2012); 11 = Bonyad et al. (2018); 12 = Peretti and Druhmman (2019); 13 = Tucci (2021); 14 = Alvanchi et al. (2021); 15 = Garmendia et al. (2012); 16 = Haselsteiner et al. (2021); 17 = Fahmy et al. (2019); 18 = Al-Harami and Furlan (2020); 19 = Tannous et al. (2020); 20 = Al-Akkam (2012); 21 = Liaros, 2020; 22 = Joshi (2017); 23 = Mang and Reed (2012); 24 = Dobson et al. (2013); 25 = Nemati (2020); 26 = Thomson and Newman (2018); 27 = Carter (2013); 28 = Forsberg and de Souza (2021); 29 = Gardner and Newman (2013); 30 = Foster (2020); 31 = Çimen (2021); 32 = Augiseau and Barles (2017); 33 = Lanau et al. (2019); 34 = Mesa et al. (2020); 35 = Xuili and Maliene (2021); 36 = Potting et al. (2017); 37 = Giorgi et al. (2019); 38 = Dalla Mora et al. (2018); 39 = Plaut et al. (2012); 40 = Pierré and Saint-Jours (2013).

Traditional SCM and even green SCM primarily focus on minimizing negative environmental impacts. However, the proposed RSCM framework shifts this focus towards actively restoring and enhancing the environment. This theoretical advancement challenges existing paradigms and introduces a new dimension to SCM literature, encouraging researchers to explore the integration of regenerative principles in various industries.

Furthermore, the RSCM framework developed in this study emphasizes the importance of contextual approaches, as highlighted in the principles of Focus on Place and Harmony with Place. This, therefore, introduces a new dimension to SCM theory. Theoretical models must now account for the variability and uniqueness of each location, promoting specific-based strategies that harmonize with the local ecosystem and community needs. This place-based approach challenges the one-size-fits-all methodology often seen in SCM theories (Carter and Rogers, 2008; Chen and Paulraj, 2004; Rezaee, 2018), thus urging a more adaptable theoretical framework.

Moreover, this study presents important methodological implications. The study suggests that future research methodologies should incorporate interdisciplinary approaches, blending insights from environmental science, urban planning, and community development to fully capture the regenerative potential of SCM practices. Researchers are encouraged to develop metrics and evaluation tools that can measure not just sustainability outcomes but also the regenerative impacts of supply chain activities which are crucial for evolving SCM practices to meet the demands of a restorative and regenerative built environment.

4.2. Practical implications

The practical implications of this study are significant. The proposed RSCM framework provides a clear roadmap for integrating regenerative principles into SCM practices. Construction companies can directly apply this framework, while other industries can use the development process of the framework to redesign their supply chain processes. This ensures that each phase contributes to environmental restoration and renewal. By adopting the principles of Focus on Place, Harmony with Place, and Co-evolution, companies can move beyond sustainability to achieve more profound and lasting positive impacts on the environment.

More so, the practical implications extend to policy-making and regulatory frameworks. The insights from this study can guide the development of policies that promote regenerative practices not only in the construction industry but also across other sectors of the economy.

However, while the potential impact of the RSCM framework is commendable, its real-world feasibility must also be considered. Implementing regenerative practices could face challenges such as industry resistance, financial constraints, regulatory barriers, and the need for specialized skills and technologies, amongst others. Addressing these obstacles is crucial for its successful adoption.

5. Conclusion

This study has highlighted the imperative need for a paradigm shift in the current green practices used along each SCM phase in construction, emphasizing regenerative thinking and practices that not only minimize adverse environmental effects or achieve sustainability but also focus on the restoration of damaged natural systems while promoting societal well-being. To attain this

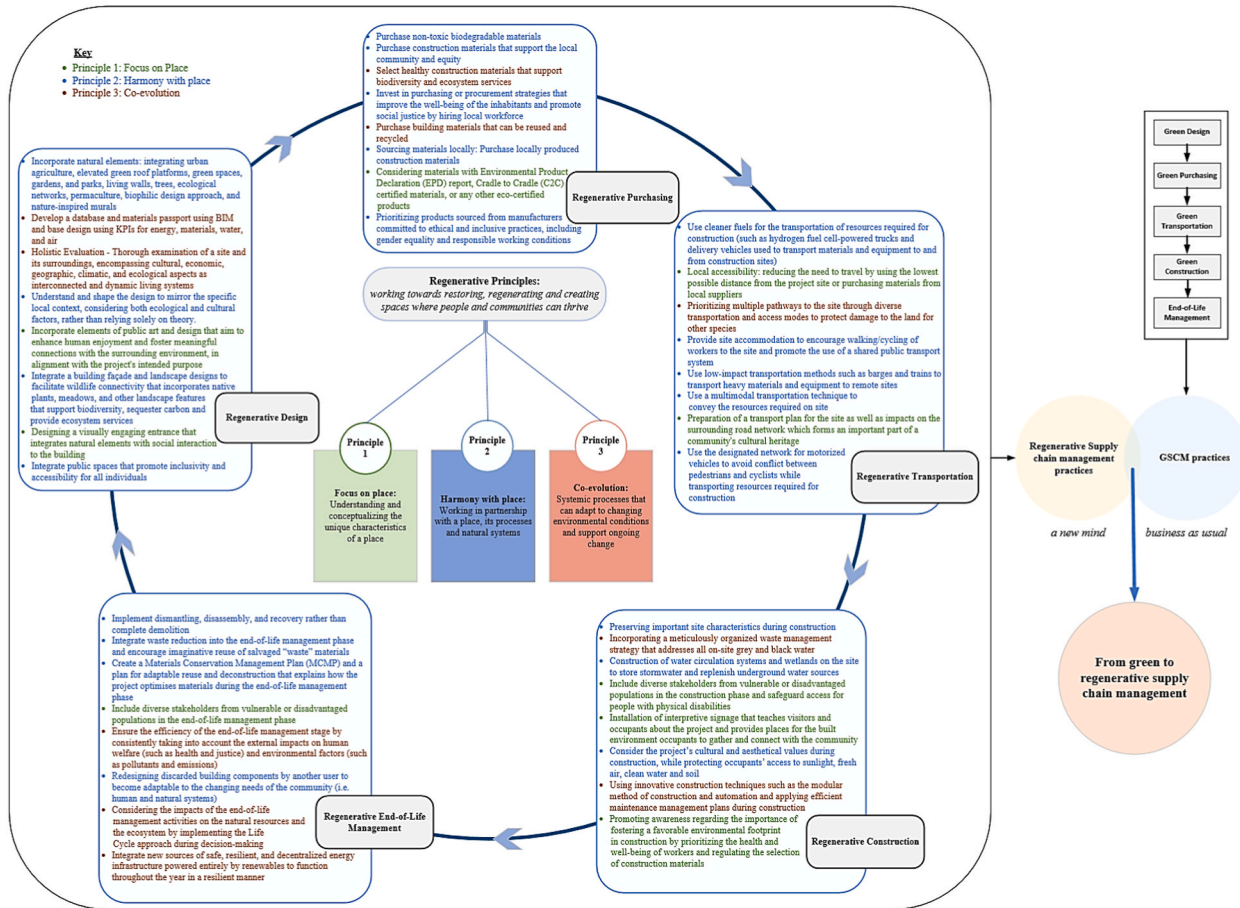


Fig. 7. The conceptual framework illustrating the shift from green (business as usual) to regenerative (new mind) supply chain management.

objective, an extensive review of existing literature was initially undertaken to assess the prevailing GSCM practices utilized in construction and their associated performance limitations. In an attempt to overcome these limitations, the comprehensive review further highlights the three principles that underpin the holistic and interconnected nature of regenerative thinking in construction: "Focus on place," "Harmony with place," and "Co-evolution."

Building upon these principles, 40 evidence-based regenerative practices were identified and categorized into five stages similar to the current GSCM stages used in construction thus forming the basis for the novel RSCM framework. Unlike existing GSCM practices, the RSCM framework integrates relevant principles, ensuring a more comprehensive and holistic approach to regenerative practices in the construction industry.

Drawing upon our findings, future studies can utilize our propositions to further explore the application of RSCM practices under the lens of its fundamental principles. Overall, this research represents a significant step towards a regenerative transformation in industries, paving the way for a more harmonious relationship between human activities and the environment.

5.1. Limitations of study

While this study provides valuable insights and contributions, it is important to acknowledge some limitations.

- This study has attempted to incorporate regenerative practices into the major stages of construction SCM. However, it is important to acknowledge that the monitoring and control stage was not specifically addressed. While this stage may receive less attention in the existing literature concerning the construction supply chain, it plays a crucial role in ongoing monitoring, quality control, and addressing any project plan deviations or issues.
- The proposed RSCM framework is primarily conceptual and has not yet been empirically tested. While it provides a theoretical basis for integrating regenerative principles into SCM practices, further research is needed to validate its effectiveness in real-world scenarios.

CRediT authorship contribution statement

Oluwatobi Nurudeen Oyefusi: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation, Conceptualization, Resources. **Wallace Imoudu Enegbuma:** Writing – review & editing, Writing – original draft, Validation, Supervision, Conceptualization, Investigation. **Andre Brown:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization, Investigation, Validation. **Maibritt Pedersen Zari:** Writing – review & editing, Writing – original draft, Conceptualization, Validation.

Declaration of Competing interest

The author(s) have reported no potential conflicts of interest.

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Data availability

Data will be made available on request.

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