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Evaluating the Impact of Government Policies on Circular Economy Adoption in the Construction Sector

Carol Emilly Hoareau[1], Nicholas Tam[2]*

[1]Public Utilities Cooperation, Seychelles.
[2]Faculty of of Civil and Environmental Engineering, Warsaw University of Life Sciences, Nowoursynowska 166, 02-787, Warsaw, Poland.

*Correspondence: tamnfy@gmail.com

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ABSTRACT: The construction sector is both essential for global economic progress and one of the largest contributors to pollution, resource depletion, and energy consumption. Given the urgent need to adopt more sustainable practices, governments in developed countries have introduced policies aimed at fostering a circular economy in this sector. These policies emphasize the use of green materials to reduce resource consumption, energy use, and greenhouse gas emissions, aligning with global sustainability goals. The waste hierarchy further governs these policies, prioritizing waste reduction, reuse, and recycling. This study analyzes the effectiveness of these government policies in promoting circular economy principles, particularly the adoption of green materials in the construction industry. Our findings reveal that while these policies have led to measurable reductions in energy consumption and emissions, the extent of green material adoption varies significantly across countries. Key factors influencing this variation include economic incentives, regulatory enforcement, and the level of industry acceptance of green technologies. One of the most important results of this study is the identification of significant gaps between policy intent and actual industry practices. In many cases, green materials, despite their favorable characteristics, have not been widely implemented due to economic, technical, and market barriers. These findings underscore the need for stronger government incentives and more consistent policy enforcement to drive broader adoption of sustainable practices. Future studies should focus on overcoming these barriers, exploring the long-term economic impacts of green material adoption, and evaluating how policy frameworks can be optimized to ensure more widespread.

KEYWORDS: Circular economy; construction sector; green materials; government policies; green materials

1. Introduction

In this digital age, where an abundance of information was readily available to the majority, people became increasingly environmentally conscious. Issues such as global warming, the climate crisis, deforestation, and pollution contributed to a growing concern for the wellbeing of the natural environment. Many recognized that while humankind had made remarkable advancements, these achievements often came at the expense of the Earth and its life-sustaining systems. Consequently, there was mounting pressure on governments worldwide to manage natural resources sustainably through the implementation of more effective regulations and policies. However, many countries faced the challenge of balancing societal development with environmental protection [1, 2].

The construction industry played a key role in driving development, providing physical infrastructure, employment, and a foundation for other economic activities [2]. In developed countries, such as EU member states, construction contributed approximately 9% to overall GDP [3]. However, the sector was also responsible for generating the highest levels of waste and resource consumption, producing 36% of global carbon dioxide emissions and accounting for 40% of energy consumption [4, 5]. The world's most developed nations, including the European Union, the United States, and China, produced substantial amounts of construction waste, estimated at 372 Mt, 600 Mt, and 1704 Mt per year, respectively [5]. Furthermore, the industry generated various forms of pollution that were harmful to the environment and public health.

In response, governments implemented stringent regulations and policies to ensure construction activities were conducted more sustainably. The majority of these policies aimed to promote a circular economy, reduce resource consumption, and mitigate pollution while fostering sustainability across all sectors. In the construction sector, circularity was achieved through regulations, planning, processes, technology, materials, and effective waste management strategies [6, 7]. This study aimed to analyze the effectiveness of government policies promoting the circular economy in the construction sector of developed countries, focusing on the implementation of green materials and their impact on reducing resource consumption, energy use, and greenhouse gas emissions.

2. Current status and Government policy on environmental management practices

2.1. Circular economy.

Many developed countries had already embraced the circular economy as the most sustainable path for continued development and societal improvement. Recent governmental policies and legislation across all sectors placed more emphasis on the circular economy, which was primarily based on eliminating waste and pollution, reusing resources and products, and regenerating natural cycles [8]. The construction sector generated many adverse environmental impacts and was therefore identified as one of the key areas with potential to contribute significantly to the success of the circular economy. Consequently, many of these developed countries had already identified and enforced measures for reducing construction and demolition waste generation, followed by the reuse and recycling of such materials [9].

The Waste Framework Directive 2008/98/EC was a legislative framework enacted by the European Parliament and Council of the European Union to ensure environmental protection and public health by providing guidelines for waste management and efficient resource use [10]. The policies outlined in this Directive were based on the principles of the waste hierarchy, which prioritized waste prevention, followed by reuse, recycling, recovery, and disposal. It was estimated that construction waste accounted for approximately one-quarter of all waste generated in the EU [11]. Thus, the Directive required member states to establish waste prevention programs by December 2013, along with appropriate benchmarks to assess progress, both quantitative and qualitative [12].

In terms of environmental management in the construction sector, countries such as the United Kingdom, Italy, the Netherlands, Denmark, and Belgium had already established and implemented policies promoting the circular economy. Examples included Belgium's ‘Material Conscious Build in Cycles,’ Denmark’s ‘Strategy for Circular Economy,’ and the Netherlands’ plan for ‘A Circular Economy by 2050.’ The UK and Italy also developed regional policy programs. These policies were considered successful, with recent statistics indicating that the 70% benchmark for recovering construction and demolition waste, as set by the ‘Waste Framework Directive,’ had been achieved since 2020 in these countries [3, 13].

Other legislative frameworks promoting environmental protection and circularity during construction activities included the ‘Roadmap to a Resource-Efficient Europe’ and the ‘EU’s Seventh Environment Action Programme.’ Previous studies classified the maturity of construction and demolition waste management systems in EU member states in terms of waste prevention, recovery, and landfilling. Generally, countries such as the Netherlands, the UK, Luxembourg, and Denmark ranked highest in terms of construction waste management systems [5, 14].

2.2. Policy instruments.

In line with the general Directives issued by the European Parliament and European Union Council, member states adapted and innovated environmental protection policies according to their local contexts. In Finland, the government intensified the activities of reuse centers, where construction and demolition wastes were converted into new building supplies or components. Pilot projects were conducted to assess material-efficient practices, education, and training for implementing greener methods in the construction sector. Guidelines were also prepared to facilitate public procurement supporting the circular economy. In France, the government encouraged renovations to extend the lifespan of buildings by setting annual renovation targets. Germany established networks of markets and centers for exchanging used building materials, while Ireland incorporated the reuse of materials such as greenfield soil and asphalt [8]. Denmark, the Netherlands, and Austria imposed high landfill taxes to divert construction and demolition waste towards reuse and recycling facilities [15]. The correlation between high landfill and raw material extraction taxes in these countries and their high recycling rates was noted [16].

Some governments developed compensation and reward schemes to encourage stakeholders to design and construct green buildings using sustainable practices [17]. In the United States, the government provided financial support through subsidiary policies aimed at reducing emissions from construction equipment. These policies acted as incentives for contractors to replace old, inefficient diesel-powered engines or retrofit in-use equipment. This approach had the potential to significantly reduce emissions, improving air quality and public health in areas surrounding construction sites. In many states, subsidies were awarded based on every ton of NOx reduced, and in some states, the government also covered the cost of retrofitting older construction equipment [18].

Hong Kong, one of the most developed cities in the world, experienced rising construction activity since the 1980s to meet the demand for new infrastructure. As a result, these activities contributed to significant environmental degradation, including waste, noise, air, and water pollution. Many construction companies made steady efforts to implement environmental management measures in line with the ISO14000 policy framework to improve sustainability, and as a result, they observed a reduction in fines related to non-compliance with environmental laws [19]. However, some parties in the construction industry found it challenging to invest in measures such as staff training, modern equipment, and technology, as they perceived these investments would lead to a net cost increase [20].

3. Overview of Planning and Purpose of Environmental Managements Practices

Construction activities cause various forms of pollution that have significant adverse impacts on the environment. This pollution can be categorized into dust, gaseous emissions, noise, ground vibrations, and solid or liquid waste. To eliminate or minimize such pollution, careful planning and implementation of environmental protection measures are required throughout a project's lifespan, from the design stage to demolition. Research and dynamic Environmental Impact Assessments (EIA) are essential, along with the application of detailed Environmental Management Systems (EMS) as defined by ISO14000. Preventative methods typically fall under technology, management, planning, and material selection and are most effective when applied in combination [19, 20].

In line with the circular economy, priority is given to the reuse and recycling of construction and demolition waste, as well as waste from other industries, to reduce unsustainable resource and energy consumption in the construction sector [15]. This is reinforced by the various legal frameworks, policies, and guidelines issued by the European Commission for managing construction and demolition waste. These include the European Waste Framework Directive, the EU Construction and Demolition Waste Protocol, and the Guidelines for Waste Audits Before Demolition and Renovation Works [10, 12]. These documents provide strategic guidance to stakeholders on enhancing efficiency and circularity throughout a building's lifecycle. The planning and purpose of environmental management practices are summarized in Figure 1.

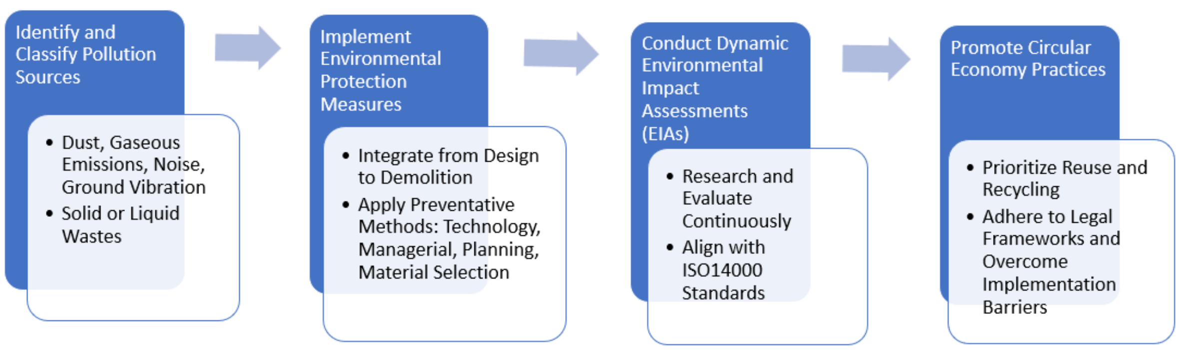

Figure 1. Planning and purpose of environmental managements practices.

However, economic and legal barriers have hindered the full implementation of such frameworks, particularly in construction waste management strategies. Issues like poor urban planning, low disposal costs compared to recycling, a lack of markets for recycled materials, and inefficient waste processing facilities are challenges faced by many EU member states. To address these barriers, member nations have promoted policies such as Green Public Procurement, End of Waste Criteria, pre-demolition audits, selective demolition, landfill and extraction taxes, traceability systems, and take-back centers [16, 21].

4. Current Situation of Green Materials for Construction

Generally, the construction sector consumes a significant amount of materials from primary resources and causes considerable environmental burdens due to extraction and processing. Since many developed nations have already begun the shift toward a more circular economy, reducing the consumption of primary resources has become a priority, primarily by increasing the lifespan of materials through the reuse of construction and demolition waste [22].

4.1. Reuse and Recycling of construction and demolition waste.

In Finland, approximately 38% of housing has been constructed with wood, demonstrating that timber is an indispensable construction material [4]. Furthermore, the nation exports a large quantity of timber and wood products, which leads to the cascading use of such products based on the waste hierarchy in consumer countries. According to statistics, wood accounted for 40% of the total construction and demolition waste generated in 2016, and over 90% of this waste wood was utilized in energy recovery practices rather than material recovery [23]. The demolition of timber buildings is typically carried out using an excavator due to its efficiency and cost-effectiveness, after which the waste is sorted into different categories for disposal processes. Usually, the waste wood is shredded in preparation for energy recovery processes, such as incineration and composting, to produce biogas [4]. Although this nation has achieved its goal of 27% renewable energy before 2030, it has not yet reached the target of reducing greenhouse gas emissions by 40% [23]. Therefore, this destructive method of demolition provides little opportunity for the reuse of structural timber elements. It is recommended that improvements be made to the waste management system to reduce the consumption of primary resources and the related carbon footprint [4, 24].

In most construction projects, concrete accounts for up to 85% of the total waste generated and is thus a valuable and plentiful source of materials for new construction projects. Recycled concrete aggregates (RCA) are one of the main secondary products obtained by recycling concrete, which may sometimes contain a small quantity of other building waste. RCA has various low-grade applications, such as earthworks and filling material for road sublayers, as well as higher-grade applications, such as the manufacture of concrete for high-quality structures [15, 25]. In 2015, the UK produced concrete using aggregates, of which 6.4% were sourced from recycled materials. However, several barriers prevent the maximum application of RCA in new projects. For instance, in countries such as Spain, the price of naturally extracted aggregates is similar to that of recycled aggregates, and the challenges of processing the aggregates into their purest mix have led to low market uptake [15].

Moreover, building elements and other construction products harvested during careful selective demolition can be reused in new projects, thereby reducing costs and improving environmental performance. Such building elements include bricks, concrete slabs, tiles, beams, and wooden frames, which would otherwise be destroyed or damaged during conventional demolition processes. Reusing construction waste is estimated to reduce carbon emissions from concrete structures by 60% and energy consumption by up to 40%, despite the need for more transportation [15, 26]. The current situation regarding green materials in construction in some developed countries is summarized in Figure 2.

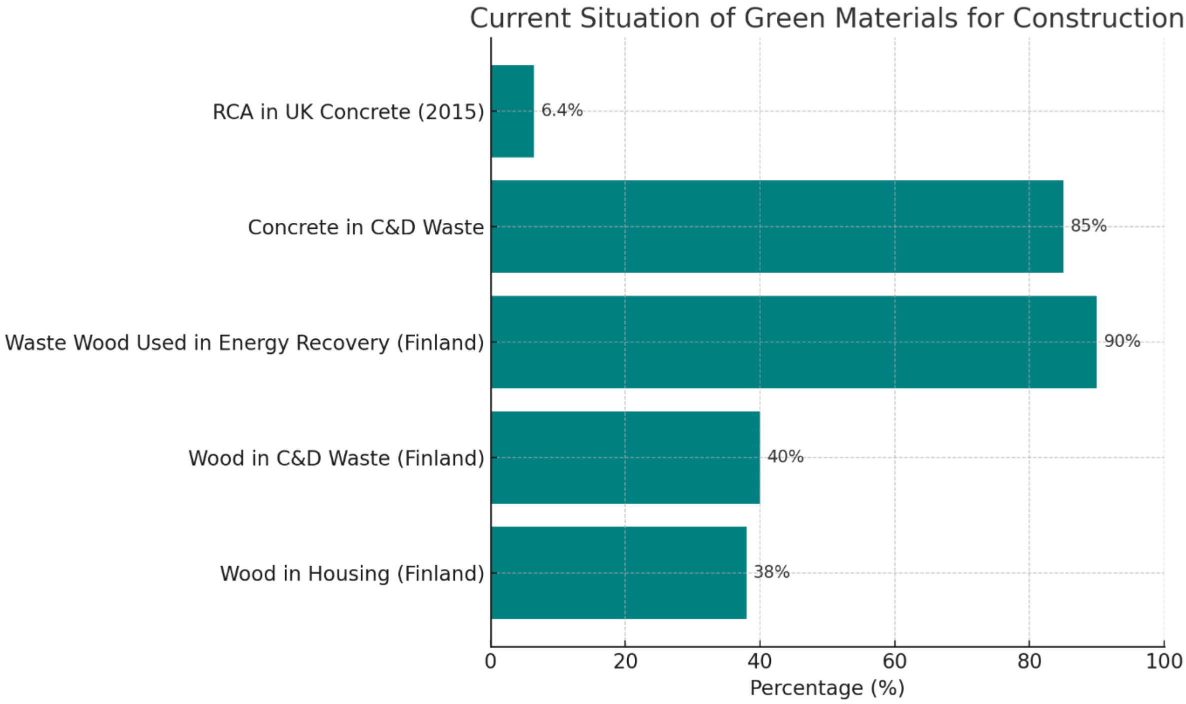

Figure 2. Current situation of green materials in construction in some developed countries.

4.2. Other green construction materials.

Various green construction materials have been innovated and were applied to different extents in developed countries based on their properties and availability [27]. For instance, the use of bamboo in construction, typical in Asia and Latin America, was usually the main component in low-end housing alongside traditional timber. However, recently developed bamboo products such as bamboo stem, plybamboo, and strand-woven bamboo have gained popularity due to their high quality, durability, and sustainability. Despite their many valuable properties, such products were less attractive to Western European markets until modern architects considered bamboo as a high-quality material for the roof structures of luxurious buildings [28].

5. Green Material Technology

A vast majority of green construction materials have been developed. These materials are considered ‘green’ as they contribute to sustainability within the construction sector by promoting the circular economy and reducing the consumption of natural resources, energy, and greenhouse gas emissions [29].

5.1. Bamboo

Bamboo is a hollow-stemmed, sturdy plant belonging to the grass family. It has traditionally been used as a building material in Asia and South America due to its availability and favorable properties such as high tensile strength, versatility, and low density. It exists in a large variety of species across different climates and grows to a maximum height of 30m within a relatively short period [30]. Bamboo fibers have a tensile strength of up to 400 N/mm², which yields a greater strength-to-weight ratio compared to wood and even steel [31], thus making the stems commonly used for roof structures, flooring, walls, and scaffolding [30]. Like other traditional materials, bamboo is now treated and processed to further improve its existing properties and derive other bamboo products. Pre-treatment is essential to enhance its durability and make it resistant to insects and mold, which is achieved by using chemical or plant-based preservatives. Many products can be obtained after processing, such as plybamboo, made from drying, smoothing, and laminating layers of bamboo strips to create panels of various thicknesses, similar to plywood [31, 32]. Strand-woven bamboo is another product fabricated by applying extreme heat and pressure to compress bamboo fibers, then laminating with phenol-formaldehyde resin to produce a hard, high-density material. This is mainly used for flooring and is one of the few bamboo products suitable for both indoor and outdoor use [32]. Compared to other materials, bamboo has more environmental benefits and is the most sustainable option when used directly in the country where it is sourced. Bamboo plantations foster healthy ecosystems, prevent soil erosion, sequester carbon, and mature in as little as three years. It is considered a good alternative to conventional timber in regions such as Europe, but emissions generated during transportation reduce its sustainability since bamboo stems have high volume, low density, and low transportation efficiency [33].

5.2. Recycled concrete products

Although concrete is the most used construction material, it has relatively low tensile strength and is brittle, making it susceptible to cracks and failure. Therefore, it is common practice to reinforce concrete by adding fibers or other materials to the wet mixture, enhancing its shear and tensile strength and ultimately decreasing construction costs. Recycled steel fiber obtained from discarded tires is a secondary material used to reinforce concrete. Due to its function in tires, recycled steel fiber has higher tensile strength compared to industrial steel fiber, which was conventionally used for this purpose [34]. Billions of tires are discarded annually, which are neither biodegradable nor suitable for incineration. Mechanical and thermal methods are employed to recycle the steel fiber from tires. This is considered a green construction material because its use helps reduce the amount of waste in landfills, consequently lowering greenhouse gas emissions. Aside from its environmental benefits, recycled steel fiber is cost-effective, sustainable, and reliable for reinforcing concrete properties [35]. Copper slag is another green construction material, a waste product generated in large quantities by the copper industry. It is one of the alternative materials that could replace sand in the production of concrete, as natural river sand is a resource being rapidly depleted [36, 37]. Recycling copper slag is a sustainable practice, as it decreases environmental impacts from landfill disposal and reduces the cost of concrete production. Furthermore, using copper slag as an aggregate instead of sand has been proven to improve compressive and tensile strength, as well as toughness [38].

5.3. Natural fibres.

Natural fibers used in construction are mostly obtained from plants such as coconut, jute, sisal, cotton, hemp, palm, bamboo, sugarcane, and eucalyptus. These natural materials have many engineering applications, including as reinforced composites in cement and mortar, road construction, roofing tiles, drainage systems, erosion control, and slope stabilization [39].

Adding natural fibers improves the toughness, tensile strength, and shear strength of other materials, attributed to their chemical composition, which consists mostly of lignin, cellulose, and hemicellulose [40]. Since these fibers are widely available, they are very cost-effective, non-hazardous, biodegradable, and have a low carbon footprint, making them an attractive alternative to synthetic fibers such as glass, steel, and polymers. However, natural fibers are hydrophilic and prone to absorbing moisture, so pre-treatment is required to improve durability. Physical pre-treatment methods like boiling or chemical treatments with compounds such as ferric hydrochloride, silane, acetic anhydride, and permanganate are commonly used [39].

5.4. Cork.

Cork is a natural material harvested from the bark of the cork oak tree and has various applications due to its favorable characteristics. A common application of cork is as a green material in construction since it is water-resistant, elastic, versatile, sturdy, low-density, biodegradable, and non-hazardous. It can be processed into tiles and planks for resilient flooring, used as insulation material in ceilings and walls, and as a sustainable alternative to polystyrene in green roof applications [41].

5.5. Ferrock.

Ferrock is an iron carbonate compound formed when iron dust, a waste product of the iron production industry, reacts with carbon dioxide and rust. Ferrock often also contains metakaolin, fly ash, and limestone, and is considered ‘carbon-negative’ since carbon is captured during its formation [42]. Ferrock has been identified as a suitable material to substitute cement in the production of concrete, as it has been proven to improve compressive, tensile, and flexural strength when added in the correct ratio. Furthermore, concrete containing ferrock is resistant to saltwater, making it a cost-effective option for constructing structures in contact with seawater. This is considered a greener material compared to traditional cement, as it reduces waste sent to landfills and has a smaller carbon footprint [43].

6. Other Environmental Considerations and Challenges

It has been particularly challenging to implement more sustainable environmental management practices in the construction sector, as many stakeholders still prefer traditional methods over adopting innovative solutions. This resistance to change stems from a variety of factors, including familiarity with established practices, perceived risks of new technologies, and the initial costs associated with transitioning to more sustainable approaches. To overcome these obstacles, greater participation and collaboration among various stakeholders—such as researchers, policymakers, producers, contractors, and customers—is essential. Such cooperation is critical for addressing the barriers that hinder a steady transition towards a circular economy within the construction sector [44]. Moreover, the reuse of construction and demolition waste presents numerous challenges, even within EU member states, where sustainability initiatives are more advanced. These challenges include technical difficulties in sorting and processing waste, inconsistent regulations across regions, and a lack of incentives for stakeholders to prioritize the reuse of materials. In many cases, the infrastructure required to support widespread recycling and reuse of construction materials is either underdeveloped or fragmented. Addressing these issues will require not only regulatory reforms but also increased awareness and training among industry professionals to foster a culture of sustainable resource management [45].

7. Conclusion

Due to the ongoing demand for infrastructure, the construction sector remains essential, even in developed nations. It serves as a foundation for various economic activities and significantly contributes to societal development. However, it is evident that the construction industry has numerous negative environmental and public health impacts, including pollution and the depletion of natural resources. To mitigate these effects, EU member states have implemented various policies and legislative frameworks, primarily based on the principles of the circular economy. These initiatives aim to reduce energy consumption, limit the use of finite natural resources, lower greenhouse gas emissions, and promote sustainability across all sectors of the economy. Environmental management policies are enforced through a range of measures, such as guidelines, audits, taxes, subsidies, and more. Effective planning at all levels is also crucial to ensure the successful implementation of these environmental measures. A key strategy for improving sustainability in the construction sector involves the use of green materials, which are either recycled from other industries' waste or developed from lesser-known materials. While there is considerable ongoing research into innovative green materials that could replace conventional ones, these alternatives have been slow to gain widespread acceptance in the industry. Stakeholders, including contractors, often prefer traditional materials due to their established reputation and familiarity. Additionally, the initial cost of implementing sustainable practices can be a barrier, though this challenge can be addressed by diversifying existing policy incentives. Governments must continuously review and adapt their laws and regulations to encourage broader adoption of circular economy principles within the construction sector. By fostering collaboration among stakeholders, promoting innovative green materials, and providing stronger incentives for sustainability, the construction industry can move closer to achieving maximum circularity and reducing its environmental impact..

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contribution

Carol Emilly Hoareau: Writing, Conceptualization, Data Collection; Nicholas Tam: Writing, Methodology

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