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Perceptions of nature-based materials in Bhutan's construction sector

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Abstract. The transition to regenerative construction practices is a promising strategy to mitigate the environmental impacts and infrastructure demands of Bhutan's rapidly urbanising cities. Drawing upon a public opinion survey, interviews, field visits, and secondary literature reviews, this research investigates the status quo of the construction sector in Bhutan and social perceptions of nature-based building materials. The study is located in the context of the regenerative built environment (RBE) concept, which integrates socio-cultural and ecological perspectives while addressing challenges within the sector. Findings indicate mixed familiarity with the RBE principles—while 46% of respondents reported at least moderate awareness, 54% had little or no familiarity, suggesting the need for greater knowledge dissemination. The most pressing concerns in Bhutan's construction sector include skilled labor shortages, inadequate thermal insulation, and high construction costs, alongside supply chain limitations and policy gaps. Barriers to adopting nature-based materials were primarily regulatory and technical, particularly the lack of standardised building codes, fire safety concerns, and perceived maintenance requirements. However, respondents acknowledged key opportunities, especially alignment with Bhutan's environmental goals, cultural aesthetics, and improved building performance. Notably, occupational background and generational differences influenced perceptions, with younger respondents prioritising environmental concerns, while older participants emphasised cost and preservation of traditional knowledge. To facilitate adoption, this study highlights the need for updated technical standards, policy incentives, specialised training, and supply chain modernisation. Demonstration projects and public awareness initiatives could help bridge the gap between traditional construction knowledge and emerging nature-based technologies. With a rich architectural heritage and strong sustainability ethos, Bhutan is well-positioned to lead in regenerative, climate-responsive building practices. Integrating cultural values, technical advancements, and policy support can foster a resilient and sustainable construction sector, paving the way for a regenerative built environment.

1. Introduction

The Regenerative Built Environment (RBE) concept stands at the crossroads of urban planning and holistic sustainability transitions within the building sector. By integrating socio-cultural and ecological perspectives, it addresses persistent challenges and promotes innovation in the built environment i.e. buildings, cities, and physical infrastructure. Regenerative development diverges from conventional sustainability by aiming not only to mitigate environmental harm but also to actively restore and revitalise natural ecosystems[1]. Yet the construction industry remains largely dependent on extractive practices that can profoundly affect natural resources and communities, often across great distances[2]. In response, an RBE approach prioritises socio-ecological systems in the built environment, extending the typical focus to include building life cycles, material value chains, and cross-sectoral stakeholder engagement[1].

The building sector generates emissions through the energy required for constructing, heating, cooling, and lighting residential and commercial structures, as well as the emissions released during the manufacture of construction materials. In 2022, the sector contributed 34% of global energy demand and 37% of energy and process-related CO_2 emissions[3]. Embodied emissions—those released during the extraction, manufacturing, transportation, and installation of building materials—remain a critical challenge[4]. Accordingly, a key objective in the RBE concept is to transition toward materials with low embodied carbon, particularly those that are locally sourced, renewable, and adhere to sustainable value chains. Nature-based materials such as sustainably harvested timber, bamboo, and hempcrete demonstrate substantially lower embodied carbon compared to conventional materials like concrete and steel. Advances in technology have further enabled the development of modern nature-based materials that can compete with traditional materials in technical performance while offering environmental, economic, and social benefits[5,6].

Socially, the utilisation of locally available natural resources can create value for communities by generating income from regionally abundant resources, and creating jobs along their value chains. Economically, adopting nature-based materials can lower construction costs by minimising transportation expenses and reducing reliance on imports, which are particularly beneficial for small lower-income countries facing budgetary constraints. Moreover, the resilience and adaptability of these materials in various climatic conditions can contribute to the long-term durability and sustainability of local infrastructure[7]. Together, these factors underscore the multifaceted advantages of integrating nature-based materials into construction practices, supporting both environmental stewardship and socio-economic development.

The transition to nature-based construction materials demands an integrated strategy that spans sustainable harvesting, material technology innovations, improved design practices, enhanced recycling techniques, and supporting policy measures. In a sector that is both risk-averse and deeply shaped by cultural norms, achieving this transition requires cultivating social acceptance and consumer confidence. In Bhutan, as elsewhere, social and cultural norms pose barriers to the widespread adoption of nature-based materials. Stakeholders across the value chain, from builders to end-users, must be persuaded of the reliability, performance, and long-term advantages of low-carbon materials, which often compete against entrenched preferences for conventional options[8-10].

Bhutan is internationally recognised for its pioneering commitment to carbon neutrality and Gross National Happiness, and it stands at a critical stage: rapid urbanisation, particularly within the Paro-Thimphu region, presents both opportunities and challenges. While urban development promises economic growth and improved living standards, it also applies considerable pressure

on Bhutan's natural ecosystems and its rich cultural heritage, particularly its distinctive architectural traditions. The country adheres to *Driglam Namzha*, the traditional code of etiquette and aesthetics, which extends beyond personal conduct to architecture, mandating features such as intricately carved timber, whitewashed walls, small arched windows, and sweeping, overhanging roofs to preserve a cohesive national identity[11]. A central question is how Bhutan can meet the burgeoning demand for new infrastructure while preserving this cultural identity, creating job opportunities, and minimising the environmental impact of construction[12,13]. Against this backdrop, this research investigates the socio-cultural, technical, logistical, and economic factors shaping Bhutan's urban material use, and attempts to identify strategic areas of intervention to enable increased acceptance of nature-based materials for construction.

2. Methods

2.1. Preliminary investigations

Preliminary desk and field research was conducted to understand the status quo of the construction sector in Bhutan and its material usage patterns. This was investigated using Google street view, fieldwork observations, and urban planning documents. Common materials in use were then categorised and analysed, distinguishing between conventional materials and nature-based materials, to arrive at a construction material database for Bhutan (see Table 1 and 2 in Supplementary Information[14]). This initial research and database connected us with relevant stakeholders and guided the development of a survey instrument.

2.2. Survey design

In order to assess participants' familiarity with the RBE concept, as well as their perceived barriers and opportunities surrounding the adoption of nature-based materials, a survey was administered. The survey was tested and validated for clarity, coherency, and relevance by our international project team, which includes researchers, architects, and local experts with experience working in Bhutan. While the original survey instrument covered a broader scope, only selected questions pertinent to this study were analysed. The full survey is available in supplementary information[14].

Key aspects of the survey instrument included demographic questions (e.g. age, occupation, educational level), a Likert-scale item measuring participants' familiarity with the RBE concept, and a list of concerns regarding the current state of Bhutan's construction sector. Drawing on literature reviews[8,15-18] and the preliminary investigation described in Section 2.1, a list of potential barriers and opportunities to the widespread use of nature-based materials was provided alongside a Likert scale.

2.3. Sampling

Respondents to the survey were identified using a convenience sampling technique. Convenience sampling does not guarantee the representativeness of the sample, but it may be used for explorative research, which was the aim of this part of the study. Participants included a diverse group of construction sector professionals in Bhutan, such as architects, engineers, government officials, private sector representatives, as well as relevant experts and representatives identified by our government partner, the Ministry of Infrastructure and Transport, Bhutan.

2.4. Data collection

The online surveys were distributed via email on 8th June and responses to the form were closed on 26th July 2024.

2.5. Data analysis

Descriptive statistics (frequencies, percentages, and means) were calculated to summarise survey responses. The list of perceived barriers and opportunities were categorised under socio-cultural, logistical, technical, and economic themes (see Table 3, Supplementary information[14]). The Likert data was analysed descriptively to highlight the items that received the most agreement or disagreement from respondents. The Likert scale was assumed to be ordinal, and responses were coded (Strongly disagree = 1, Strongly agree = 5). Mean scores and standard deviations were calculated to assess barriers and opportunities with the highest level of agreement in terms of frequency of responses as well as dispersion of responses. Mean scores of 4 or higher indicated a high level of agreement, while means closer to 3 indicated neutral responses, and means lower than 3 indicated disagreement. Higher standard deviation indicates greater variance in responses while lower standard deviations indicate greater consensus within the range of answers.

Where appropriate, responses were correlated with demographic variables—particularly age and occupation—to identify potential group-level differences. All analyses were performed using standard statistical procedures (e.g., grouping "Agree" and "Strongly Agree" responses as positive) to ensure clarity in interpreting attitudinal trends.

2.6. Ethical considerations

Prior to participating in the survey, all respondents were provided with an informed consent statement explaining the study's purpose, the voluntary nature of their participation, and their right to withdraw at any time. Respondents were assured that their responses would be kept confidential and would only be used for research purposes. To protect respondent privacy, all data was anonymised prior to analysis and was stored securely on password-protected computers.

3. Results and discussion

Data collection was completed approximately 6 weeks after the survey was sent out. A total of 106 responses were obtained out of 550 people who were invited to participate, indicating a response rate of 19%.

3.1. Demographic overview of participants

Of the survey respondents, 74% were male and 26% were female; no respondents selected the open-ended option for a diverse gender identity. More than 70% were between 25 and 45 years of age (53% in the 25–35 range and 21% in the 35–45 range), while 16% were aged 45–55 and 5% were 55–65. In terms of occupation, 34% worked in government or civil service, 29% were civil engineers, 15% were privately employed, 10% were architects, 5% were students, and 4% were structural engineers. Educational levels were relatively high: 51% held a Bachelor's or equivalent degree, 34% had earned a Master's or equivalent, and 13% had completed a diploma or equivalent.

3.2. Familiarity with the concept

Familiarity with the concept of an RBE was mixed, with 9% of respondents reporting no familiarity at all, 44% reporting slight familiarity, 25% reporting moderate familiarity, 20% high familiarity, and 2% extreme familiarity. A combined 22% reported high or extremely high familiarity, and when moderate familiarity was included, this figure rose to 46%. The remaining 54% had low or no awareness of the concept, suggesting that more targeted efforts may be required to enhance understanding and engagement in this sector.

3.3. Current state of the construction sector in Bhutan

Respondents were asked to select their primary concerns regarding the current state of the built environment in Bhutan, with the aim of identifying potential areas for intervention to facilitate a transition toward a regenerative built environment. The most frequently cited concern was a lack of domestic skilled labour (89 respondents), closely followed by buildings with poor thermal insulation (81). Limited availability of construction materials within Bhutan and a lack of supportive policies for innovative construction practices both received 80 responses, highlighting ongoing challenges related to supply chains and public-sector incentives. High costs—both of importing materials (72) and of construction in general (71)—also emerged as pressing issues. Environmental impacts, though still significant, were relatively less prominent: 66 respondents voiced concern over the impact of conventional building materials (steel, cement, concrete) on the environment, and 59 cited pollution from construction activities.

Moderate levels of concern were expressed for the loss of traditional building knowledge and practices (53), deforestation and resource depletion (51), and challenges related to transporting materials to construction sites (51). Low seismic performance (33), difficulty designing buildings that align with Bhutanese aesthetic preferences (39), and concerns over the durability of buildings (17) were mentioned less frequently, yet still pointed to gaps in structural performance and cultural compatibility. In terms of age-related trends, younger respondents (15–25 years) demonstrated heightened concern about the environmental impact of conventional materials and pollution, while those aged 25–35 offered a more diverse set of priorities, highlighting the high cost of construction and material availability. In contrast, respondents aged 35–45 and older were more focused on preserving traditional building knowledge and addressing material costs. Overall, younger age groups (15–25 and 25–35) reported a greater number of concerns than older groups, illustrating how perspectives vary by generation.

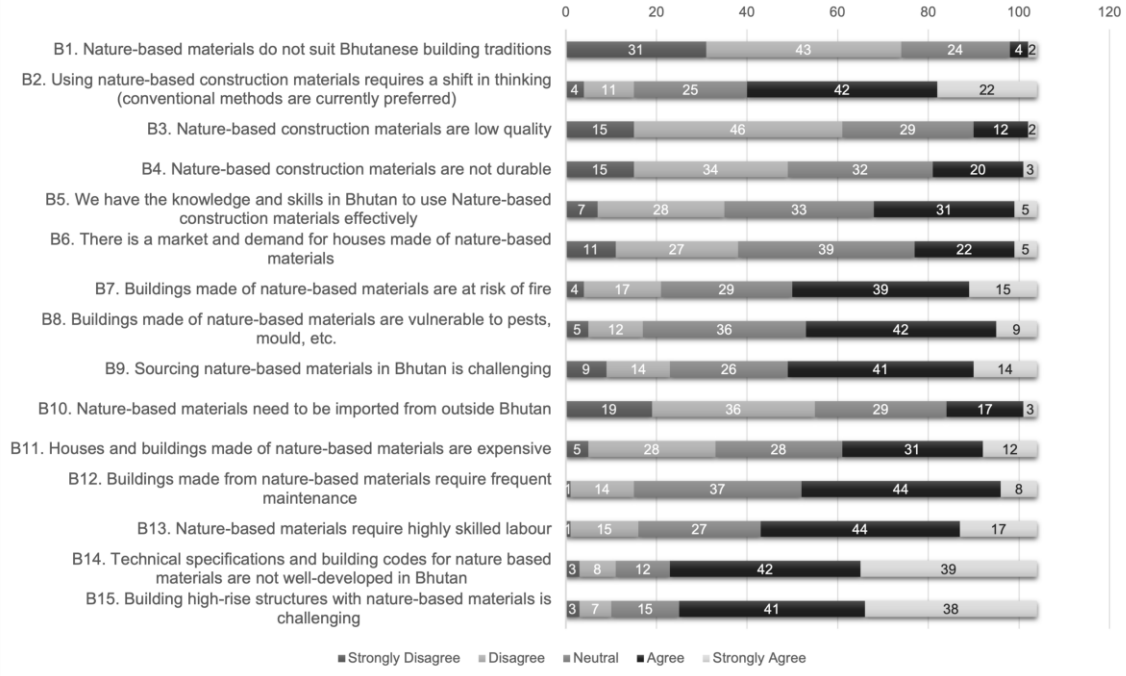

Figure 1. Barriers to the widespread adoption of nature-based materials in Bhutan.

3.4. Barriers to the widespread adoption of nature-based materials in Bhutan

The survey results indicated that certain barriers were widely endorsed by respondents as seen in Figure 1. The highest-rated barriers, with mean scores of 4, centered on regulatory and technical constraints, with respondents emphasising the lack of well-developed building codes (B14) and the perceived difficulty of constructing high-rise structures using nature-based materials (B15). The notion that these materials are not low quality (B3) also received strong agreement, indicating that respondents do not generally doubt their intrinsic properties. Nonetheless, respondents moderately agreed with concerns over fire safety (B7), frequent maintenance (B12), and susceptibility to pests and mould (B8), suggesting technical uncertainties persist. Technical barriers underscore a lack of familiarity with respect to advanced nature-based materials such as mass timber among many construction sector professionals. These findings suggest that investing in the development of modern nature-based construction products and exhibiting their capabilities through demonstrator buildings could overcome crucial barriers to their adoption.

Despite strong agreement with the suitability of nature-based materials to Bhutan's building traditions (B1), more than half of respondents (64 positive responses) felt a cultural mindset shift (B2) is needed to transition away from conventional construction. Skilled labour requirements (B13) were identified as a key factor impeding broad adoption. The standard deviation of mean scores was calculated to examine items over which respondents held differing opinions. Notably, B12, and B8, along with B1, exhibited relatively low standard deviations, indicating that respondents voted similarly on these issues, further emphasising the significance of these barriers. Across occupations, B3, B8 and B9 had highest agreement, while B12, B11 and B10 had the most divergent responses as seen in Figure 2. Overall, there was a high level of consensus towards all barriers among architects, civil engineers, government officials, structural engineers and privately employed people, while academics and members of Gyalsung, a voluntary youth organisation, diverged from this consensus. This highlights the importance of stakeholder consultations that account for a wide range of perspectives, even those not directly connected to the construction sector. The findings also highlight concerns about the existing regulatory framework, professional knowledge, and the logistical challenges of using nature-based materials

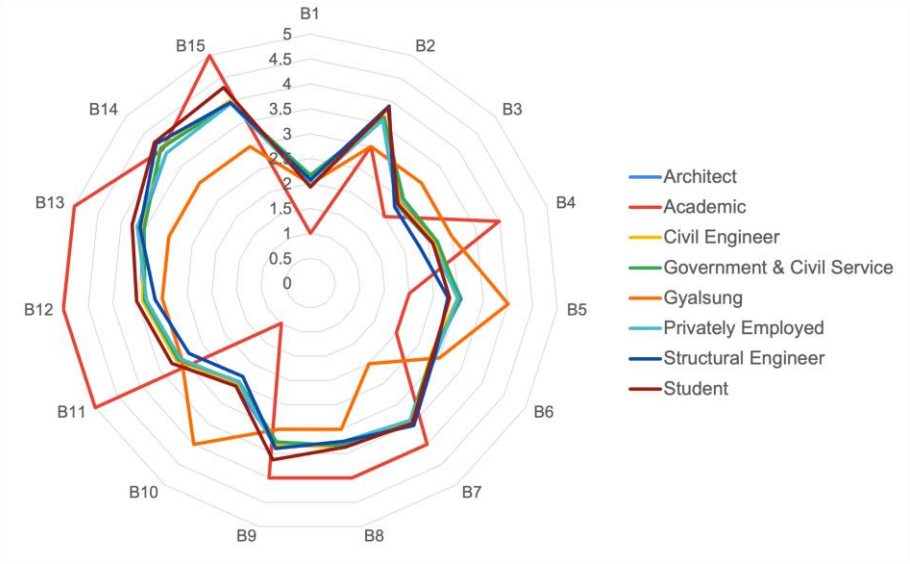

Figure 2. Perceived barriers to nature-based construction materials by occupation.

especially for large-scale projects. Future efforts should, therefore, address supply chains, standards, building codes, and training programs as well as cultural attitudes and norms across a wide range of stakeholders.

Statements that elicited the highest standard deviations were concerns about the difficulty of sourcing nature-based materials in Bhutan (B9) and the expense of building with these materials (B11), which reflect real-world conditions. Supply chains for nature-based materials, in so far as they intersect with natural resource management, community rights, and the need for ecological protection, can be difficult to establish on an industrial scale[7]. Moreover, while several papers have established the cost effectiveness of construction with, for example, mass timber, these studies have largely been conducted in highly industrialised economies where high labour costs are reduced through increased mechanisation[19]. Thus, the cost of nature-based materials in emerging economies like Bhutan could be a more contentious factor affecting the uptake of these materials. The findings suggest that while cost and material availability may be significant barriers for some, there is less consensus among participants regarding how strongly these factors limit the adoption of nature-based construction.

3.5. Opportunities for the widespread adoption of nature-based materials in Bhutan

In the final section of the survey, participants were asked to evaluate potential opportunities for adopting nature-based materials in Bhutan's construction sector, depicted in Figure 3. No individual item received a mean score of 4 or higher, which indicates only moderate acceptance, yet every opportunity statement yielded a standard deviation below 1, suggesting a high degree of consensus among respondents as seen in Figure 4. Alignment with Bhutan's commitment to carbon neutrality (O10) and the aesthetic appeal of natural materials (O2) received the highest mean ratings, suggesting that socio-cultural acceptance of nature-based materials are likely to be

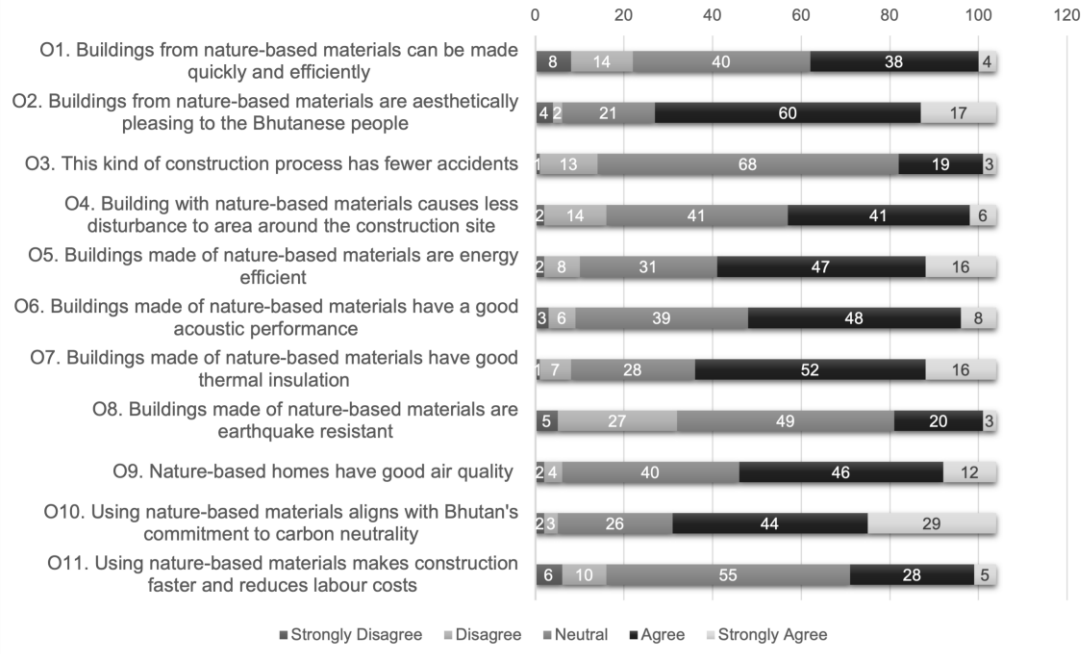

Figure 3. Opportunities for the widespread adoption of nature-based materials in Bhutan.

high. This additionally corresponds with the aesthetic preferences of end-users likely overlapping with traditional architectural methods that employ a variety of natural materials.

On the technical side, thermal performance (O7) and energy efficiency (O5) were rated highly. This is especially significant in Bhutan as conventional construction systems do not typically employed thermal insulation measures, resulting in poor indoor thermal comfort and high energy usage. Energy usage is one of the largest sources of greenhouse gas (GHG) emissions in Bhutan, where residential and commercial buildings account for 41.6 percent of energy consumption[20]. Thus the improved efficiency of nature-based buildings could be a key driving factor in the widespread adoption of alternative materials. Other beneficial attributes—such as good indoor air quality (O9), acoustic performance (O6), and reduced site disturbance (O4)—garnered moderate support, pointing to awareness of tangible advantages but also some uncertainty about their practical implementation. Interestingly, faster construction (O1) and fewer on-site accidents (O3) scored neutral responses, implying that logistical benefits are not fully proven or recognised among respondents.

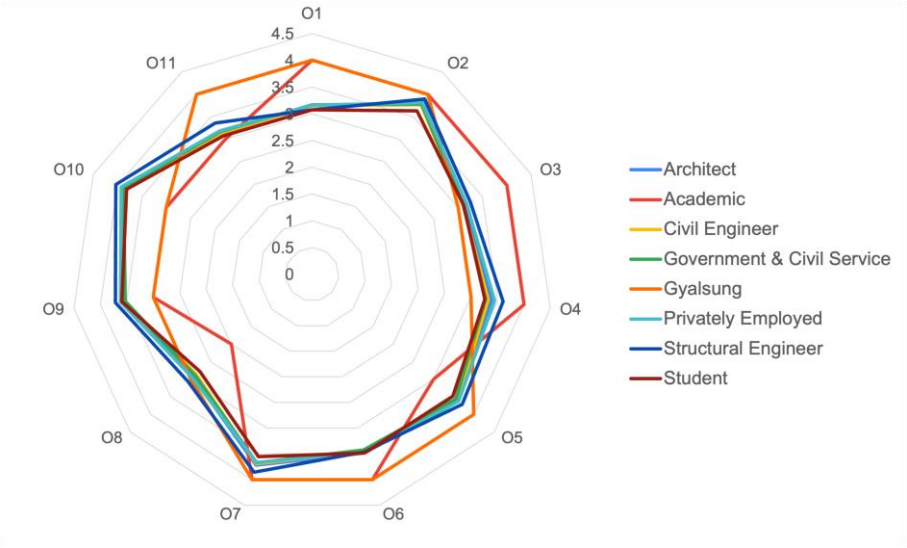

Figure 4. Perceived opportunities for nature-based construction materials by occupation.

Differences across occupations emerged most clearly on logistical and performance-related statements, particularly O4 (reduced impact on construction sites) and O8 (earthquake resistance). Respondents in technical or engineering roles showed higher acceptance about the ability of nature-based materials to mitigate seismic risks, while academics and Gyalsung members remained negative and neutral. Given Bhutan's location in a seismically active zone and its history of significant earthquake-related losses[21], it is critical to design and demonstrate buildings that harness the strengths and limitations of new materials, particularly in relation to seismic resilience. In sum, while acceptance of the examined opportunities is generally moderate, the high frequency of neutral responses for these opportunities, especially ones related to their technical and logistical performance, underscore a lack of more specific knowledge about these materials and perhaps uncertainty about their feasibility in the context of Bhutan.

4. Conclusion

This study explored perceptions of nature-based materials within Bhutan's construction sector, assessing familiarity with the RBE concept, the current challenges facing the industry, and the barriers and opportunities influencing the adoption of sustainable building materials. The findings underscore a mixed awareness of RBE principles, with nearly half of respondents (46%) demonstrating at least moderate familiarity, and slightly more than half (54%) reporting little or no awareness. This highlights a need for targeted education and outreach efforts to integrate regenerative principles into Bhutan's construction discourse. The survey also identified critical challenges within the sector, particularly a shortage of skilled labour, poor thermal insulation, limited material availability, and high construction costs. While supply chain constraints and policy gaps were flagged as pressing ongoing concerns, environmental considerations, though still significant, were somewhat secondary to economic and logistical barriers.

Regarding barriers to nature-based materials, the most prominent concerns revolved around regulatory gaps, technical uncertainties, and cultural perceptions. While respondents rejected the notion that such materials are inherently low quality, they expressed strong concerns about fire safety, maintenance requirements, and pest susceptibility. Conversely, opportunities for nature-based construction were widely recognised, particularly in relation to Bhutan's carbon neutrality commitment, cultural aesthetics, and the potential for improved building performance. However, the relatively neutral or uncertain responses to logistical and efficiency-related benefits suggest a lack of familiarity with modern advancements in nature-based construction, which could be addressed through demonstration projects and industry engagement.

Improving policy incentives, technical standards, and building codes will create an enabling environment for the transition toward an RBE in Bhutan. Investment in local material production, modernising supply chains, and specialised training will in turn enhance the availability and usability of advanced nature-based materials for construction. In addition, multi-stakeholder collaboration, bringing together government agencies, academia, the private sector, and local communities, will be crucial for overcoming structural and perceptual barriers. Ultimately, Bhutan's rich tradition of natural material construction, coupled with its strong commitment to sustainability, presents a unique opportunity to lead the adoption of regenerative building practices in emerging economies.

5. Acknowledgements

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