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Overcoming Barriers to the Adoption of Recycled Construction Materials: A Comprehensive PEST Analysis and Tailored Strategies

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Abstract: In the face of rampant urbanization, industrialization, and continuous advancements in construction technology, sustainable development in the construction industry becomes increasingly imperative. A promising avenue toward this sustainability is through the adoption of Recycled Construction Materials (RCMs), yet their widespread use remains complex and filled with numerous barriers, signifying an urgent need for the systematic investigation of these obstacles. This study uniquely employs a qualitative PEST (Political, Economic, Social, and Technological) analysis to illuminate the intricate impediments to the adoption and promotion of RCMs. Data for this study were collected through in-depth, semi-structured interviews with a variety of experts in the field. The research identifies substantial barriers within each PEST category. Political factors include regulatory biases and limited funding for RCM research, while economic factors involve the higher costs and limited availability of RCMs. Social aspects revolve around public awareness, safety concerns, and resistance to change within the industry. Technological issues focus on the development, performance, and compatibility of RCMs, the slow innovation pace, and the absence of standardized guidelines. Additionally, this study stands out by suggesting strategic, context-specific recommendations aimed at surmounting these obstacles and further fostering the adoption of RCMs. The solutions proposed are intimately linked to the challenges identified, highlighting the practical value and relevance of this study for guiding future research and policy development in the face of ongoing advancements in construction technology.

Keywords: recycled construction materials; semi-structured interview; PEST analysis; barriers; facilitators



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1. Introduction

The ongoing global urbanization and industrialization have triggered substantial growth in the building sector [1]. This expansion, while economically beneficial, has led to a concerning increase in the consumption of natural resources, a surge in waste generation, and elevated greenhouse gas emissions [2]. As non-renewable resources continue to dwindle and waste management challenges escalate, there is an undeniable need for sustainable and eco-friendly alternatives in the construction field [3]. A promising strategy in this regard is the use of Recycled Construction Materials (RCMs) in building projects.

RCMs comprise a broad category of building materials derived from the reprocessing and repurposing of waste materials generated during construction, renovation, and demolition activities [4]. Examples of RCMs are as diverse as recycled concrete aggregate, which is produced by crushing and processing waste concrete [5]; recycled asphalt pavement, which is generated by milling or grinding waste asphalt [6]; salvaged brick and masonry [7]; crushed waste glass, which is used as cullet [8]; processed waste plastics, which are incorporated into construction materials [9]; recycled metals, such as steel and

aluminum [10]; processed waste wood, which is used for engineered wood products [11]; and ground recycled gypsum, which is utilized in gypsum-based products [12]. These materials provide an environmentally friendly alternative to conventional construction materials and play a pivotal role in promoting resource conservation, reducing waste, and enhancing energy efficiency.

The utilization of a wide variety of RCMs has garnered increasing attention as a sustainable solution to reduce the environmental impact of building projects. The range of RCMs available enables construction professionals to select materials that are suitable for a broad range of applications with performance characteristics that can rival those of traditional building materials. Many previous studies have highlighted the good performance characteristics of various RCMs. For instance, the reviews of Nedeljković [13] and Makul [14] have shown that recycled concrete aggregates can offer comparable mechanical properties and durability to traditional concrete aggregates. Their performance can be further enhanced through methods such as surface treatments, binder improvements, optimized mixing techniques, and calcium carbonate precipitation [15–17]. Devulapalli [18] and Ji [19] indicated that recycled asphalt pavement performs well in road construction and maintenance with good resistance to moisture damage and rutting. According to Tamanna [20], crushed waste glass has been shown to improve the strength and durability of concrete when used as a partial replacement for sand. Correspondingly, treated waste plastics, reclaimed metals, residual wood, and recycled gypsum have been demonstrated to provide equivalent or superior performance attributes when compared to conventional construction materials [21,22]. The findings from these investigations suggest that RCMs represent a feasible and eco-friendly substitute for traditional building materials, possessing the capacity to augment the comprehensive quality and resilience of construction endeavors. Furthermore, the employment of RCMs aids in waste reduction and the preservation of natural resources [23], and it can assist in attaining green building accreditations [24], including LEED [25] and BREEAM [26]. As such, RCMs represent a significant opportunity for the construction industry to transition toward a more sustainable and circular economy [27,28].

The application of RCMs in the construction industry has increased in recent years, which has been driven by growing environmental concerns and government policies promoting sustainable building practices. There have been successful examples of RCMs applications in various construction projects. As an example, RCMs have been employed in road development, demonstrating favorable performance attributes and concurrently diminishing the ecological consequences of construction processes. Despite the growing utilization of RCMs, their extensive adoption remains limited. As per a study conducted by the World Green Building Council (WGBC), RCMs constitute merely a minor portion of the international construction materials market with recycled concrete and steel representing less than 1% of their respective markets. Therefore, it is necessary to continue research efforts to identify and address the factors limiting RCMs' adoption and further promote their application for sustainable building environment.

Despite the growing utilization of RCMs, their extensive adoption remains constrained. As per a study conducted by the World Green Building Council (WGBC) [29], RCMs make up only a minor portion of the international construction materials market; for instance, recycled concrete and steel account for less than 1% of their respective markets [30]. Taking this into account, the primary purpose of this research is to conduct an in-depth qualitative analysis of political, economic, social, and technological barriers to the adoption of recycled construction materials and to develop recommendations for overcoming these barriers. Specific tasks for this study include identifying key barriers and enablers, suggesting actionable solutions, and recommending policy changes that could foster broader RCM adoption. This study thereby aims to provide a comprehensive understanding of the multi-dimensional challenges impeding the widespread use of RCMs and offer insights for future research and policy formulation.

While previous studies have indicated that the performance of many RCMs has been shown to be comparable or even superior to traditional building materials, other factors such as market barriers, limited availability, and potential health and safety risks that limit their widespread adoption have not been extensively studied [31]. To better understand the factors that limit the widespread adoption of RCMs, this study aims to conduct a qualitative analysis of expert interviews using the PEST analysis framework. PEST are commonly used to assess the external environmental factors that may impact an industry or market. Through the examination of interview data, this research aims to pinpoint the critical external elements influencing the incorporation of RCMs in addition to potential approaches and remedies that can be employed to surmount these obstacles. The outcomes of this investigation will facilitate a deeper comprehension of the challenges and prospects linked to the integration of RCMs within the building sector, thereby guiding subsequent research and policy endeavors in this domain. Further material is divided into several parts. In Section 2, we introduced the methodologies of this study. Section 3 illustrated the PEST analysis results, while Section 4 contains the proposed solutions based on results. Section 5 includes the discussion, and Section 6 presents the conclusions and outlines the prospects for further research.

2. Materials and Methods

To achieve a comprehensive understanding of the factors influencing the adoption of RCMs in the construction industry, we employed a qualitative approach. The study focused on identifying barriers and facilitators that affect the promotion of RCMs within China's construction sector. Specifically, we conducted in-depth semi-structured interviews with experts from diverse fields related to construction to gather insights on these barriers and facilitators. These interview data were then analyzed using the PEST framework, allowing us to categorize the impact of various political, economic, social, and technological factors on RCM adoption.

Figure 1 illustrates the workflow of the study's methodology, serving as a roadmap for our research process. The figure is divided into two main components: Semi-structured Interviews and PEST Analysis. The Semi-structured Interviews component outlines the sequential steps involved, starting from the 'Determination of Interviewees Criteria' to 'Data Verification.' It captures the comprehensive approach we took to ensure that the collected data are both relevant and verified. The second component, PEST Analysis, is further segmented into Political, Economic, Social, and Technological Analysis, which were used to systematically evaluate the collected data. The chosen methodologies were complemented by a literature review to explore potential solutions for overcoming barriers in the promotion of RCMs.

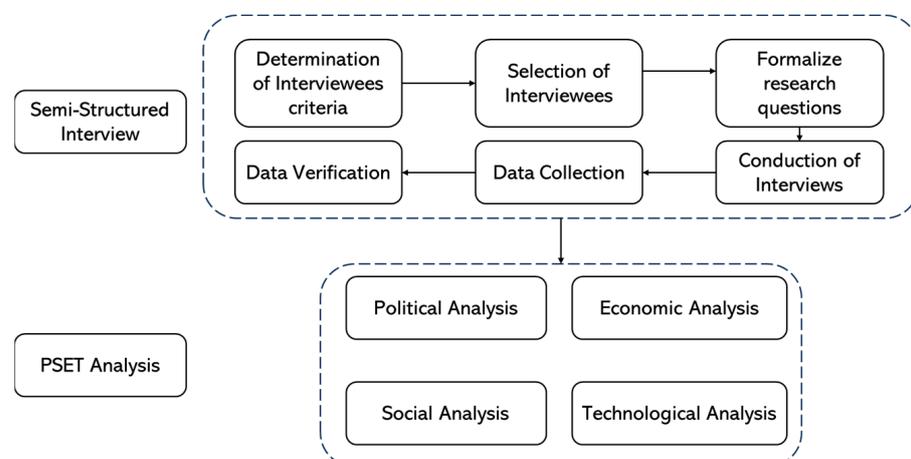


Figure 1. Research method flowchart.

2.1. Semi-Structured Interview

Semi-structured interviews are a valuable qualitative research method that allows researchers to gather a variety of valuable information from respondents [32]. This method involves asking predetermined yet open-ended questions, which promotes the free expression of opinions [33]. In the context of studying the promotion of RCMs within the construction industry, semi-structured interviews are particularly valuable in soliciting the opinions of a broad range of stakeholders concerning the barriers and facilitators of promoting RCMs.

The selection of interviewees for this study was guided by two primary criteria. Firstly, they were required to possess an in-depth understanding of the promotion of RCMs within the construction industry and provide valuable insights on the topic. This criterion necessitated that the selected interviewees had relevant work experience in this field, with a minimum of 5 years of experience to ensure their expertise. Secondly, the chosen interviewees must possess diverse roles that cover various phases of RCMs promotion to offer a comprehensive understanding. The promotion of RCMs within the construction industry involved various stakeholders, including those from the government, industry, and academia. Therefore, this study aims to include all relevant stakeholders to obtain a comprehensive understanding of the barriers and facilitators of promoting RCMs in the industry. Table 1 provides details of the 15 interviewees, including their roles, years of experience, and relevant affiliations.

Table 1. Profiles of interviewees.

No.	Roles	Work Experience
1	An on-site engineer in building engineering.	8 years
2	A manager of a construction material manufacturer.	9 years
3	An engineer in a construction material manufacturer.	11 years
4	A professor in construction materials.	14 years
5	A construction manager.	7 years
6	A manager in real estate developer.	5 years
7	An officer in Ministry of Housing and Urban–Rural Development.	6 years
8	An associate professor in construction management.	7 years
9	A structural designer.	5 years
10	An on-site construction engineer in civil engineering.	9 years
11	An architect.	7 years
12	A manager in construction waste recycling company	8 years
13	A manager in a construction and infrastructure development company.	12 years
14	A head of policy development in a construction regulatory body.	15 years
15	A production manager in a recycled construction material manufacturing company.	10 years

Following Table 1, it is important to elaborate on who these interviewees are in relation to the construction industry and the implementation of RCMs. The profiles of our 15 interviewees span across diverse roles within the industry, ensuring a well-rounded perspective on the subject matter. For instance, on-site engineers and construction managers (Interviewees 1, 5, and 10) provide hands-on operational insights into the challenges of using RCMs in day-to-day construction projects. Professionals from construction material manufacturing and waste recycling companies (Interviewees 2, 3, 12, and 15) offer insights into the production, quality control, and market availability of RCMs. Experts from academia (Interviewees 4 and 8) contribute to our understanding of the scientific and theoretical aspects of RCMs, as well as the effectiveness of current educational strategies to promote RCMs. Government officers and policy developers (Interviewees 7 and 14) shed light on the regulatory landscape affecting RCM adoption. Other roles like architects,

structural designers, and managers in real estate development (Interviewees 9, 11, and 6, respectively) provide perspectives that complete the spectrum of opinions from design considerations to market demands.

By including stakeholders with a minimum of 5 years of experience in the field, we ensured that each participant is highly qualified to speak on the complexities and challenges in promoting RCMs within the construction industry. Thus, the selected interviewees represent a comprehensive and diversified overview of the barriers and facilitators in the implementation of RCMs.

It should be noted that the selection of the 15 interviewees was based on the principle of 'data saturation' common in qualitative research. Data saturation is achieved when additional interviews do not provide significant new insights, themes, or information [34]. Therefore, despite the seemingly small sample size, the data gathered from these 15 diverse experts provided a comprehensive understanding of the barriers and facilitators to promoting RCMs.

Before conducting the interviews, ethical considerations were thoroughly assessed to ensure the participants' protection and confidentiality throughout the research process. These ethical considerations included obtaining informed consent from participants for answering interview questions, ensuring the confidentiality and anonymity of the research data, and obtaining permission to record the interviews. The semi-structured interviews were conducted remotely via video calls in the Chinese language. Participants were asked to respond to five open-ended questions related to the promotion of RCMs in the construction industry. These questions were designed to elicit insights into the participants' experiences and perceptions of the barriers and facilitators of promoting RCMs. The questions were as follows:

- (1) What are your experiences and perceptions of using RCMs in construction projects?
- (2) What do you think are the main barriers to the wider adoption of RCMs in the construction industry?
- (3) How do you envision the future of RCMs in the construction industry?
- (4) What strategies or policies could be implemented to promote the use of RCMs in the construction industry?
- (5) What lessons can be learned from successful examples of recycled materials application in construction projects, and how can these lessons be applied to overcome challenges in promoting recycled materials in construction?

Each interview lasted approximately 30 min and was audio-recorded for accurate and comprehensive data collection. The recorded interviews were transcribed verbatim by trained personnel to ensure the fidelity and completeness of the data. The transcripts were then sent to each interviewee for verification and validation of the accuracy and authenticity of the content, thus ensuring the content validity of the study.

2.2. PEST Analysis

In this study, we employed PEST analysis, a well-established strategic management tool, alongside semi-structured interviews to scrutinize the macro-environmental factors affecting the promotion of RCMs in the construction industry [35]. PEST analysis evaluates the external influences that could impact an organization or industry, including Political, Economic, Social, and Technological aspects [36]. Given the multifaceted nature of factors that could impact the adoption of RCMs—from government policies to consumer perceptions—a PEST analysis was deemed an appropriate methodological choice for this investigation.

We analyzed the data collected from the semi-structured interviews and categorized them according to the four PEST factors [37]. A thematic analysis approach was employed to interpret the transcribed interview data. The political category comprised interviews pertaining to governmental policies, regulations, and incentives. The economic category included discussions about the financial feasibility of RCMs, such as cost-effectiveness, market demand, and supply chain factors. The social factor focused on elements like social

awareness, consumer perceptions, and stakeholder interests, whereas the technological factor involved interviews regarding technological advancements that could potentially facilitate RCM adoption.

The findings presented in this study are grounded in statements made by a minimum of three participants and were subsequently corroborated through an exhaustive review of the relevant literature. Thus, the results are considered highly dependable.

3. PEST Analysis Results

Adhering to the proposed PEST analysis methodology, barriers to the RCMs promotion were identified, coded, and synthesized. For example, a relevant statement extracted from the interview data was as follows: “Public awareness and understanding of RCMs’ environmental and sustainability benefits are essential for their widespread adoption. If people are not aware of these advantages or hold misconceptions about RCMs, it can be challenging to convince construction companies and clients to use them.” Subsequently, a code encapsulating the core concept within the statement was discerned: “People’s awareness, perceptions, and preferences regarding RCMs.” This code was then connected to an overarching theme (“Social factors”) that emerged from the analysis of multiple interviews. This methodology was consistently applied to all interview transcripts, facilitating the systematic identification and organization of data-driven codes and themes within the PEST framework. As a result, the PEST factors impacting RCMs promotion were identified in Table 2. These factors, identified through the PEST analysis, contribute to a comprehensive understanding of the barriers and facilitators influencing the adoption of RCMs in the construction industry. Details about these factors can be found in followed sections.

Table 2. Grouping of factors that inhibit RCMs promotion.

Theme	No.	Code
Political factors	P1	Regulatory bias favoring traditional construction materials
	P2	Uncertainty due to inconsistent or unclear regulations
	P3	Limited government funding for RCM research and development
Economic factors	E1	Higher cost of RCMs compared to traditional construction materials
	E2	Lack of economies of scale in RCM production
	E3	Limited availability in the market
Social factors	S1	Low level of public awareness, perceptions, and preferences regarding RCMs
	S2	Safety and health concerns
	S3	Resistance to change within the construction industry
Technological factors	T1	Inadequate development, performance, and compatibility with existing construction methodologies and systems.
	T2	Slow pace of innovation in RCM development
	T3	Absence of standardized testing, certification, and guidelines for RCM usage

3.1. Political Factors

Political factors refer to the influence of government policies, laws, and regulations on the promotion of RCMs in the construction industry. Government policies and regulations that favor traditional construction materials over RCMs can hinder the promotion of RCMs in the construction industry. These policies and regulations may create a regulatory bias that limits the use of RCMs in construction projects. The lack of clear and consistent regulations on the use of RCMs can further exacerbate this issue. The limited funding allocated for RCM research and development by the government can also hinder the development and promotion of RCMs in the construction industry. These factors combined can contribute to the underutilization of RCMs in construction projects and limit their potential benefits.

Interviewee 1 explained:

“Government policies and regulations play a significant role in shaping the construction industry. However, the lack of policies that incentivize the use of RCMs, coupled with policies that favor traditional construction materials, creates a disincentive for construction companies to adopt RCMs. This can be due to the perception that RCMs are riskier and less reliable than traditional materials and the resulting uncertainty about their performance and safety”.

Interviewee 3 mentioned:

“Inconsistent and unclear regulations regarding the use of RCMs can pose significant barriers to their wider adoption in the construction industry. For instance, different regions may have different regulations or standards for the use of RCMs, making it challenging for companies to operate consistently across different locations. Moreover, ambiguous regulations can create uncertainty among construction companies about the legal implications of using RCMs in their projects, which can be a significant barrier to adoption”.

According to Interviewee 6:

“Government funding is an important source of support for R&D in the construction industry. However, limited government funding for RCM research and development can hinder the growth and wider adoption of RCMs. This can be due to a lack of investment in the development of new RCM technologies, resulting in limited options for construction companies to choose from”.

Interviewee 13 mentioned:

“There is also the need for government institutions to form strategic alliances with research institutions and construction companies to foster the development and implementation of RCMs. Without these collaborations, it might be challenging to attain the necessary advancement in RCM technologies”.

As per the analysis, political factors play a crucial role in hindering the adoption of RCMs due to regulatory bias, uncertainty, and limited funding for R&D. These factors ultimately limit the potential benefits of RCMs and their promotion on a larger scale. This finding is consistent with previous studies that also highlight the role of government policies and regulations in limiting the adoption of sustainable building materials. For example, Shooshtarian [38] highlights the important role of policy in RCMs promotion. They indicated that the government should improve sustainable procurement strategies, increase awareness, ensure the traceability of RCMs, use contract conditions to promote RCMs, and provide financial support. Taghipour [39] indicated that broad policy factors such as financial assistance, logistics, and fundraising guidance significantly influenced the efficiency of steel recycling. Similar conclusions were also drawn from many other studies such as Ma [40], Lingling and Hongping [41], Katerusha [42], etc. Therefore, it is imperative for governments to implement policies that promote the adoption of RCMs and sustainable building materials to ensure the realization of their potential benefits.

3.2. Economic Factors

Economic factors can also have a significant impact on the promotion of RCMs in the construction industry. The cost of RCMs can be higher than traditional construction materials, which can create a disincentive for construction companies to adopt RCMs. The lack of economies of scale in RCM production can also contribute to higher costs, as production volumes are often lower than for traditional materials. This can make it challenging for RCMs to compete with traditional materials on price.

Interviewee 2 explained:

“Although RCMs have many potential benefits, their higher cost can be a significant barrier to adoption. This is especially true in markets where cost is the primary consideration. While the long-term benefits of RCMs may outweigh the upfront costs, many construction companies may not have the financial resources to invest in RCMs without a clear and immediate return on investment”.

Interviewee 5 further elaborated on this issue, stating:

“The demand for RCMs ultimately depends on the preferences and priorities of clients and end-users. If they are not willing to pay a premium for sustainable or environmentally friendly materials, then there is limited market demand for RCMs. This can create a vicious cycle where low demand leads to limited supply and higher costs, further decreasing demand”.

Another economic factor hindering the adoption of RCMs is the limited availability of RCMs in the market. As a relatively new and less established industry compared to traditional construction materials, the supply of RCMs is limited, resulting in higher prices and longer lead times for delivery. This can make it challenging for construction companies to source RCMs in a timely and cost-effective manner, further limiting their adoption.

Interviewee 4 indicated:

“The limited availability of RCMs can pose a significant barrier to their adoption, particularly for larger construction projects that require a high volume of materials. Construction companies may be hesitant to take on the risk of using RCMs if there is a chance that they will not be able to source enough materials to complete the project on time and on budget”.

Interviewee 14 shared:

“The risk associated with investing in RCMs is another concern. This uncertainty, coupled with the higher initial costs, can be a deterrent for construction companies contemplating the adoption of RCMs. Thus, the creation of risk mitigation strategies and policies is fundamental for easing these economic burdens”.

The analysis of economic factors reveals the challenges that RCMs face in competing with traditional construction materials on cost and availability. RCM production lacks economies of scale, leading to higher costs, which can be a significant barrier to adoption, particularly for small-scale projects with tighter budgets. Moreover, the limited availability and longer lead times for RCM delivery can further increase the cost and risk associated with using RCMs, making them less attractive to construction companies. The need for a clear and immediate return on investment, combined with these economic factors, can hinder the growth and adoption of RCMs. These economic factors were also reported in previous studies. For instance, Salehi [43] conducted a literature review about the life cycle cost of RCMs and indicated that the high cost of recycling is one of the main drawbacks to the incorporation of RCMs in pavements. Cheng [44] proved that the limited and unstable sources of raw materials hinder the production and promotion of RCMs. Economic factors are also highlighted in Yao [45], Coelho and de Brito [46], Wijayasundara, Mendis [47], etc. To address these challenges, there is a need to invest in cost-effective RCM production methods, establish efficient supply chains, and develop innovative financing models that can promote the adoption of RCMs in the construction industry.

3.3. Social Factors

Social factors are often overlooked in discussions about the adoption of RCMs. However, these factors can have a significant impact on the demand for these materials. People's awareness, perceptions, and preferences regarding RCMs can determine the level of demand and acceptance of these materials. If sustainable building materials are not seen as a social norm, construction companies may be less likely to prioritize their use.

Interviewee 3 explained:

“Public awareness and understanding of RCMs' environmental and sustainability benefits are essential for their widespread adoption. If people are not aware of these advantages or hold misconceptions about RCMs, it can be challenging to convince construction companies and clients to use them”.

Interviewee 8 further added:

“Changing people's preferences and attitudes towards RCMs is crucial. A shift in preferences can lead to increased demand, which can subsequently drive down costs and promote the use of RCMs in construction projects”.

Safety and health concerns also play a vital role in the social factors affecting the adoption of RCMs. Construction professionals and end-users may have concerns about the safety and potential health implications of RCMs, especially if they are not familiar with their properties and potential risks.

Interviewee 9 highlighted:

“Safety and health concerns can be a significant barrier to the adoption of RCMs. If construction professionals and end-users perceive RCMs as potentially hazardous or posing health risks compared to traditional materials, they may be reluctant to adopt these materials in their projects”.

Another social factor hindering the adoption of RCMs is the potential resistance to change from industry professionals. This resistance often arises from familiarity and comfort with traditional construction materials and methods. However, it is important to note that some specific health concerns could reinforce this reluctance. For instance, certain types of RCMs may pose health risks such as exposure to harmful chemicals, dust, or potential contaminants originating from the recycling process. These concerns can slow down the integration of RCMs into the construction industry.

Interviewee 1 indicated:

“The construction industry has long-standing traditions and established practices, which can make it resistant to change. Introducing RCMs requires re-educating professionals and challenging their existing assumptions about materials and methods. This process can be slow and met with resistance, as industry professionals may be hesitant to adopt unfamiliar materials without a proven track record”.

Interviewee 15 stated:

“The need for more education and training within the industry is also a significant factor. Unless construction professionals are adequately equipped with knowledge about the benefits and usage of RCMs, the shift from traditional construction materials to RCMs could be slower than expected. Therefore, training programs and awareness campaigns can contribute to accelerating this transition”.

The examination of social factors underscores the significance of public perception, awareness, and preferences in fostering the adoption of RCMs in the construction industry. The attitudes and preferences of individuals toward RCMs can exert a considerable influence on the demand for and acceptance of these materials. Moreover, it is crucial to address safety and health concerns and overcome resistance to change within the construction industry to ensure the successful integration of RCMs into existing practices. The significance of these social factors is supported by previous studies. For instance, Ramos and Martinho [48] emphasized the importance of public perception and preferences in promoting the use of RCMs in the construction projects. The study found that a positive public perception of RCMs can influence their acceptance and utilization. Ding [49] highlighted the role of public awareness and knowledge in promoting sustainable construction practices, including the use of RCMs. Cheng [50] argued that effective communication strategies and public education initiatives can improve the perception and acceptance of RCMs. Furthermore, the significance of addressing safety and health concerns, and overcoming resistance to change in the promotion of sustainable construction practices, including RCMs, has been emphasized by other studies such as Oyebisi and Owamah [51], Ding [52], etc.

3.4. Technological Factors

Technological factors considerably influence the promotion and adoption of RCMs within the construction industry. The development, performance, and compatibility of RCMs with existing construction methodologies and systems can determine their level of acceptance and utilization in construction endeavors.

Interviewee 10 expounded:

“The efficacy and dependability of RCMs serve as pivotal determinants affecting their incorporation in the construction industry. If RCMs fail to meet or surpass the performance criteria of conventional materials, construction companies and clients might exhibit reluctance towards employing them, especially in projects where structural robustness and longevity are of utmost importance”.

Interviewee 11 further elaborated on this matter, stating:

“The compatibility of RCMs with extant construction methods and systems is indispensable for their successful amalgamation into the industry. If RCMs necessitate substantial modifications

to traditional construction processes or present challenges when integrating them with conventional materials, it can pose a significant impediment to their adoption”.

An additional technological factor impeding the adoption of RCMs is the slow pace of innovation. The development of novel regenerative materials and their integration into existing building practices might be time consuming, thereby delaying their extensive adoption.

Interviewee 13 indicated:

“The rate of innovation in the development of RCMs can be a constraining factor in their adoption. As emerging materials and technologies surface, the industry might require time to adjust and incorporate them into prevailing construction practices. This gradual pace of innovation can defer the widespread utilization of RCMs and obstruct their growth within the market”.

Furthermore, the absence of standardized testing, certification, and guidelines for RCM usage constitutes a substantial barrier. The lack of clear and universally accepted standards for RCMs can engender uncertainty and confusion among construction professionals, leading to a reluctance to employ these materials in their projects.

Interviewee 12 indicated:

“The deficiency of standardized testing and certification procedures for RCMs can be a significant hindrance to their acceptance within the construction industry. In the absence of explicit and widely acknowledged standards, construction professionals might harbor doubts regarding the performance and quality of RCMs, rendering them disinclined to adopt these materials in their projects”.

To summarize, technological factors play a critical role in the adoption and promotion of RCMs. The development and performance of RCMs, as well as their compatibility with existing construction methods, are crucial determinants that influence their acceptance and utilization. The slow pace of innovation and the lack of standardized testing and certification procedures for RCMs pose substantial obstacles to their widespread adoption. The significance of technological factors in driving the adoption of RCMs is supported by numerous studies. For example, Wijayasundara [53] highlighted the importance of performance and compatibility of RCMs with existing construction methods in promoting their utilization. Similarly, Ho [54] emphasized the compatibility and integration of RCMs with traditional construction materials and techniques as critical factors that influence their adoption. Additionally, the slow pace of innovation and the lack of standardized testing and certification procedures for RCMs have been identified as significant barriers to their adoption by several studies, including those of Byrne [55], Malešev [56], and Tam [57]. The industry needs to address these technological factors to ensure that RCMs are integrated successfully into the construction industry and become a viable and sustainable alternative to conventional materials.

4. Proposed Solutions Based on PEST Factors

To effectively address the Political, Economic, Social, and Technological (PEST) challenges in the adoption of RCMs, this section outlines a set of strategic measures aimed at overcoming these obstacles and fostering a more sustainable and environmentally friendly construction industry. These solutions were proposed based on expert interview and literature review. By implementing these proposed solutions, construction stakeholders can tackle the barriers that hinder the widespread adoption of RCMs and, ultimately, contribute to a more sustainable built environment.

4.1. Political Solutions

(1) Develop and implement policies and regulations that favor RCMs

Governments should create policies and incentives that support the adoption of RCMs in construction projects. These can include tax breaks, subsidies, or preferential procurement policies for projects utilizing RCMs [58]. By providing a favorable regulatory environment, governments can encourage construction companies to adopt RCMs more readily. In addition, governments should develop clear and consistent guidelines for the use of RCMs across different regions, reducing confusion and uncertainty in the industry [59].

(2) Increase funding for RCM research and development

Governments should allocate more funding for RCM research and development to accelerate their improvement and commercialization. This can involve direct investment in RCM-focused research institutions or providing grants and financial incentives for private sector research and development initiatives. Increased funding can also be directed toward educating construction professionals about the benefits and proper use of RCMs, building confidence and trust in the industry [60].

4.2. Economic Solutions

(1) Reduce the cost of RCMs through economies of scale

Governments, industry associations, and private companies should collaborate to promote the large-scale production of RCMs. This can help reduce costs through economies of scale, making RCMs more competitive with traditional construction materials in terms of pricing [61]. Encouraging partnerships between RCM producers and construction companies can foster innovation and enable cost-sharing, further reducing the financial barriers to RCM adoption.

(2) Develop innovative business models to facilitate RCM adoption

To overcome the barriers of high upfront costs, new business models, such as leasing or performance-based contracts, can be developed to make RCMs more accessible for construction companies. This can help shift the focus from short-term costs to long-term value and sustainability, promoting the adoption of RCMs [62].

(3) Create demand for RCMs through public awareness campaigns

Governments and industry associations should invest in public awareness campaigns to educate clients and end-users about the benefits of RCMs. By creating demand for sustainable and environmentally friendly materials, these campaigns can help drive down costs and promote the use of RCMs in construction projects [63].

4.3. Social Solutions

(1) Raise awareness and understanding of RCM benefits

Public education campaigns should be implemented to increase awareness and understanding of the environmental and sustainability benefits of RCMs. These campaigns can target construction professionals, clients, and end-users, addressing misconceptions and promoting the advantages of RCMs over traditional construction materials [64].

(2) Address safety and health concerns

Governments and industry associations should establish clear guidelines and standards for the safe use of RCMs in construction projects. This can help alleviate safety and health concerns among construction professionals and end-users, building trust and confidence in RCMs. Additionally, education and training programs should be developed to ensure that construction professionals are well-versed in the safe handling and application of RCMs [65].

(3) Overcome resistance to change

To promote the adoption of RCMs within the construction industry, targeted training and education programs should be developed to help industry professionals adapt to new materials and methods. These programs can focus on the technical aspects of working with RCMs as well as the broader benefits of adopting sustainable construction practices.

4.4. Technological Solutions

(1) Enhance RCM performance and compatibility

Emphasis should be placed on research and development endeavors to boost the performance and compatibility of RCMs with prevalent construction techniques and systems. By guaranteeing that RCMs fulfill or surpass the performance standards of traditional materials, construction firms and clients may exhibit a greater inclination to adopt them in their projects.

(2) Expedite innovation in RCM advancement

To hasten innovation in RCM progression, governments and industry associations ought to promote cooperation between researchers, material providers, and construction enterprises. This can be realized through the establishment of RCM-centric research hubs or by fostering alliances between academic institutions and private sector organizations.

(3) Capitalize on digital technologies to optimize RCM utilization

Digital technologies, such as Building Information Modeling (BIM), can serve a pivotal role in optimizing the employment of RCMs in construction initiatives. By integrating RCM data—such as material properties, life-cycle assessments, and cost estimates—into BIM systems, construction specialists can better comprehend the performance and potential advantages of using RCMs, resulting in more informed decision making and increased adoption [66–68].

(4) Encourage knowledge sharing and best practices in RCM application

To further stimulate the adoption of RCMs within the construction sector, knowledge-sharing platforms should be established to enable the exchange of information, research outcomes, and best practices among industry stakeholders. These platforms can encompass online repositories, conferences, workshops, and training programs, which can aid in constructing a supportive community around RCMs and endorse their widespread use [69,70].

5. Discussion

This study provides an in-depth exploration into the multifaceted factors that influence the adoption and promotion of RCMs. A sample of 15 interviewees contributes to a broad and comprehensive understanding of the political, economic, social, and technological challenges facing this sector.

In the existing body of research, this study offers several unique and novel contributions. Firstly, our broad sampling method, encompassing 15 interviewees from diverse stakeholder groups such as government, academia, and industry, allows for a more comprehensive analysis compared to existing studies. Secondly, the integration of PEST analysis with qualitative interviews provides a more holistic understanding of the adoption barriers, which is a methodological novelty in the context of RCM research. Furthermore, our study highlights the interconnected nature of these barriers in a way that has not been emphasized in previous studies, offering a comprehensive framework for future research and policy interventions. Finally, this study uncovers new barriers, such as inconsistencies in regulations across regions and the limited market availability due to technological infancy, which were not previously identified. Therefore, these aspects substantiate the scientific novelty of our work.

Political barriers have been identified as one of the key obstacles inhibiting the widespread adoption of RCMs. The research suggests that regulatory biases toward traditional construction materials are common, implying a deep-seated predisposition in the industry that hampers the acceptance of innovative materials. Additionally, inconsistencies in regulations across different regions further compound this issue, creating an uncertain legal environment that discourages investment in RCMs. The limited government funding for RCM research and development also surfaced as a significant constraint. To overcome these barriers, it is recommended to harmonize regulations across regions and increase government funding dedicated to RCM research and development.

On the economic front, the findings expose some stark realities. The higher costs of RCMs compared to traditional construction materials and the absence of economies of scale in RCM production deter potential adopters. Furthermore, the limited market availability of RCMs resulting from technological infancy and regulatory hurdles exacerbates this situation, underscoring the intertwined nature of these barriers. To address these economic issues, it is suggested to provide financial incentives such as subsidies or tax breaks to RCM manufacturers and implement measures to boost their market availability.

The research also unveils crucial social elements that play an influential role in the adoption of RCMs. Public awareness about RCMs is found to be alarmingly low, and an inherent resistance to change within the construction industry stands as a formidable

barrier to progress. Safety and health concerns associated with these novel materials also contribute to their slow acceptance rate. In light of this, it is recommended to enhance public and industry awareness through targeted information campaigns and address health and safety concerns by establishing and communicating rigorous standards for RCMs.

From a technological standpoint, the research highlights several factors that contribute to the slow adoption rate. Issues pertaining to the development, performance, and compatibility of RCMs with existing construction practices underline a significant gap in the market. Additionally, the slow pace of innovation in RCMs and the lack of standardized testing, certification, and usage guidelines are identified as areas needing considerable improvement. Therefore, recommendations include fostering collaborations between academia and industry to speed up technological innovation and developing standardized procedures for the testing, certification, and usage of RCMs.

This research brings to light the interconnectedness of these factors. A clear demonstration is seen in how political decisions can substantially influence economic factors or how societal elements can impact technological adoption. This interconnectedness implies that the strategies for promoting RCMs must be holistic, taking into account all the influencing factors and their complex interrelationships.

Finally, the critical need for active participation from all stakeholders in the construction industry is underscored. It emphasizes that manufacturers, construction companies, governments, and the general public must all contribute to promoting RCMs. Their collective effort and commitment are essential to surmounting the identified barriers and advancing RCM adoption effectively. In light of this, it is recommended to establish multi-stakeholder forums for effective dialogue and collaboration.

This study contributes significantly to the existing body of knowledge about RCM adoption and promotion by providing nuanced insights and tailored solutions. It underscores the importance of adopting a comprehensive and collaborative approach to tackle the identified challenges and illuminates the path toward a sustainable future in construction.

6. Conclusions and Future Research

This study presents a comprehensive analysis of the critical factors influencing the adoption and promotion of RCMs based on an expanded sample of 15 interviewees for a refined PEST analysis. The identified political factors include regulatory biases favoring traditional construction materials, uncertainties linked to inconsistent regulations, and limited government funding for RCM research and development. Economic barriers involve the higher cost of RCMs compared to conventional construction materials, lack of economies of scale in RCM production, and limited market availability. Social elements encompass public awareness, perceptions, and preferences for RCMs, safety and health concerns, and resistance to change within the construction industry. Technological issues include the development, performance, and compatibility of RCMs with existing construction practices, the slow pace of RCM innovation, and the absence of standardized testing, certification, and usage guidelines.

While this study has made novel contributions by providing an in-depth qualitative analysis of RCM adoption factors, it acknowledges the limitations of qualitative research in fully understanding these factors' significance. Future research could use quantitative methods like survey research and the Analytic Hierarchy Process to understand each factor's relative importance. Furthermore, this research has underscored the need to assess the effectiveness of our proposed solutions in addressing identified barriers and promoting RCMs.

Finally, this study recognizes the potential for variation among different RCM types, each possessing unique properties and characteristics. For instance, future research could explore the differential adoption patterns and challenges associated with specific types of RCMs like bio-based materials, recycled aggregates, and self-healing materials, providing construction professionals with insights to select the most suitable RCMs for their projects.

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