Improving Environmental Sustainability in Construction: Nature-Based Solutions and Products with Recycled Content

Abstract:
Building and construction projects are being completed at an unprecedented rate globally. Unsurprisingly, this level of construction generates a substantial amount of waste. Despite increases in the rate of recycling, products with recycled content are underutilised in construction projects. It is well-documented that the use of products with recycled content may increase carbon emissions in construction projects under certain conditions. These emissions are the direct result of the energy necessary for waste resource management, recycling and transportation. To address this issue, the concept of nature-based solutions can provide an innovative approach to offset carbon emissions caused by recycling and related activities. The aim of this research is to delve into the relationship between products with recycled content and nature-based solutions by conducting a brief analysis of the existing literature. The review has highlighted six application areas where these concepts have been reported to be applicable. Furthermore, this study proposes a practical framework for the adoption of nature-based solutions + products with recycled content in the building and construction sector. The findings from this review will serve as a foundation for developing a framework that can guide policy development and industry practices in promoting optimised utilisation of products with recycled content, while simultaneously striving towards achieving net-zero emissions.

Keywords:
Built environment decarbonisation, circular economy, construction and demolition waste management, nature-based solution, products with recycled content

1 Introduction

The abrupt increase in the production of carbon and greenhouse gas (GHG) has caught the attention of researchers, policy makers and industry. It has been a pressing issue across the globe for the last decade. The increase in carbon emissions due to economic developments is the source of global warming and number of other environmental issues such as a rise in the global sea level, decrease in diversity of species and extreme weather changes (Lu et al., 2021). All these issues are leading towards a series of problems for both human beings and the environment.

The world's total emissions of GHG in 2021 was 54.59 billion tons, which is the result of a 24% increase in the last two decades (Ritchie et al., 2020). The statistics show a constant increase in these emissions over the years. Energy is consumed in the extraction, transportation and manufacturing process, and the combustion of fossil fuels, land-use and industrial process emit carbon in the atmosphere (Gustavsson and Sathre, 2006). The building, manufacturing and construction sectors consume and release a large portion of energy and carbon emissions. In 2019, these sectors contributed 9.04 billion tons of GHG (Ritchie et al., 2020). This is 16.5% of the total emissions, which need to be addressed at a minute level.

The recent changes in climate, with extreme weather conditions, heat waves and flash flooding, are affecting quality of life and infrastructure at the same time. Hence, the building and construction sector is now moving towards environmental sustainability. For instance, a public acceptance towards nature-based solutions (NbS) has recently been observed (Badura et al., 2021). Nature-based solutions is a concept driven by nature-

inspired steps to address environmental challenges through providing multiple solutions that will result in biodiversity gain and development of a viable economy (Sowińska-Świerkosz and García, 2022). In a nutshell, nature-based solutions focuses on both human beings and nature, recognising that both play a key role in the eco-system and cannot survive independently (Ershad Sarabi et al., 2019). Nature-based solutions can be a source of infrastructure re-development and advancement. Some of the key factors that can be considered while designing these solutions are: aesthetically appealing for the locals, trust of local-government bodies for the experimentation, collaborative governance and replicable in a long-term plan (Frantzeskaki, 2019).

In several developed nations, policies aimed at motivating the application of nature-based solutions have recently been developed with the goal of enhancing the environmental performance of a wide range of industries (Seddon et al., 2020). For instance, in 2022, the White House Council on Environmental Quality (2022) created a roadmap that provides a comprehensive set of strategic recommendations for harnessing nature-based solutions to combat climate change, halt biodiversity loss and address issues of equity. Such policies have the potential to incentivise key stakeholders, encouraging them to make informed decisions and collaborate to advance the implementation of nature-based solutions within urban settings, thereby addressing environmental challenges more effectively (Ershad Sarabi et al., 2019). Over the past decade, the concept of nature-based solutions as an umbrella term has been gaining traction among environmental scientists and international environmental negotiators, as well as within political jurisdictions such as the European Union (UN) and international organisations such as the World Bank, conservation organisations, the United Nations (UN) and intergovernmental agencies (Qi and Dauvergne, 2022).

One of the environmentally challenging areas in the building and construction sector is the management of construction and demolition (C&D) waste. The sector currently produces about 35% of the total waste sent to landfill worldwide (Zheng et al., 2017). Furthermore, globally, nearly 100 billion tonnes of C&D waste are generated in the industry, of which 35% is destined for landfills (United Nations Environment Programme, 2022). The utilisation of products with recycled content (PwRC) has been suggested as a way to sustainably manage these resources (Lu and Yuan, 2011, National Waste Policy, 2018). If planned properly, this management strategy will minimise waste disposal, keeping resources' value in the economy loop as long as possible and reducing the need for new material extractions. Therefore, the use of products with recycled content can assist governments to meet their waste management targets (Active Sustainability, 2020). The ultimate aim of this application is to address a variety of waste-related environmental, social and economic challenges.

Despite the perceived environmental benefits of using products with recycled content, there is evidence indicating that it may, under certain conditions, lead to an increase in GHG in construction projects (Zhang et al., 2022). These emissions are the direct result of the energy necessary for waste resource management, recycling and transportation. Therefore, it is imperative to find a way to justify the enhanced carbon footprint of using products with recycled content in the construction industry.

To address this issue, the concept of nature-based solutions can provide an innovative approach to reducing carbon emissions caused by waste recycling activities (Kisser et al., 2020), in turn contributing to developing a circular economy (CE) in the building and construction sector and cities as a whole (Bona et al., 2022). This paper aims to explore the integration of nature-based solutions into construction projects, with the goal of

enhancing the environmental sustainability of products with recycled content applications within the building and construction sector. It proposes a practical framework to guide joint efforts by various key players to realise the benefits of nature-based solutions + products with recycled content co-application.

2 Research Methodology

2.1 Data collection

To achieve the research aim, this study applied a systematic literature review method. Based on this method, this investigation relied on secondary data derived from relevant literature in a specific period (2012–2023). This research used different scholarly search engines to gather the relevant literature including 'Google Scholar', 'Web of Science' and 'Scopus' in addition to other sources. Several keywords were used to collect the sources: built environment decarbonisation, circular economy, construction and demolition waste management, nature-based solutions, construction industry and products with recycled content. The literature used for this study included journal articles, conference papers, industry reports and other grey literature.

2.2 Selection criteria

To find the most relevant literature, a set of selection criteria was applied. These included the following:

a. The literature was published within the last decade to ensure the quality and relevance of the literature review
b. It reports on the application of nature-based solutions in the building and construction sector
c. Its scope is relevant to construction and demolition waste management or circular economy.

3 Findings and Discussion

3.1 Bibliometric analysis

A concise bibliometric analysis reveals a notable upsurge in publications pertaining to the utilisation of nature-based solutions within the building and construction sector over the last seven years (2017–2023). The number of publications, sourced from Scopus, has increased by nine times between 2017 and 2022. This finding signifies the emerging need for changes to the way we create built environments in cities to tackle environmental issues. As illustrated in Figure 1, the scholars primarily affiliated with institutions in Italy and the UK have emerged as the foremost contributors, underscoring the salience of this topic within European academic discourse. In particular, in the EU, the implementation of nature-based solutions has been recognised and included in relevant legislation (EU Water Framework Directive and the Floods Directive) and initiatives (e.g., Horizon 2020, Green Deal, Urban Agenda for the UN).

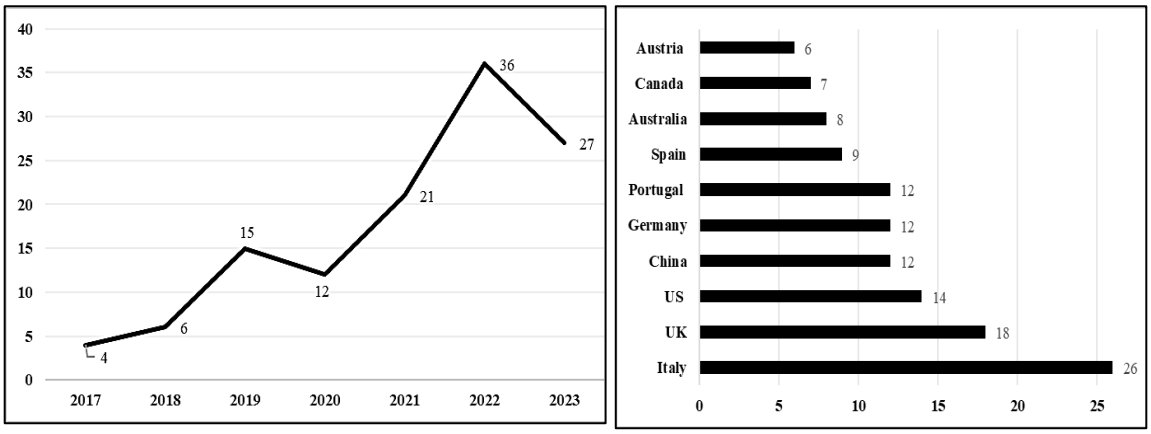

Figure 1. The number of publications per year (*left*), number of publications by country (*right*)

3.2 Nature-based solutions integration with products with recycled content: Application areas

The extant literature offers several general objectives for nature-based solutions application in the building and construction sector. These range from climate change mitigation benefits to public health and well-being improvement (Ershad Sarabi et al., 2019, Xing et al., 2017). However, this section exclusively outlines six applications in which the synergistic integration of nature-based solutions with products with recycled content, henceforth co-application, enhances the environmental sustainability of the building and construction sector (Figure 2). In particular, these applications are intended to enhance the sector's carbon footprint.

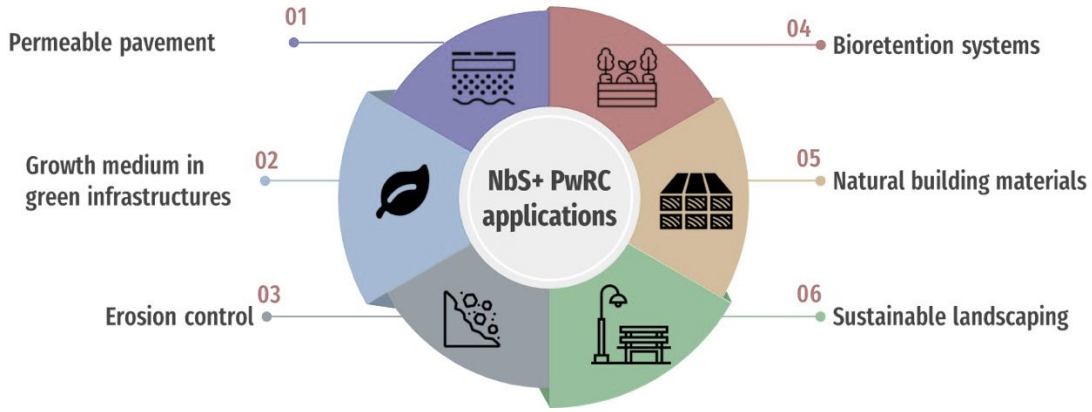

Figure 2. Six applications of NbS in the construction industry.

3.2.1 Permeable pavement

Creating permeable pavement offers several environment benefits. These include mitigation of urban heat island (UHI) effects, stormwater management, water quality improvement and erosion control. A new function of these constructs is the utilisation of products with recycled content in urban pavements (Song, 2022). This function was applied for the sponge city, which has the ultimate goal to reduce carbon emissions. The consumption of products with recycled content for pavement will benefit two important aspects: carbon reduction and waste management. There is growing evidence proving the suitability of these resources for creating permeable pavement. In urban environments, permeable pavements made from products with recycled content can incorporate elements like vegetation blocks, grassed joints or plastic grass blocks, showcasing their versatility for various applications, including car parking (Badura et al., 2021). Within infrastructure projects, the extant literature underscores the suitability of products with

recycled content for meeting performance criteria in road infrastructure. For instance, Li et al. (2023a) conducted experiments that demonstrated exceptional permeability of some products with recycled content, rendering it a viable choice for use as pavement fillers. A technical review by Pourkhorshidi et al. (2020) concurred, concluding that the incorporation of products with recycled content in permeable pavement construction has proven to be a practical strategy for harnessing their residual beneficial attributes.

3.2.2 Growth medium in green infrastructures

Green infrastructure is one of the viable instruments for nature-based solutions application, aiming to build back nature, develop resilience against climate change and reduce carbon emissions. Hence, it addresses several of the UN sustainable development goals (SDG) including SDG-11 (sustainable cities and communities), SDG-13 (climate action) and SDG 15 (life on land) (Anderson and Gough, 2022). Research into utilising products with recycled content in green infrastructure, particularly in the context of green roofs, has recently made advancements. In 2012, empirical research conducted by Bianchini and Hewage (2012) showed that incorporating products with recycled content could enhance the environmental footprint of green roofs and yield potential economic advantages without significantly compromising their environmental benefits. In terms of carbon emissions, it has been reported that green roofs using products with recycled content as substrate have a better carbon sequestration capacity (Fan et al., 2020) than that of local natural soil and mixed sewage-sludge substrate (Lou et al., 2020) with minimum pollution risk (López-Uceda et al., 2018). However, in other studies like Li et al. (2023b), this capability—carbon emission reduction—was not observed in green roofs, suggesting the need for comparative research across diverse climates and other contextual conditions.

3.2.3 Erosion control

A co-application integrated approach offers a viable method to mitigate soil erosion by effectively stabilising soil and preventing sediment runoff into water bodies. This eco-engineered product has been reported to enhance soil quality, increase carbon storage, reduce soil compaction, minimise or prevent soil erosion, and improve riverbank protection and hillside stabilisation (Langergraber et al., 2021). Zalewski et al. (2018) argued that these structures are less expensive to install and manage than civil engineering structures, and it is better integrated into the landscape. This application, however, necessitates the meticulous ecological engineering design of erosion control structures that seamlessly integrate products with recycled content and ecological elements such as plants. Hence, it requires careful consideration of the site's unique erosion challenges, encompassing factors such as soil and plant type, slope and climate.

3.2.4 Bioretention systems

Bioretention systems, such as rain gardens and bio-swales, use vegetation and soil to capture, filter and manage stormwater runoff. They help reduce the risk of flooding, mitigate UHI effects and improve water quality by removing pollutants. Previous research has shown that the use of products with recycled content can be an effective component of bioretention systems. In 2015, an experimental study demonstrated that recycled brick and concrete can be employed safely as an adsorption medium for ecological measures, such as bioretention systems and constructed wetlands (Wang et al., 2015). A research study showed that reclaimed asphalt material and crushed brick effectively trap pollutants and meet environmental requirements, suggesting their use in bioretention systems is viable (Rahman et al., 2016).

3.2.5 Natural building materials

Using products with recycled content extracted from waste resources such as bamboo, mud bricks, wool and timber in construction reduces the environmental footprint of the building and construction sector. These materials are renewable, energy-efficient and promote a healthier indoor environment. Prior research has demonstrated that the use of natural building materials within biophilic design can lead to stress reduction, enhanced cognitive function and creativity, and an overall improvement in the well-being of urban residents (Terrapin Bright Green, 2014). In terms of carbon management, the use of natural building materials can reduce the carbon footprint of the building industry. For instance, it was reported that for every 100,000 homes built from recycled timber, more than one metric ton of carbon dioxide equivalent (MtCO2 e) of carbon is stored (The Alliance for Sustainable Building Products, 2021). Furthermore, products with recycled content can exhibit excellent thermal qualities, facilitating natural climate control and supporting nature-based solutions for climate adaptation by diminishing the energy demand for heating and cooling in buildings.

3.2.6 Sustainable landscaping

The utilisation of products with recycled content in nature-inspired landscaping projects like urban parks and streetscape is on the rise and is driven by a multitude of factors. For instance, in a residential development project, products with recycled content extracted from the demolition of an old high school (Shooshtarian et al., 2023) were used in hardscape elements such as seating areas, toilet and retaining walls to preserve the site's heritage value. The use of products with recycled content can be incorporated in sustainable landscaping in a manner that supports the implementation of nature-based solutions in these projects. For instance, reclaimed timber from demolition sites can be used to create habitats for local wildlife including birdhouses, bat boxes and insect hotels. Rehan (2013) reported that tree grates made from recycled scrap metal are durable and have proven their longevity in the streetscape, requiring minimal replacement or maintenance.

3.3 Framework for the study co-application

Effective implementation of the study co-application entails collaborative efforts from different parties. To better understand these efforts, the relevant literature was analysed to determine the key players in adopting this co-application in the sector (Ershad Sarabi et al., 2019, Sowińska-Świerkosz and García, 2022). This analysis suggests eight types of stakeholder groups play a key role in this space: client, builder, architect and design (A&D) community, recyclers, education institute, financial institution, project coordinator and government. Figure 3 indicates how these stakeholders contribute to enabling the co-application in the areas identified above.

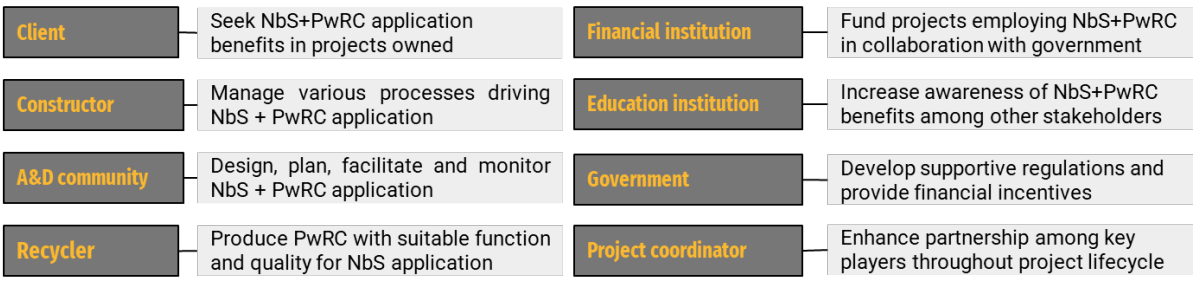

Figure 3. Key stakeholders and their primary roles in enabling NbS + PwRC co-application in the building and construction sector.

Drawing on the information provided in Figure 3, the following diagram was developed to outline the relationship between key stakeholders (Figure 4). The proposed framework is simple but is grounded in evidence gathered in this study. The frameworks are designed to be easily understood and implemented by various stakeholders involved in construction projects, to ensure higher adoption rates. They provide clear and consistent guidelines for the entire construction process relating to improving environmental sustainability in the sector.

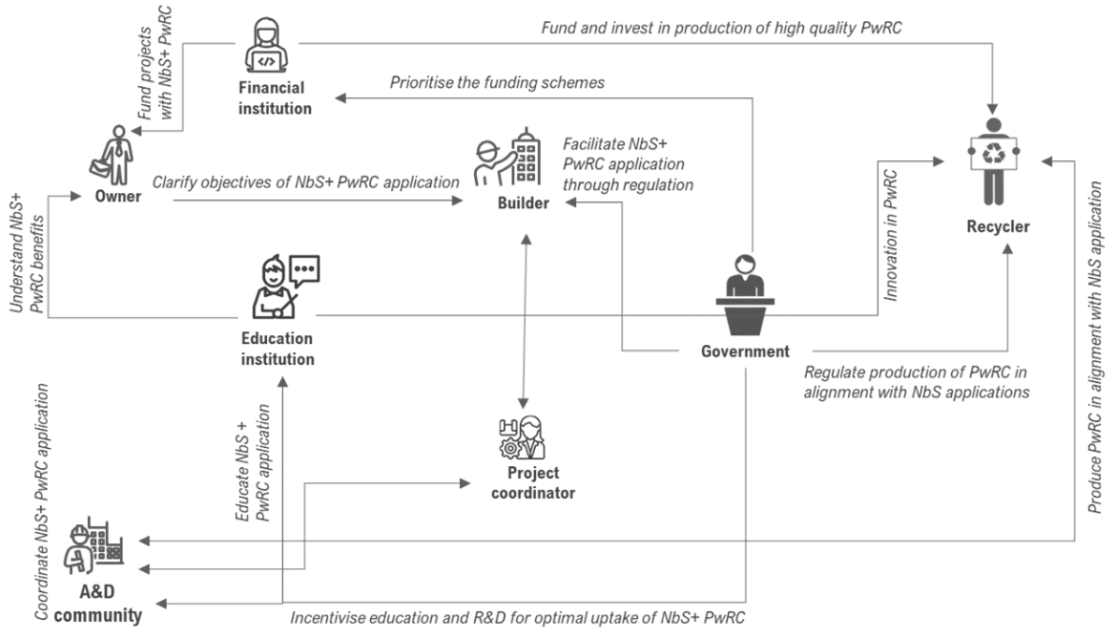

Figure 4. A simple framework to optimal application of NbS + PwRC in the building and construction sector.

In this framework, which delineates the principal stakeholders, paramount emphasis is accorded to the role of government. Through the strategic utilisation of legislative power and incentivisation mechanisms, government represents a pivotal force, possessing the capacity to effectively catalyse and steer the implementation of co-application within the sector. It is worth noting that within the broader landscape of stakeholders, there exists the potential for the inclusion of additional actors able to further facilitate the operationalisation of the study co-application. Nevertheless, it is wise to be careful about adding more stakeholders. If we add too many, it could add complications and reduce the framework's usefulness in making a real difference in the sector.

4 Conclusion and Further Research

This study is one of the first attempts to explore the co-application of nature-based solutions and products with recycled content in construction projects to improve the environmental sustainability outcomes in the building and construction sector. This study contributes to the theory and practice of a circular economy in the building and construction sector in multiple ways. First, this study identified six applications for using products with recycled content in this sector that are informed by nature-based solutions principles. Second, it demonstrates how, through purposeful implementation of nature-based solutions, emphasising multifunctionality and interdisciplinary approaches, a more comprehensive contribution can be realised in advancing the circular management of

finite resources within this sector. Third, the theoretical contribution of the paper lies in addressing the 'how' question of wider adoption of the study co-application within the building and construction sector context. In doing so, the paper acts as the bridge between the 'why' question of a transition to the co-application and the 'how' question of managing the episode of change and facilitating a transition, which to date, has received scant attention. Hence, this paper contributes to the existing body of knowledge by raising awareness of possible areas of implementation of the study co-application within the sector.

Note that the feasibility of using products with recycled content in the identified applications can vary depending on local regulations, the type and condition of these materials, and project-specific considerations. Hence, it is advisable that proper testing and assessment should be conducted to ensure the safety and effectiveness of using products with recycled content in construction. Furthermore, despite the expanding technical possibilities of these applications, large-scale implementation continues to lag due to various factors, including technical immaturity and non-technical bottlenecks. Hence, future research should not solely concentrate on the technical aspects of these applications but should also place particular emphasis on their social dimensions, aiming to formulate actionable recommendations for their optimal adoption. As innovations continue to advance in the building and construction sector, the list of potential areas of the study co-application is expected to grow, eventually leading to their adoption as standard practices within the sector in the near future.

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