

Article

Sustainable Construction and Climate Change Mitigation: Insights from China, Malaysia, South Africa, and Peru

Adnan Yousaf ^{1,*}, Safeer Ullah ^{2,3}, Jianping Wu ^{4,5,6}, Deqing Huang ¹  and Muhammad Hussain ⁷ ¹ School of Electrical Engineering, Southwest Jiaotong University, Chengdu 611756, China; elehd@home.swjtu.edu.cn² College of Management Science, Chengdu University of Technology, Chengdu 610059, China; safeerullah@my.swjtu.edu.cn³ Postdoctoral Research Station of Management Science and Engineering, Chengdu University of Technology, Chengdu 610059, China⁴ School of Civil Engineering, Tsinghua University, Beijing 100084, China; jianpingwu@tsinghua.edu.cn⁵ Research Center for Autonomous Driving and Intelligent Transportation, Tsinghua University Research Institute at Shenzhen, Nanshan, Shenzhen 518000, China⁶ Zero Carbon Transportation Research Center in Sichuan Tianfu Yongxing Laboratory, Chengdu 610213, China⁷ Western Australian Centre for Road Safety Research School of Psychological Science (M304), University of Western Australia, Perth, WA 6009, Australia; muhammad.hussain@uwa.edu.au

* Correspondence: adnanyousaf@swjtu.edu.cn

Abstract

The building industry is central to climate change mitigation because it generates substantial energy use and carbon emissions across the full building life-cycle, from material production to operation. Passive and energy-efficient designs, renewable energy integration, use of low-carbon and reusable materials, digital optimization, and circular waste management can minimize operational and embodied emissions, and climate-responsive design can enhance heat, water stress, and other environmental resilience. This study explores sustainable construction practices and climate change mitigation strategies in four different economies: China, Malaysia, South Africa, and Peru. Based on questionnaire data collected from professional engineering and green building networks associated with the World Federation of Engineering Organizations (WFEO), the study applies thematic analysis to compare national priorities and strategies. The findings show that each country pursues sustainability according to its resources, development needs, environmental challenges, and technological strengths. China and Malaysia emphasize energy-efficient design and digital building systems, South Africa focuses on climate-responsive design and material recovery, while Peru prioritizes bio-based materials and local solutions. Overall, renewable energy, circularity, resource optimization, and digital technologies emerge as key trends in advancing low-carbon, climate-resilient construction.

Keywords: climate change; thematic analysis; energy efficiency; sustainable construction; carbon emissions



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1. Introduction

The construction sector is a major participant in the global climate agenda, as buildings and construction as a whole account for a large share of the world's energy consumption and carbon emissions. Carbon-intensive products such as steel and cement (8% of the world's CO₂ emissions) [1] continue to dominate the industry (32% of the world's energy generated and 34% of the world's carbon emissions) according to the latest global analysis

by the United Nations Environment Program (UNEP) and the Global Alliance of Buildings and Construction [2]. The Intergovernmental Panel on Climate Change (IPCC) recommends that the built environment be decarbonized in order to achieve the objectives of the Paris Agreement [3], but also notes that building emissions have grown tremendously over the past decades [4].

The climatic impact of construction needs a whole-life-cycle approach that extends beyond energy consumption during operations. Recent studies have shown that successful decarbonization involves a combination of various supplementary strategies, including circularity, low-carbon and recycled materials, passive and energy-efficient building design, integration of renewable energy, and digitally empowered decision-making [5–9]. In particular, embodied carbon in building materials has become a pressing issue, with a focus on material efficiency, reuse, and other bio-based substitutes [10]. Moreover, according to field reviews, effective mitigation requires coordinated activities in design and material selection, construction processes, building operations, and end-of-life management; that is, no single intervention can be effective in isolation [11–13].

However, there are regional and national differences in the shift to sustainable building. Recent systematic reviews suggest that institutional maturity, financial capability, regulatory support, industry expertise, market incentives, and sociocultural factors affect the adoption of sustainable construction techniques, in addition to technological availability [14,15]. Comparative studies of net-zero and green building pathways show that national strategies for defining, prioritizing, and applying low-carbon construction methods differ considerably. The differences suggest that a sustainable building can be understood only as a contextual process, motivated by local environmental problems, resource endowments, development agendas, and regulatory environments, rather than by a universal set of technical guidelines.

Even though the literature on low-carbon materials, green buildings, and building innovation has grown tremendously, a gap remains. The majority of current studies focus on technologies, specific materials, certification programs, or experience in the country. There is a lack of studies that apply a single analytical prism to compare the expression of sustainable construction priorities across different national settings. This difference is especially relevant to emerging and transitional economies, where the goals of climate mitigation often have to be balanced with constraints regarding funding, inadequate infrastructure, rapid urbanization, and environmentally specific issues. Thus, the comparative approach is necessary to better understand how other countries conceptualize and practice sustainable construction, and how context affects the choice of tactics deemed most effective and successful.

Based on these facts, this research analyzes methods of climate change mitigation and sustainable construction across four national settings: China, Malaysia, South Africa, and Peru. The research focuses on understanding the perception and priority of key elements of sustainable construction across different countries, using questionnaire data collected via professional engineering and green building networks and analyzed using thematic analysis. The purpose of the comparative design is to retain the same analytical framework while measuring variance across different built-environment conditions and development paths. The paper explores the divergent national conditions that lead to distinct priorities in design, materials, technology, waste policies, and energy-related policies, rather than whether a single strategy can decarbonize the construction sector. The initial sampling frame included nine member countries (China, Malaysia, South Africa, the United Kingdom, the United States of America, Japan, Indonesia, Kenya, and Peru) of the WFEO which were chosen to represent variations in geographic region, climatic exposure, conditions in the construction market, institutional development, and technological capacity. The final

sample for comparison was made up of China, Malaysia, South Africa, and Peru, four countries that had returned questionnaires that were sufficiently complete for thematic analysis. Such was the case with the final cases, which were therefore response-contingent and not selected as the sole interest in this study.

This study adds to the body of knowledge in three aspects. It first offers a qualitative comparative lens into sustainable construction in four under-compared national contexts. Second, it promotes a context-sensitive interpretation of the influence of local conditions on the development of climate mitigation strategies in the construction industry, rather than focusing on technical factors. Third, it provides policymakers, engineers, urban planners, and construction professionals with information to hasten the shift to a lower-carbon, more climate-resilient built environment. By considering common issues and context-specific priorities, the study clarifies how national experiences can inform larger international efforts to decarbonize construction, in line with sustainable development objectives. This research is especially pertinent to many countries that are aligning their building and urban development sectors with the UN Sustainable Development Goals (SDGs), especially SDG 11, which aims to achieve inclusive, safe, resilient, and sustainable cities and human settlements.

2. Literature Review

The existing literature is unanimous in stating that the construction industry is among the largest contributors to climate change, as its effects on the environment are felt in the production of construction materials and during construction processes. Almost forty percent of all carbon dioxide (CO₂) emissions related to energy production are ascribed to the building industry, along with the output produced during the production of building materials (cement, steel, and glass) and the heating, cooling, and lighting of buildings throughout their service life [16]. Of all these sources, cement production alone accounts for nearly 8% of total CO₂ emissions worldwide, illustrating the magnitude of the embodied carbon associated with traditional construction methods [1]. This fact has shifted the scholarly and policy discussion about buildings as energy-consuming objects to the realization that buildings are a climate issue throughout their life-cycles. Simultaneously, the literature indicates that the sector also has good mitigation potential. The operational energy requirement can be reduced through green building methods such as passive solar design, high-performance insulation, and energy-efficient HVAC systems, as well as the use of other low-carbon materials and enhanced design strategies, thereby minimizing the total carbon footprint of a building [17]. It is therefore believed that decarbonizing the built environment is a key component of achieving the broader climate goals set by the Paris Agreement [3].

Sustainable building has become a prevailing concept for addressing these apprehensions by rethinking the design, construction, and management of the built environment. Strategies for green buildings are designed to reduce environmental impacts through energy efficiency, water conservation, and sustainable material use [1,18]. One of the most significant trends of this transition has been the proliferation of green building certification systems, which have institutionalized sustainability by translating general environmental goals into more specific performance targets. LEED, BREEAM, Green Star, and EDGE are among the most common international certification systems [19–22], and their adoption demonstrates the growing need to assess construction performance at the international level. LEED is applied in more than 160 countries [22], whereas BREEAM has already certified many projects worldwide, especially in Europe [19]. However, the literature also indicates that certification does not always lead to sustainability. On the other hand, certification may be used most efficiently by implementing them to make design decisions,

enhance accountability, and create uniform standards across the project and locations. It means that certification systems are significant development indicators, yet they should be viewed in the broader context of national and institutional levels.

In this study, sustainable construction is used as the broader concept covering environmental performance across the complete construction life-cycle and its supporting institutional, economic, and resource systems. Green building refers more narrowly to building-level design, construction, certification, and operational practices intended to reduce environmental impacts. Green building is therefore treated as one component of sustainable construction rather than as a fully interchangeable term.

Regional Differences, National Policy Contexts, and Country-Specific Constraints

While energy efficiency, renewable energy, low-carbon materials, digital technologies and circular resource use are key components of sustainable construction strategies, geographical, economic, institutional, and sociocultural factors play a significant role in their implementation. While there are common goals with international green building systems and climate frameworks, there are not the same pathways for implementation. Comparative studies of net-zero buildings reveal significant variations in how they are defined, the regulations and requirements they must meet, the extent of the carbon accounting boundaries, certification systems, climatic assumptions, and the capacity for their implementation between countries [15]. Likewise, the adoption of sustainable building has been found to be as dependent on the maturity of regulations, provision of incentives, financing opportunities, professional knowledge, public awareness, material availability, and institutional coordination as it is on technology [14]. Such a global shift toward low-carbon buildings, then, must be interpreted in terms of countries' and regions' specific national and regional paths—not as a single universal technical one. Recent studies also show the benefits of using a mix of qualitative and quantitative indicators to evaluate building sustainability and resilience. Di Ruocco, Luisi [23] created an integrated multi-indicator model to assess building resilience with regard to environmental and building life-cycle aspects. The method highlights the importance of considering sustainable construction from a systems perspective, with context sensitivity, and not only based on individual technology or single performance parameters.

China has a relatively planning-driven approach to green building development. National carbon-peaking/building carbon-neutrality targets have been integrated into programs pertaining to energy conservation, renewable energy, green buildings, prefabrication, and building renovation. The 14th Five-Year Plan framework has also linked the growth of the building sector with the national goals of green cities, industrial modernization, digitalization, and energy- and carbon-intensity reduction. This policy has enabled the growth of green building standards, industrial building construction, Building Information Modeling, renewable energy systems, and high-performance building technologies. However, there is a great deal of variation within China. The diversity of climate, economic development, urbanization, construction market maturity, fiscal resources, and policy implementation at the provincial and municipal levels leads to different patterns of development of green buildings. Regional variability has been found in green building performance and policy intensity as a result of various studies [24–26].

Malaysia's sustainable construction priorities are influenced by the hot and humid climate, high cooling demand, heavy rainfall, flood risk, and fast urbanization rates. The importance of passive ventilation, solar control, efficient cooling, daylighting, water management, and flood resilience are amplified. National Construction Policy 2030 supports sustainability, digitalization, productivity, technological innovation, and resilient infrastructure. The high initial costs, lengthy payback periods, lack of knowledge among stakehold-

ers, awareness, and inconsistent policy implementation are, however, hindering broader adoption. As a result, successful projects in major cities are considered to be good examples and not a sign of national rollout [27].

Sustainable construction is closely related to energy security, water scarcity, climate adaptation, and socioeconomic inequality in South Africa. This is in line with SANS 10400-XA [28], which sets the standards for energy efficiency in buildings, and the Climate Change Act 2024 [29], which aims to make development more low-carbon and climate-resilient. Passive design, use of solar energy, efficient building envelopes, water harvesting, water reuse, and use of recycled materials are relevant practices. Nonetheless, high perceived costs, lack of technical training, weak coordination of actors, and low access to sustainable technologies are limiting factors. These barriers are especially significant when looking at internationally recognized commercial projects versus smaller companies, public housing, rural areas, and less-resourced municipalities [30].

The coastal, Andean, and Amazonian areas of Peru have very different climates, water supplies, material resources, access, and building traditions. The Sustainable Construction Technical Code and the National Housing and Urbanism Policy to 2030 provide foundations for energy and water efficiency, renewable energy, and sustainable urban development. It is also possible to incorporate locally available materials, bio-based materials, and to integrate vernacular knowledge with contemporary building codes in Peru. However, there are some issues that can lead to inconsistent implementation, including geographical diversity, uneven municipal capacity, limited technical expertise, and coordination issues between national, regional, and local authorities. Innovative bio-based and/or climate-responsive buildings, therefore, should not be regarded as evidence of common national practice but rather as examples of specific contexts.

In general, the four countries have similar sustainability goals, but achieve them in different ways. China focuses on national planning, technical standards, prefabrication, and digital construction. Malaysia presents a characteristic mix of tropical climate-responsive design and modernization of the construction industry. South Africa emphasizes energy and water limitations, the use of materials and passive design elements, and the recovery of materials, while Peru stresses the use of local materials and geographically responsive solutions. These differences are not a measure of the superiority of one national model; rather, they suggest that the priorities for sustainable construction vary depending on the environmental, economic, technological, and institutional conditions of specific countries.

Table 1 shows that the differences identified in the thematic analysis correspond to different policy, regulatory, financial, climatic, and resource situations. China has a mature regulatory and construction supply chain, which facilitates prefabrication, digitalization, and high-performance technology. The tropical climate, energy consumption, and green investment policies of Malaysia reinforce an efficient focus on cooling, energy, and industrialized construction. The electricity and water scarcity make passive design, renewable energy, water conservation, and material recycling more critical in South Africa. Peru's geographical diversity, regional capacity gaps, and access to local and bio-based materials foster climate-responsive and locally adapted construction solutions. These contextual conditions are provided to aid in the understanding of the priorities reported by the participating institutions, and are not intended to suggest one national approach is better than another.

This distinction also makes direct cross-country comparisons more difficult. The scope and maturity of national policies is different across countries; enforcement, certification, monitoring, and implementation of the policies are different; and countries have different ways of defining green buildings, calculating emissions, reporting waste, and assessing performance. Large, certified projects may also not be representative of the typical construction

of smaller cities, rural areas, low-income housing, and informal settlements. However, the present study is not intended to rank countries, but rather to make thematic comparisons between national priorities.

Table 1. Policy, regulatory, economic, and resource context of the four countries.

Country	Climate Policies and Target	Building Codes and Standards	Economic Incentives	Materials and Technologies Reported as Available
China	Carbon dioxide emissions are to peak before 2030, and carbon neutrality is targeted before 2060. China's 2035 NDC also targets a 7–10% reduction in economy-wide net greenhouse gas emissions from peak levels.	GB 55015-2021 [31] regulates building energy efficiency and renewable energy use, while GB/T 50378-2019 [32] provides the national green building evaluation framework.	Green construction is supported through green finance, preferential lending, public procurement, and locally administered subsidies and incentives, although arrangements differ among provinces and municipalities.	The submission reported extensive availability of concrete, steel, engineered materials, prefabricated systems, BIM, renewable energy systems, smart controls, and high-performance building technologies.
Malaysia	Malaysia maintains a 45% reduction target for economy-wide carbon intensity by 2030 relative to 2005 and, under its newer NDC, aims to peak emissions around 2030 and reduce emissions below peak levels by 2035.	MS 1525:2019 [33] addresses energy efficiency and renewable energy use in non-residential buildings. GBI, GreenRE, MyCrest, LEED, and related systems provide additional assessment frameworks.	Green Investment Tax Allowance and Green Income Tax Exemption mechanisms support eligible green buildings, renewable energy, and energy-efficiency investments.	The submission reported established cement and steel supply, solar technologies, efficient HVAC and lighting, BIM, and industrialized building systems, although initial cost and technical capacity barriers remain.
South Africa	South Africa's NDC establishes a 2030 emissions range of 350–420 MtCO ₂ e, while the Climate Change Act 2024 provides the framework for a low-carbon and climate-resilient transition.	SANS 10400-XA [28] establishes energy-efficiency requirements for new buildings and alterations, while Green Star South Africa provides voluntary sustainability certification.	Section 12L provides tax deductions for verified energy-efficiency savings and has been extended to years of assessment ending before 1 January 2031.	The submission emphasized solar energy, water-saving technologies, recycled steel, reclaimed wood, recycled aggregates, and climate-responsive design, but access to green technologies remains uneven outside major formal projects.
Peru	Peru's NDC 3.0 commits the country to keeping net greenhouse gas emissions at or below 179 MtCO ₂ e by 2035, supported by the National Climate Change Strategy to 2050.	The National Building Regulations and the Sustainable Construction Technical Code, approved through Supreme Decree 014-2021-VIVIENDA [34] and subsequently updated, address energy, water, waste, and environmental performance.	The MiVivienda Verde program provides financing and subsidies for certified sustainable housing.	The submission reported conventional concrete and steel alongside locally available bamboo, agricultural fibers, mushroom-based materials, rice residues, BIM, drones, and 3D technologies, although availability varies considerably among regions.

Note: Policy, code, standard, and incentive information was obtained from official government and UNFCCC sources, whereas information on material and technology availability was derived from country-level institutional questionnaire submissions.

Material innovation is one element of inquiry within the broader sustainability agenda, since the choice of materials significantly influences the environmental impact of buildings early in their design. Sustainable construction studies are beginning to recognize that decarbonization cannot be achieved solely through operational energy-saving measures, as the embodied energy of conventional materials can be significant. Studies of low-carbon concrete and other cement-based binders indicate that improving the environmental performance of cement-based materials is a priority [35–37]. Meanwhile, recycling of other materials (e.g., reclaimed wood, recycled steel) has been encouraged as a solution to lower resource extraction and environmental load [38]. Nevertheless, in recent years, the literature has taken a new turn toward bio-based materials, such as mycelium, hempcrete, and bamboo, as alternatives to traditional materials because they are renewable and low in carbon emissions [39,40]. Bamboo has been highly touted as a low-carbon substitute for steel, concrete, and timber in some applications because of its fast growth and high

renewability [41]. Similarly, mycelium composites are also being considered as sources of biodegradable blocks and insulation materials [39,42,43]. Meanwhile, modular and prefabricated building methods are gaining popularity as means to improve efficiency, minimize waste, and enhance the accuracy and value-based utilization of materials by shifting construction to a more controlled context [44]. These developments, combined, show that sustainable building is increasingly reliant on reassessing the materials used and the manufacture of building elements.

Sustainability in the construction industry is also becoming a primary driver of technological change and material innovation. The recent literature is mainly interested in how digitalization can enhance the quality of design, construction efficiency, and resource management. Special emphasis has been placed upon Building Information Modeling (BIM), which helps in the development of digital models of the physical and functional characteristics of a building, enhances coordination, minimizes errors, and allows simulation of performance [9]. BIM can be used in conjunction with sustainability analysis to support effective resource use, model energy requirements, and enhance life-cycle decision-making. The construction process is becoming more accurate, with less material waste, thanks to BIM, robotics, 3D printing, and drones [45]. Additive manufacturing has been cited as a viable solution to manufacture parts with less material and less waste. Machine learning and artificial intelligence in construction management, in turn, have been implemented to optimize schedules, improve resource use, and enable predictive maintenance, thereby enhancing long-term economic and environmental performance [46]. Nonetheless, the literature also suggests that technological innovation offers sustainability benefits, conditioned by broader institutional and organizational capacity to effectively implement and integrate the tools. To this extent, technology cannot be regarded as a solution but only as an enabler of situations, and the impacts are also situation-dependent.

The relevance of sustainability in energy conservation and waste management is another aspect highlighted by the continued importance of green buildings. Energy efficiency is one of the most developed principles of green building, as operational energy consumption still accounts for a considerable share of emissions in most buildings. The performance of buildings has been improved through the development of passive solar heating, high-performance insulation, efficient HVAC systems, and the integration of renewable energy [47–50]. Nevertheless, there is an increasingly robust body of literature that argues for enhancing operational efficiency by better managing material flows and construction waste to achieve significant sustainability gains. Construction and demolition waste accounts for a high proportion of total waste worldwide; therefore, recycling, reuse, and end-of-life planning are significant aspects of sustainable construction [51,52]. In particular, deconstruction, rather than demolition, design is an important method for prolonging the life-cycle of materials and reducing the consumption of virgin materials [53,54]. The literature shows that a single intervention may not guarantee sustainable construction, but the combination of design efficiency, material innovation, digital technologies, renewable integration, and circular waste practices does. What is not so well-known, though, is the mechanism concerning the integration and ranking of such priorities within different national contexts. Much of the literature focuses on individual technologies, materials, or certification systems in isolation, and there is a paucity of information on the understanding and application of sustainable construction across a wide range of economic, environmental, and institutional contexts. This study addresses this gap by examining how countries define and implement key dimensions of sustainable construction to mitigate climate change.

3. Methodology

The methodology adopted in this research study is illustrated by Figure 1 below; further details are discussed in subsequent sections.

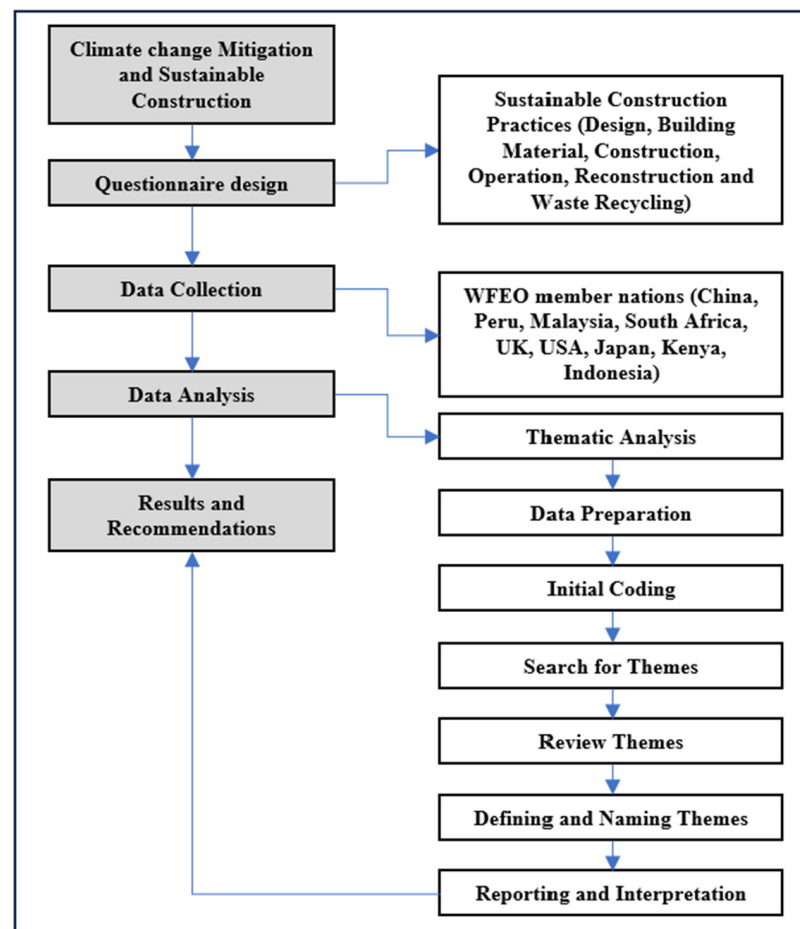


Figure 1. Methodology for thematic analysis.

3.1. Questionnaire Design

Data were collected using a questionnaire, and each question was structured to address various issues related to sustainable construction practices. The various domains are as follows:

- a. **Design:** Data on case studies and standards about low-carbon and green building methods are gathered by the Design section. It begins with a proposal for regional or national regulations and standards for energy efficiency, carbon reduction, and sustainability in civil engineering. Subsequently, it asks to provide real-world design initiatives that have drastically reduced carbon emissions and energy consumption, and to compare them with similar nearby buildings using data for at least a year. The section also seeks data on architectural innovations, such as natural lighting, passive ventilation, and optimized layouts, as well as on material innovations, such as high-performance steel and concrete. Finally, it seeks information about the use of green energy technologies, including reflective roofing and solar panels.
- b. **Building Materials:** The Building Materials section is primarily focused on gathering the various types of materials that are used in construction and their sustainability. It asks about new materials or production processes that reduce carbon emissions, what can be done to reduce the energy and emissions footprint of traditional materials, and which materials are most used and in what situations. It also includes rapidly

- renewable materials, such as the reuse of solid waste; technologies or standards that promote modular or standardized components; and the reuse of construction parts.
- c. **Construction:** The construction process is considered in the Construction section of sustainability. It starts with asking about the most frequently used building methods (prefabricated or cast-in-place). Following is a discussion on organizational strategies and processes to minimize energy use and emissions on the work site. Moreover, it asks about ways to minimize equipment emissions and promotes reporting on the use of digital tools, such as automation technologies, construction robots, and Building Information Modeling (BIM).
 - d. **Operation:** Information about energy-efficient building management is sought after by the Operation section. It asks about local/regional energy-management initiatives across different types of equipment, real-world examples of how cutting-edge technology can reduce emissions, and how digital technologies, including artificial intelligence and big data, can be applied to make buildings more efficient.
 - e. **Reconstruction:** Sustainable rehabilitation methods and material reuse are discussed in the Reconstruction section. It asks for examples of robotics in retrofitting and surveying for rebuilding, and for details on efforts and technologies to extend building life or repurpose existing buildings.
 - f. **Waste:** Data on trash management and recycling procedures is gathered by the trash department. It demands the means to monitor and regulate the transportation and treatment of construction waste, technologies for recycling resources such as steel, glass, and cement, and technologies to reduce the adverse environmental impacts of waste.
 - g. **Macro Indicators (optional):** The Macro Indicators section collects data at the national level. This includes geographical and climatic classification, the amount of building materials used annually, the volume of construction, statistics on emissions and energy, and carbon per-square-meter or per-person for a particular material, e.g., steel and cement. This section aims to provide a contextual background and compare the effects of construction in all studied countries.

The questionnaire was tailored to the above domains to investigate and capture the various strategies adopted in each country to reduce climate change and ensure the sustainability of building practices. The World Federation of Engineering Organizations (WFEO) and its member countries, particularly China, were instrumental in developing the questionnaire.

3.2. Data Collection

The questionnaire was emailed to the Green Building Councils and other relevant civil engineering institutions in the WFEO countries to collect data. The WFEO members, to which the questionnaire was distributed, are China, Malaysia, South Africa, the United Kingdom, the United States of America, Japan, Indonesia, Kenya, and Peru. The first invitation frame was designed to be purposeful to capture the geographical and contextual variation in climate conditions, construction systems, institutional arrangements, and sustainable construction practices. It is not intended to be statistically representative of all WFEO member countries. Completed and usable country-level submissions were received from China, Malaysia, South Africa, and Peru, corresponding to a country-level participation rate of 44.4% (4/9). Because distribution occurred through institutional networks and the total number of individual recipients was not recorded, the reported 44.4% rate refers specifically to country-level participation rather than individual-level response. The countries that responded to the questionnaire provide rich cross-sectional insights into sustainable building practice and enable comparisons and contrasts between economic and regional contexts.

All four questionnaire country-level submissions from China, Malaysia, South Africa and Peru were used across the formal thematic analysis. The questionnaires included 23 basic questions and sub-questions on six analytical domains, resulting in 92 country-by-question response units. Of this, 69 units (75.0% of the data) were coded for substantive information. Twenty-three units had no data reported, specified as “No data” or stated to be outside the responding institution’s scope. These entries were not used as substantive material for the themes, but were retained as part of the analytical matrix to show the limits of the evidence. Questions that were not mandatory as formal thematic synthesis questions were macro indicator questions which were not completed to a satisfactory degree across countries, and so were not incorporated into the formal thematic synthesis.

This study collected institutional and country-level information from national Green Building Councils and relevant professional engineering organizations. The questionnaire was directed towards sustainable construction policies, standards, technologies, and project practices and did not seek to gather personal, sensitive, medical, or individually identifiable information. The organizations voluntarily filled in and returned the questionnaire. The analysis and reporting did not include identifying individual contributors and the results were only reported at the country- or institutional-level. The authors did not recruit or study anyone as a human research participant, so institutional approval from ethics committees and informed consent from individuals were not required.

3.3. Data Analysis

3.3.1. Thematic Analysis

Thematic analysis is a qualitative research technique for identifying, examining, and generalizing patterns (themes) in data. It is mainly applied to written documents, open-ended questionnaires, and interview transcripts to measure the meanings and insights in a set of data [55–58]. The approach adopted in this research was thematic analysis owing to a series of important reasons:

- i. **Suitability for Qualitative Data:** The data collected in the questionnaires were predominantly in qualitative format, primarily the open-ended questions that describe sustainable construction practices, technologies, and mitigating actions on climate change. Thematic analysis is a qualitative research method for analyzing textual data and revealing patterns and themes.
- ii. **Flexibility:** Thematic analysis can be adapted to any other research context and data. Such versatility was required to analyze a wide range of datasets, since each of the countries in which the study was undertaken has its own share of problems and approaches to sustainable building.
- iii. **Identifying Patterns:** Thematic analysis is one of the methods that can be applied to detect and analyze patterns in big data. The similarities in sustainable building practices identified in this study, without overlooking regional differences, were important.
- iv. **Systematic Approach:** Thematic analysis is a fairly structured step-by-step process that offers a systematic overview and analysis of all data. The process of familiarization with the data, code generation, theme identification, theme review, and analysis writing offers a succinct analysis framework that can be replicated.
- v. **Comparative Study:** This is a research paper that aims to compare the practices of sustainable construction in different regions. Thematic analysis may be a valuable tool for comparing and contrasting practices and for identifying regional as well as climate change mitigation trends. The research can also identify major themes that cut across individual countries’ practices and provide actionable insights into global sustainability through thematic analysis.

3.3.2. Thematic Analysis Coding Procedure

Thematic analysis is a methodological approach to comprehending the ideas and meanings in qualitative data. The process that will be used to determine different themes associated with sustainable construction procedures in the current study comprises six stages [55], which are as follows:

- i. **Familiarization with Data:** This stage involves the preparation of data, audio, or data transcription where necessary, reading and re-reading the materials, and devising initial thoughts.
- ii. **Initial Coding:** During this stage, the interesting features of the entire dataset are coded. A code is a sign with meaning, attached to a piece of information that appears important to the question.
- iii. **Searching for Themes:** In this stage, the analysis is based not on the individual codes but on the broader patterns. The codes generated in the earlier stage are then clustered into larger themes (meaningful aspects of the data relevant to the research question) based on their relevance to one another.
- iv. **Reviewing Themes:** During this step, the appropriate themes are contrasted against the entire dataset and the coded extracts. Some themes are combined, divided, or revised, while others are dropped due to insufficient evidence. This, as explained by Braun and Clarke [55], entails assessing the validity of the themes at two levels: first, with the coded extracts, and later, with the whole dataset. Good themes are internally consistent, although they are varied.
- v. **Defining and Naming Themes:** Once the thematic structure is stable, each of the themes is refined in such a way that its essence can be seen. This involves listing the components of each theme, delineating its boundaries, describing how it interrelates with other themes, and assigning an appropriate name that best describes its nature.
- vi. **Reporting and Interpretation:** This is the last step that is highly critical to the analysis process, and it does not just entail reporting the findings. Here, relevant extracts are selected, their roles in interpretation are explained, and the themes are aligned with the study question and the literature. The end presentation, as Braun and Clarke describe it [59], should not be a list of quotes, sorted under headings, but should be succinct, logical, coherent, and analytically persuasive.

All country-level questionnaires were considered as one comparative case for each country. The answers were analyzed and then compared across the four countries to reveal similarities and differences. The first level of analysis was each country's answer to a separate question or sub-question. If there were more than one relevant idea in a response, the responses were broken down into meaningful units of each idea and coded accordingly. Each meaningful unit was assigned a code for the country as well as an identifier for the item on the questionnaire to which it was related, so that the researchers could follow back to the raw response, to the next level of code, and to the final theme level. Items that lacked an answer, explicit "No data" responses, and answers that explained that a question was outside the scope of the responding institution have been included in the analytical matrix to capture the response status and the limits of the evidence. Entries were not considered substantive evidence of the themes, but rather were reported as missing or non-applicable information.

A manual coding approach was used for thematic analysis in the study. This approach was considered appropriate, as thematic analysis is based on reading, coding, reflection, and interpretation; the human mind will always be at the center of such analytical decisions, with or without software. The literature [60,61] therefore indicates that software is a facilitative tool rather than a substitute for the analytic process.

Initial codes were obtained by re-reading the full responses. The questionnaire domains were used as an organizational structure, but codes were created for the content of the responses, rather than mechanically equated to the headings of the questionnaire. The coded extracts were compared with similar codes, grouped in candidate themes, and then compared with the full-country submissions. The final analysis revealed five overarching themes: sustainable building design; material innovation/reuse; technological innovation; waste management and recycling; and energy efficiency and carbon emissions reduction. Common patterns, country-specific priorities, contradictory evidence, and items where there was no information were compared in a country-by-code and country-by-theme matrix.

The frequency counts of codes were computed as a descriptive measure following the coding process and the thematic structure. One frequency is a coded reference (one meaningful unit) given to one subtheme. The 69 substantive response units resulted in 77 coded references over the five final themes, as some response units had multiple meaningful units. These frequencies were used only as descriptive indicators of the prominence of the theme and as evidential support. They should not be viewed as numbers of respondents, population estimates, or inferential statistical results. The *n* values in the bar charts were coded and should not be interpreted as actual numbers of participants as the dataset included four institutional submissions from China, Malaysia, South Africa, and Peru.

Each substantive country-question response unit was coded for the presence or absence of each of the five themes for the descriptive country comparison. When a response was counted multiple times in the same theme, this was considered one response. A response was only counted once in a given theme, although multiple themes could be assigned to the same response if supported by the content. Responses that were blank, held no data, or were denoted as non-applicable were not included, as were out-of-scope responses. The percentages in the themes were based on the number of substantive response units available for each country. These frequencies were used as a measure of emphasis in the institutional submissions, not as a measure of national prevalence.

3.3.3. Trustworthiness and Analytic Rigor

A triangulation was conducted at three levels. First, within each country, answers from six questionnaire domains (design, materials, construction, operation, reconstruction, and waste management) were analyzed in relation to the other answers to see if there was evidence to support the reported priorities within each domain. Second, the narrative responses were correlated with the supporting information provided by the respondents, such as the standards, regulations, institutional guidance, project examples, technologies, performance data, and documentary links. Third, a country-by-theme matrix was used to find similarities and differences between China, Malaysia, South Africa, and Peru. Unavailable/unreported information was not interpreted as evidence for lack of practice.

Repeated reading of the entire data, iterative coding of the codebook, and checking the themes against the coded extracts and country submissions generally increased credibility. The codebook provided code definitions, inclusion/exclusion criteria, and representative examples. Internal consistency, uniqueness, and relevance to the research questions were considered for the candidate themes. Responses that were contradictory, negative, or non-applicable did not change because they showed a non-uniform picture of sustainable construction practices.

The analysis was supported by maintenance of an audit trail. It contained the original questionnaire workbook, the cleaned country-by-question response matrix, the working codebook, coded extracts, country-by-theme comparisons, and records of decisions made as to the combining, splitting, renaming, retaining, and rejecting of codes and themes. This

process ensured that a clear connection could be established between the original answers, first codes, final themes, and reported interpretations.

Because the analysis covered the complete and fixed set of usable country submissions, the dataset was treated as bounded. Traditional saturation was not used as a prospective recruitment or data-collection stopping criterion, and the study does not claim thematic saturation across the global construction sector. Coding ceased after all four submissions and all substantive response units had been coded, the codebook had been refined, and the themes had been reviewed against both the coded extracts and the complete dataset. The final country case contributed additional examples and country-specific variations but did not require the creation of a new higher-order theme. The analysis was therefore judged to have achieved thematic sufficiency for the four-country comparison, rather than universal thematic saturation.

Initial coding and theme development were undertaken by the lead researcher. The code definitions, extracts, and the distribution of evidence to the five final themes were then reviewed by a second researcher. Discussions were used to resolve differences, and the original responses were re-examined. In line with reflexive thematic analysis, this review was employed not only to dispute interpretations and enhance consistency, but also to provide greater transparency, and not to imply that there was only one objectively valid coding solution. The academic background of the lead researcher in the fields of civil engineering and sustainable buildings could have made him more sensitive towards the technological, material, regulatory, and energy-related responses. This background could potentially have resulted in greater emphasis being placed on technically oriented solutions. To minimize the risk of this happening, reflexive notes were used throughout coding; interpretations were regularly compared with the original responses; contradictory and negative evidence was kept; and missing evidence was not interpreted as evidence of absent practice. The coded extracts were given to a second researcher for a critical review of the code definitions, themes emerging from the coding, and the assignment of evidence to the final themes, including unsupported assumptions, overlapping themes, and country-specific evidence. If there were differences in interpretation, these were resolved by discussion and re-examination of the original responses to the questionnaire.

4. Results

Table 2 summarizes the representative projects reported by the responding institutions together with the links to support these projects.

A thematic analysis with 77 coded references corresponding to five key themes was created. Most of the themes were represented by coded references of 20, which included Material Innovation and Reuse and Energy Efficiency and Carbon Emissions Reduction. Technological Innovations, Sustainable Building Design, and Waste Management and Recycling were next with 15, 12, and 10 coded references, respectively. Thematic diagrams are shown in Figures 2, 4, 6, 8 and 10, and the descriptive frequency distribution of the main subthemes within the themes is provided in bar charts (Figures 3, 5, 7, 9 and 11). The purpose of these charts is to illustrate the empirical basis and relative salience of the coded topics, not the statistical generalizability.

The relative emphasis of the submissions on energy efficiency and carbon emissions reduction was highest for the submissions from China and Malaysia (see Table 3). Peru demonstrated relatively positive proof of technological innovation, especially in the use of BIM, drones, automation, big data, and digital applications. The information available in South Africa focused predominantly on sustainable building design and innovations in materials, with a few questions on technology being considered outside of the institution's scope of response. These differences are descriptive only, and are not meant to be inter-

puted as being statistically significant at the national level. While the same questionnaire was used in all four countries, the frequencies may also reflect the comprehensiveness and detail of the institutional responses.

Table 2. Representative projects and their supporting links as reported by responding institutions.

Country	Project	Relevance to the Analysis	Supporting Reference
China	Shanghai Ecological Office Demonstration Building	Energy-efficient design, renewable energy, natural ventilation, and low operational energy use	https://www.shgbc.org/xiangmujijin/1046.html (accessed on 15 April 2026)
Malaysia	Menara Shell/Shell Headquarters Tower	Reduction in energy and carbon emissions, and green building certification	https://www.hijjas.com/menara-shell/ (accessed on 15 April 2026) https://mrcb.com.my/assets/images/pages/pdf/2013/Media-Release-MENARA-SHELL-HAS-GOOD-FENG-SHUI-ELEMENTS.pdf (accessed on 15 April 2026)
	Teknion Showroom Malaysia	LEED certification and energy-efficient lighting and air-conditioning	https://www.usgbc.org/projects/teknion-showroom-malaysia (accessed on 15 April 2026)
South Africa	Serra Services	Renewable energy and efficient building operation	https://www.gbcsa.org.za/project/1060/ (accessed on 15 April 2026)
	The Ridge	Cross-laminated timber, eco-bricks, and material innovation	https://www.gbcsa.org.za/project/772/ (accessed on 15 April 2026)
	144 Oxford	Reuse of construction materials and recycled content in structural steel	https://www.gbcsa.org.za/project/894/ (accessed on 15 April 2026)
Peru	No information provided		

Table 3. Distribution of themes across substantive country–question response units.

Theme	China, <i>n</i> = 16	Malaysia, <i>n</i> = 22	Peru, <i>n</i> = 21	South Africa, <i>n</i> = 10
Sustainable building design	6 (37.5%)	8 (36.4%)	3 (14.3%)	5 (50.0%)
Material innovation and reuse	5 (31.2%)	7 (31.8%)	6 (28.6%)	5 (50.0%)
Technological innovation	3 (18.8%)	5 (22.7%)	9 (42.9%)	0 (0.0%)
Waste management and recycling	4 (25.0%)	4 (18.2%)	4 (19.0%)	2 (20.0%)
Energy efficiency and carbon emissions reduction	7 (43.8%)	10 (45.5%)	9 (42.9%)	4 (40.0%)

Note: Percentages indicate the percentage of substantive response units in each country that showed evidence of the theme. Percentages for each country do not add to 100% as a response unit may include more than one theme.

4.1. Sustainable Building Design Theme

Sustainable Building Design was one of the key themes identified in the data. This theme covers energy-efficient construction design, integration of renewable energy, and climate-friendly design. The results of this study revealed that the countries examined in this study have unique strategies for sustainable building design, with variations in energy design, climate adaptation, renewable energy integration, and in green building standards. There were 12 coded references in this theme. The thematic diagram of Sustainable Building Design is shown in Figure 2, and the subthemes are shown in frequency distribution in Figure 3.

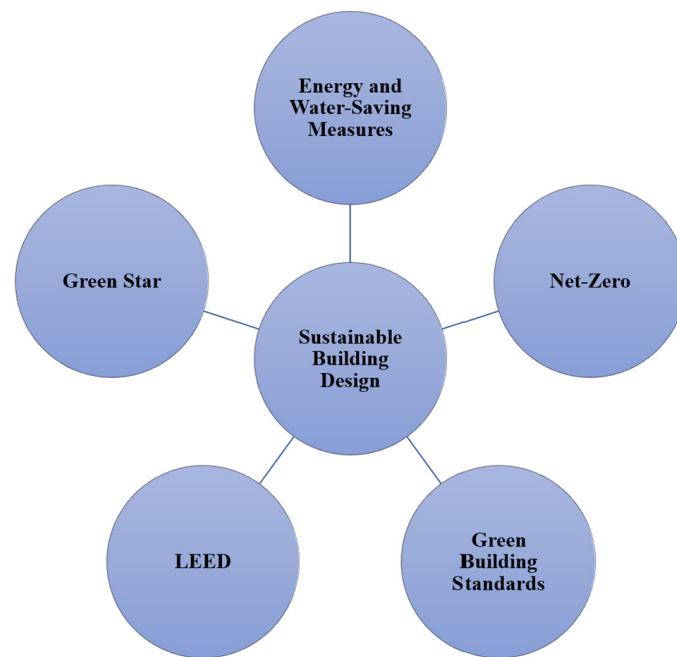
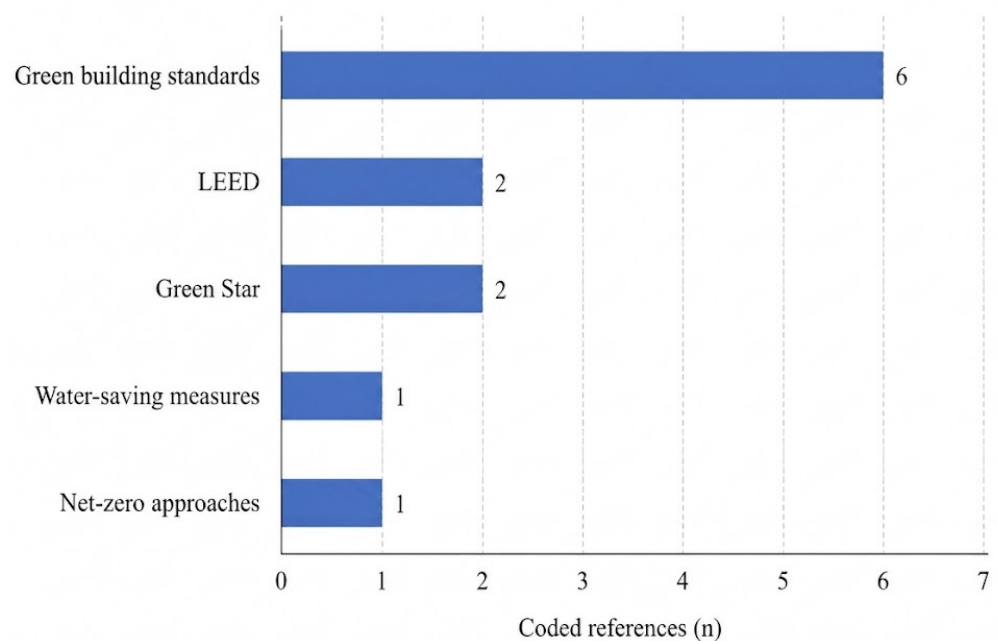


Figure 2. Thematic analysis diagram of Sustainable Building Design.



Note: *n* represents coded references derived from four country-level institutional submissions, not individual respondents.

Figure 3. Frequency distribution of coded references for the principal subthemes of Sustainable Building Design ($n = 12$).

China: China has made significant progress in adopting energy-efficient designs to address its high energy consumption and urbanization. Some of them include the notable technologies of solar thermal power, smart heating and ventilation, and high-performance insulation. The eco-office of the Shanghai Academy of Building was a significant example, achieving a 75% reduction in energy use compared to similar buildings in the area. **Malaysia:** Malaysia was more concerned with reducing energy and water use. The Shell Tower in Kuala Lumpur was featured for its energy-efficient glazing, solar panels, and water-efficient fixtures. It was also found that incorporating green roofs and natural ventilation

was a significant factor in reducing air-conditioning requirements. South Africa: Focused on climate resilience and resource management, especially in areas with limited water resources. Buildings such as the Serra Services light industrial building featured water-conserving features, including rainwater harvesting and greywater recycling, as well as energy-saving building designs. Peru: Peru is rich in natural materials, and its building materials are based on bio-products, such as bamboo and mycelium-based insulation. When building the Ridge Building in Peru, cross-laminated timber (CLT) and eco-bricks were used to minimize the building's carbon footprint and ensure sustainable sourcing of materials.

4.2. Material Innovation and Reuse Theme

The second key theme was Material Innovation and Reuse, including the use of sustainable materials and low-carbon materials, material substitution, recycling, and the reuse of construction materials. This theme was reflected in all four country submissions, with 20 coded references. The thematic diagram of this theme is presented in Figure 4 and the frequency distribution of its principal subthemes is presented in Figure 5.

China: China demonstrated significant improvements in the use of green building materials, such as recycled steel and high-performance concrete. The three-star rating system has driven demand for low-carbon cement and energy-saving building materials. Malaysia: The construction industry is also turning to steel recycling and locally available materials to reduce its environmental impact. The Teknion Showroom in Malaysia was a LEED Platinum building that used energy-efficient materials, with energy conservation up to 34% compared to conventional standards. South Africa: Construction projects were normally completed with reclaimed wood and recycled bricks. These materials, together with recycled concrete aggregates, were used in structures such as the 144 Oxford building, which prioritized sustainability in its design. Peru: Peru demonstrated a good attitude towards bio-based materials. An example of this is the Ridge Building, which used banana fibers, sunflower composites, and wheat-based insulation boards to minimize the embodied carbon in its building materials.

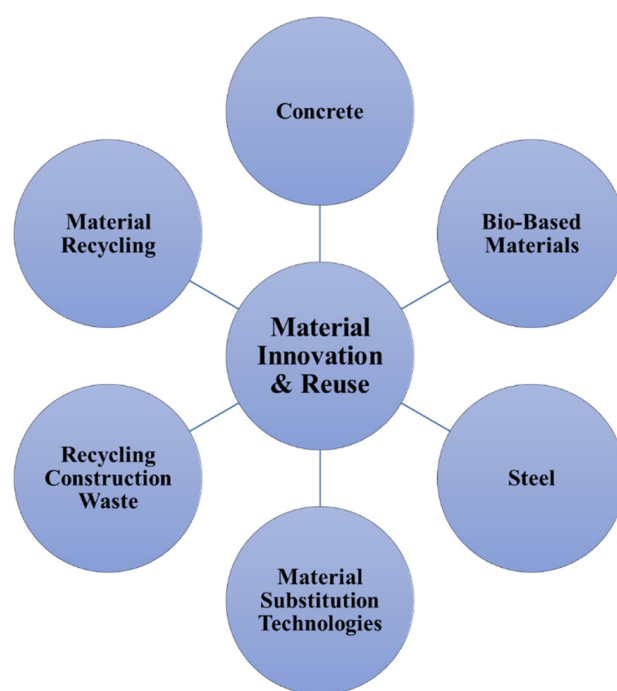
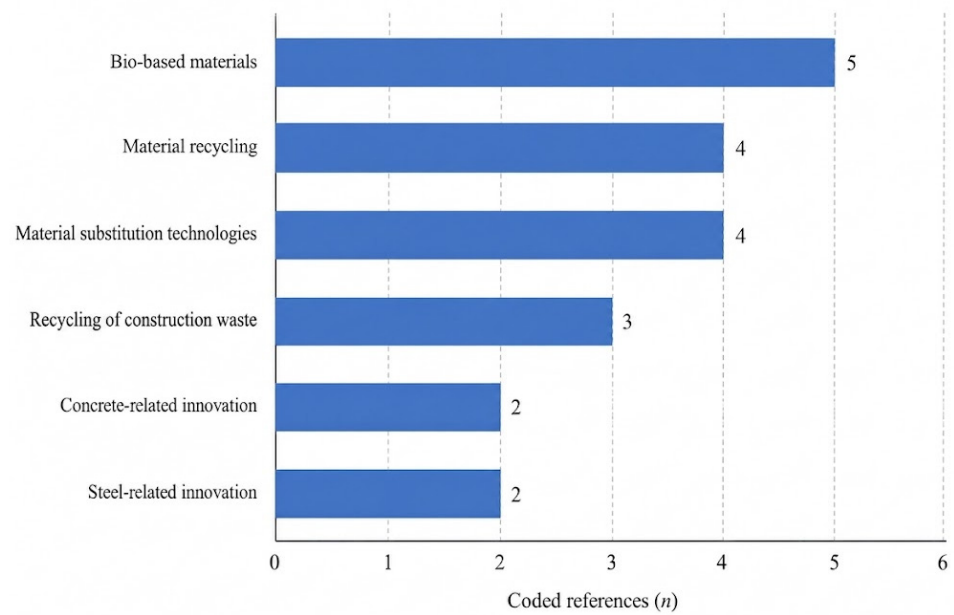


Figure 4. Thematic diagram regarding Material Innovation and Reuse.



Note: n represents coded references derived from four country-level institutional submissions, not individual respondents.

Figure 5. Frequency distribution of coded references for the principal subthemes of Material Innovation and Reuse ($n = 20$).

4.3. Technological Innovations Theme

Technological Innovations was another key theme, with digital and automated technologies being used to achieve better building design, construction efficiency, waste minimization, and environmental performance. There were 15 coded references in this theme. The thematic diagram is depicted in Figure 6 and the frequency distribution of its main subthemes in Figure 7.

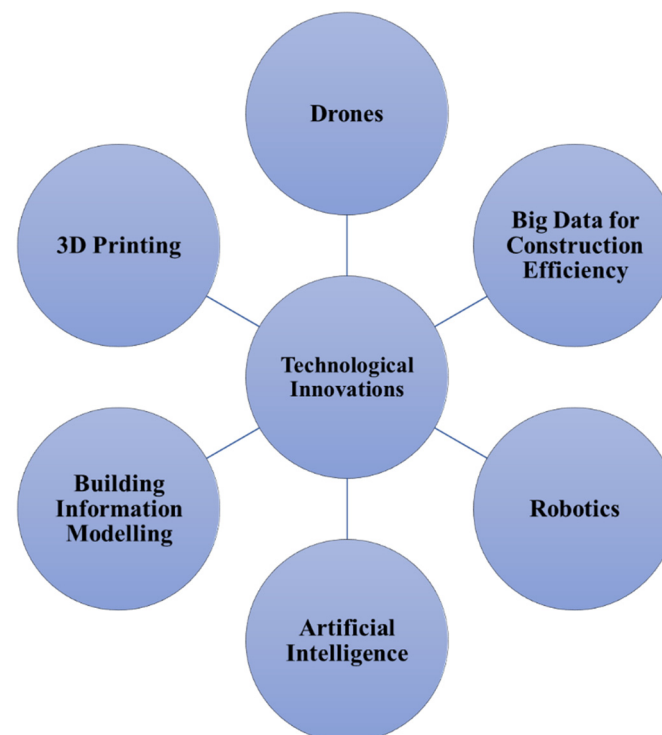
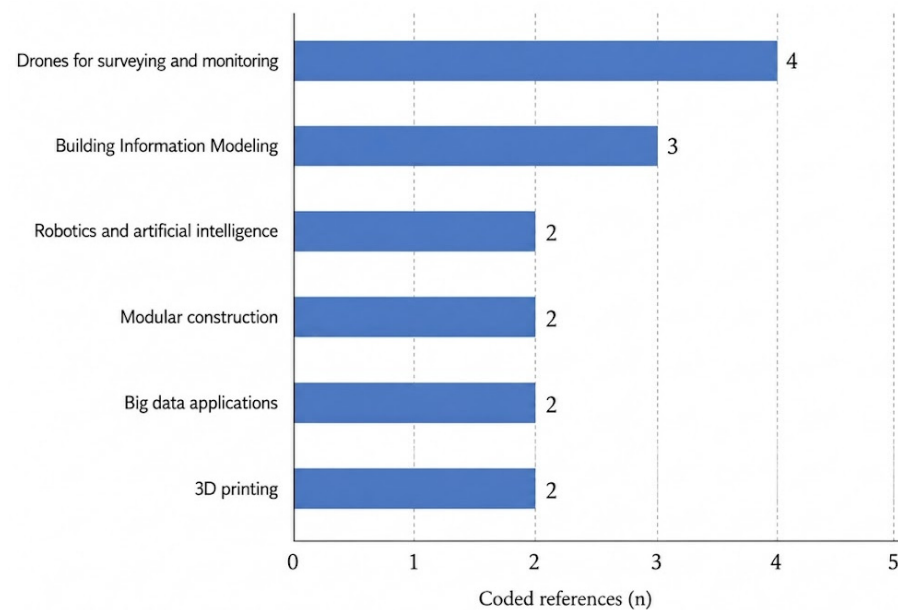


Figure 6. Technological Innovations thematic diagram.



Note: n represents coded references derived from four country-level institutional submissions, not individual respondents.

Figure 7. Frequency distribution of coded references for the principal subthemes of Technological Innovations ($n = 15$).

China: Building Information Modeling (BIM), complex HVAC systems, and other technologies were used as key tools for optimizing building energy consumption. The introduction of solar-powered systems and automated building management systems in buildings such as the Shanghai Academy of Building contributed to a high level of energy saving. Malaysia: Malaysia is implementing smart grid systems and lighting automation and has been effective in cutting building-energy use, as exemplified by the Shell Tower, where dual-chilled water circuits and ceiling-flushed active chilled beams have achieved significant energy savings. South Africa: South Africa has considered the deployment of AI-based building monitoring systems, such as those by Serra Services, to monitor energy use and optimize HVAC systems. This has assisted in lowering total energy requirements and enhancing operational efficiency. Peru: Peru has already implemented 3D printing in construction and robotic tools (e.g., bricklaying) to minimize material waste. Site surveys and construction monitoring progress at Ridge Building projects were performed using drones.

4.4. Waste Management and Recycling in Construction Theme

This theme covers the measures and practices used to reduce construction waste, improve waste handling, recover materials, and support circular resource use in the construction sector. It includes recycling, reuse, waste minimization, and other waste-management technologies. This theme contained 10 coded references. Figure 8 presents the thematic diagram of Waste Management and Recycling, while Figure 9 presents the frequency distribution of its principal subthemes.

China: China is concentrating on the recycling of materials, e.g., recycled concrete aggregates and steel, in massive projects. The management of construction waste is also an important area of concern for environmental sustainability. Malaysia: On-site waste reduction is achieved through modular construction and prefabricated components. Reusing steel and concrete from demolished structures is also a priority. South Africa: South Africa is at the forefront of construction- and demolition-waste recycling, with reclaimed wood and recycled aggregates used for the construction of the 144 Oxford building. Peru: Peru is

using bio-based waste materials, such as banana fibers and rice husks, to produce composite construction boards. Construction works are also using plastic waste for reuse.

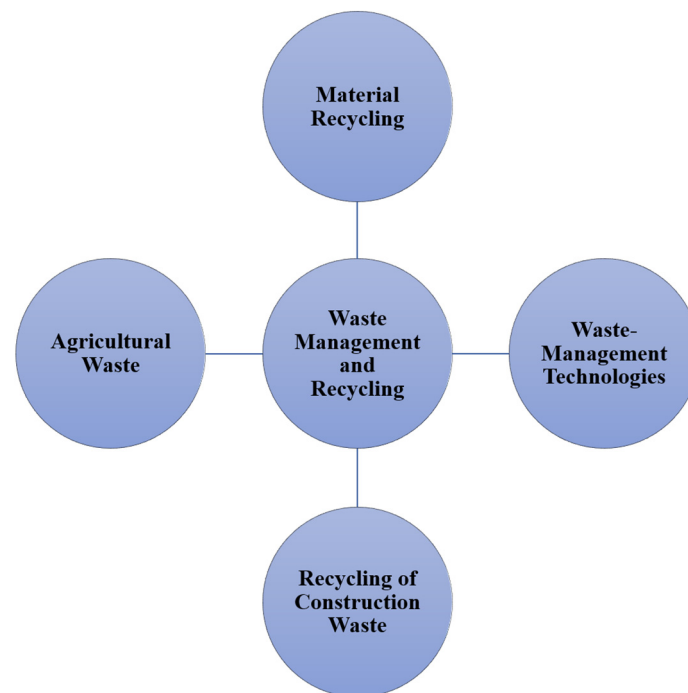
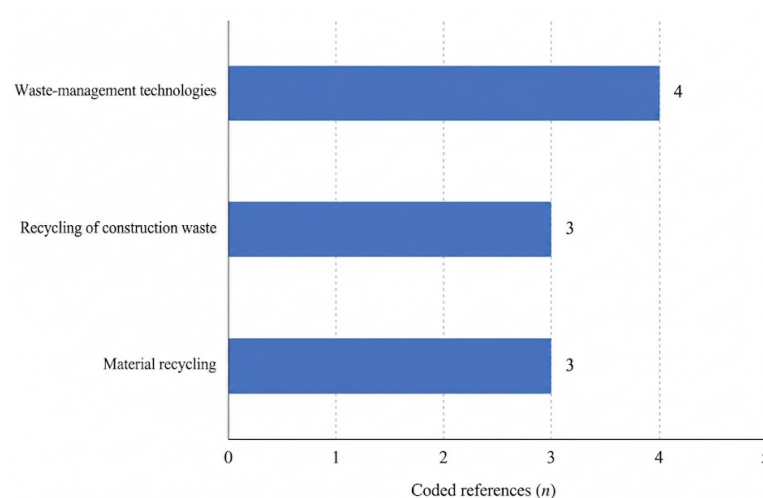


Figure 8. Waste Management and Recycling thematic diagram.



Note: n represents coded references derived from four country-level institutional submissions, not individual respondents.

Figure 9. Frequency distribution of coded references for the principal subthemes of Waste Management and Recycling ($n = 10$).

4.5. Energy Efficiency and Carbon Emissions Reduction Theme

This theme aims to enhance the energy performance and carbon emissions reduction of buildings via the use of renewable energy systems, such as efficient building technologies, HVAC optimization, energy-efficient lighting, and other carbon-reduction strategies. In this theme, 20 coded references were found. The thematic diagram of Energy Efficiency and Carbon Emissions Reduction is presented in Figure 10, and the frequency distribution of the main subthemes is presented in Figure 11.

China: China has implemented massive programs to reduce energy use, including installing solar, wind, and geothermal systems. Another area the nation is investing heavily in is energy-management systems and environmentally friendly building materials. **Malaysia:** New buildings are equipped with solar panels, green roofs, and efficient HVAC to minimize energy requirements. Residential and commercial buildings share common energy-efficient lighting and solar water-heating systems. **South Africa:** South Africa incorporates renewable energy sources, including solar and wind power, into buildings and focuses on low-carbon building technologies to reduce carbon emissions in the building sector. **Peru:** Bio-based materials help the country conserve energy by using natural insulation, thereby enhancing thermal efficiency and reducing the need for energy-intensive heating and cooling systems.

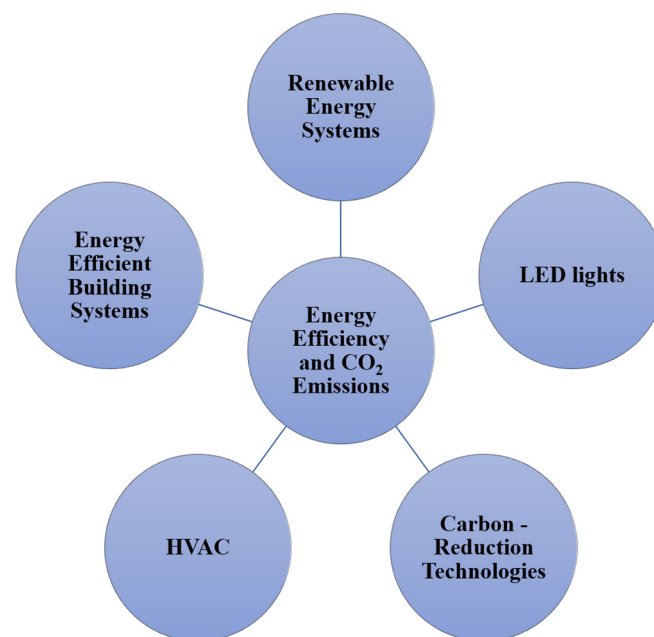
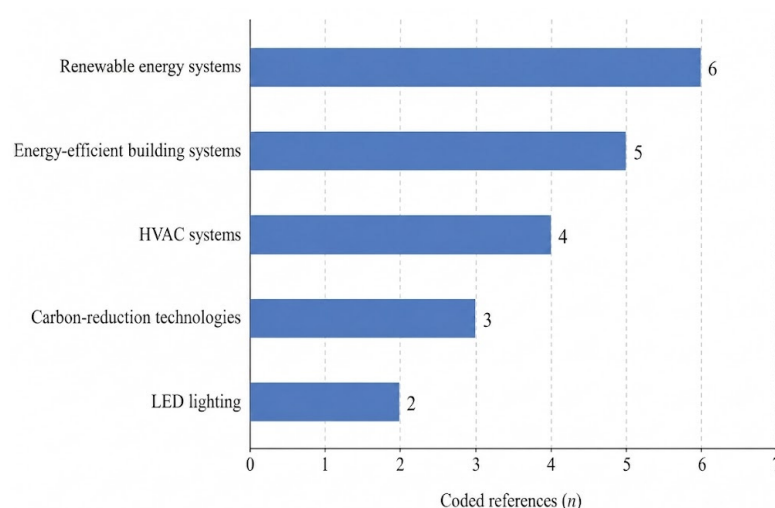


Figure 10. Energy Efficiency and Carbon Emissions Reduction thematic diagram.



Note: *n* represents coded references derived from four country-level institutional submissions, not individual respondents.

Figure 11. Frequency distribution of coded references for the principal subthemes of Energy Efficiency and Carbon Emissions Reduction ($n = 20$).

5. Discussion

The study's findings can enhance understanding of how sustainable building practices can address climate change across different countries. The thematic analysis identified five major dimensions of sustainable construction: sustainable building design, material innovation and reuse, technological innovation, waste management and recycling, and energy efficiency and carbon emissions reduction. These themes illustrate sustainability in the construction industry as a multidimensional concept and the fact that countries implement different methods, anchored in their economic status, environmental concerns, and technological potential. Findings must be analyzed within the context of the institution of the study. The data were supplied via professional engineering organizations and Green Building Councils and hence are largely representative of formal, regulated, and institutionally documented construction practice. They offer no holistic evidence of informal construction, small enterprises, self-built dwellings, or vernacular practitioners who may have widely varying priorities, resource needs, material selection, and sustainability practices. As such, the country comparisons are based on the participating institutional networks and not on the construction sector in each country.

The country-level differences also should be read in the context of the country policy and resource context described in Table 1. Regulatory requirements, economic factors, industrial capacity, climatic factors, and the availability of specific materials or technologies shape which sustainable construction strategies are promoted. The results are thus not due to the influence of technological preferences alone but are instead the outcome of the confluence of national goals, institutional capacity, environmental limitations, and construction resources. Thematic diagrams are retained to maintain the interpretive structure of the qualitative analysis, while the bar charts are included for each theme for a brief descriptive summary of the coded evidence that supports each theme.

To begin with, the results show that sustainable building design lies at the center of reducing the environmental impact of the construction industry. China and Malaysia are examples of countries where energy-efficient design elements, such as HVAC systems, passive building design, and renewable energy technologies, are highly valued. This finding is consistent with prior research [27,62,63] that has identified building design optimization as one of the most effective strategies to reduce operational carbon emissions in the built environment. This is of particular interest to fast-urbanizing economies like China, where the construction of expansive infrastructure is a major contributor to energy consumption [63]. On the same note, Malaysia aligns with green building requirements and energy-efficient building systems as it is already experiencing an increase in the use of green design in emerging economies [27].

Second, one of the best strategies for reducing the embodied carbon of construction projects was material innovation. Recycled materials are widely used in many countries, especially in China and South Africa, including recycled steel and reclaimed wood. Meanwhile, Peru is also geared towards bio-based building materials, such as bamboo, agricultural fibers, and biodegradable composites. These findings concur with previous research [6,7,64–67], which has shown that bio-based materials can help reduce carbon emissions throughout the entire construction life-cycle. The fact that such materials are being adopted also indicates increased awareness among the world at large that material production is a significant contributor to greenhouse gas emissions, particularly in carbon-intensive sectors such as cement and steel production.

Third, technological advances have become increasingly applicable to advancing sustainability in the construction industry. Technologies that improve the construction process by making it more efficient, waste-reducing, and energy-efficient include BIM, artificial intelligence, robotics, and digital monitoring systems. China and Malaysia seem to be the

most active users of digital technologies in construction management, and Peru and South Africa are adopting new digital tools, including drones, automated construction methods, and 3D printing. These technological innovations may be regarded as a continuation of earlier studies [5,68–70], and imply that the digitalization of the construction industry can go a long way toward improving resource efficiency and the sustainability of projects.

Moreover, another significant theme of this study is waste management and the shift towards circular construction. Construction and demolition waste is a significant environmental issue worldwide, and the results indicate that the four countries are shifting towards developing policies and other material-recovery methods, such as recycling. South Africa, in particular, is taking a keen interest in reclaimed construction materials, and China and Malaysia are promoting modular construction and prefabrication to minimize on-site waste to the bare minimum. These measures align with circular-economy principles [71–73], which aim to increase the useful life of materials and reduce resource extraction.

Lastly, energy efficiency and the reduction of carbon emissions were the key factors in all the countries analyzed in this research. Renewable energy technologies increasingly integrated into modern building projects include solar panels, geothermal systems, and energy-efficient lighting. These programs reflect policy measures on an international scale [4,65,73] to decarbonize the building sector and meet climate mitigation standards in the context of global accords, including the Paris Agreement [3]. Developed construction markets are more attentive to technological optimization and digital monitoring systems, while developing economies are more willing to apply locally available resources and climate-sensitive building construction to boost energy performance.

Overall, the results indicate that sustainable construction plans are very situational. Various nations have different approaches based on their resource endowments, economic development, technological capabilities, and environmental issues. However, despite these variations, several common trends can be identified across all cases, including increased adoption of renewable energy technologies, greater emphasis on material sustainability, and the implementation of digital technologies in construction management. In line with similar trends, the global construction sector is gradually adopting more environmentally friendly, sustainable practices.

The similarities identified across the four country submissions indicate areas in which international learning may be feasible, including digital building management, passive design, low-carbon materials, prefabrication, and the recovery of construction waste. However, the study did not collect direct evidence of formal technology transfer or verify whether practices originating in one country had subsequently been adopted in another. The findings should therefore be interpreted as identifying transferable areas of practice rather than demonstrating complete cross-country transfer.

6. Conclusions

The study demonstrates that sustainability is a complex and comprehensive concept, which is supported by design efficiency, material development, technological advancements, resource recyclability, and energy efficiency in the construction domains, represented by the participating professional bodies in the formal construction process and the institutionally documented construction process. Countries are not converging towards a single world model, but rather adopting country-based policies that integrate their economic models, environmental agendas, and technological preparedness. This contextual plurality cannot be perceived as disintegration; instead, it is a form of adaptive advantage that reveals a wide range of ways to a shared international objective. Notably, the results indicate that the shift toward systems-based construction with integrated approaches is gradually but clearly underway. The growing popularity of digital technologies such as

Building Information Modeling (BIM), the emergence of bio-based and recycled materials, and the integration of circular-economy principles are all signs of a structural change in the industry. These changes point to sustainability shifting from a compliance-based approach to innovation-based approaches that generate environmental and economic value. The redesign of the construction industry to become more sustainable is needed and is in progress. The plurality of methods we have seen in this paper ultimately converge on a common vision of a low-carbon, resource-efficient, and climate-resilient built environment. The difficulty in the future is not finding solutions, but rather scaling and integrating them successfully in both global and local settings. The research thus adds to the growing literature on sustainable construction by illustrating how strategies from different countries can be pooled to mitigate global climate change. Knowledge of these regional differences enables policymakers, city planners, and building professionals to develop more effective sustainability designs for the built environment.

6.1. Policy Implications

The study's results have multiple useful implications for policymakers seeking to accelerate sustainability transitions in the construction industry. Firstly, governments should stop separating environmental policies and adopt integrated policy frameworks based on building design, material use, energy systems, and waste-management practices. Comprehensive regulation practices can also be used to reflect the multidimensionality of sustainable construction in the present study. Second, significant emphasis should be placed on improving the certification of green buildings, such as LEED, BREEAM, and Green Star, to harmonize sustainability standards across territories. Policymakers might also consider encouraging adoption by increasing tax credits, subsidies, or expediting certification in more developed economies where adoption remains disproportionately low. Third, low-carbon materials should be developed through targeted policies, such as financial support for research, the establishment of joint ventures, and the encouragement of green procurement. The embodied carbon emissions of certain industries, especially those that consume large amounts of carbon, such as cement and steel manufacturing, can be significantly reduced by facilitating the development and proliferation of recycled and biodegradable materials.

In addition, governments may make efforts to digitalize the construction sector to enhance the use of existing technologies, including BIM, artificial intelligence, and intelligent monitoring systems. This can be achieved through capacity-building programs, regulatory requirements, and investing in digital infrastructure. Lastly, national construction policies should align with international climate change policies, such as the Paris Agreement. It is necessary that policymakers ensure that strategies in the construction sector are properly incorporated into national climate action plans, and that these plans include targets to reduce carbon emissions, increase energy efficiency, and minimize waste.

6.2. Practical Implications

This study has identified realistic measures that construction professionals, developers, and others in the construction industry can implement to improve the sustainability performance of real-world buildings. To begin with, the sustainability principles should be integrated into the design process. Energy conservation, passive design, and climate change solutions should also be given attention by architects and engineers to reduce long-term environmental impacts. Second, practitioners are encouraged to actively contribute to sustainable materials, such as recycled, reclaimed, and bio-based materials. The materials used should consider the entire life-cycle, not just the initial cost, so companies can minimize embodied carbon and achieve long-term sustainability. Thirdly, information

technologies such as BIM, automated tools, and data-based monitoring systems may also play a significant role in enhancing project efficiency, reducing waste, and maximizing energy use. The benefit of companies investing in such technologies will be that they will gain an environmental and competitive edge.

Further, construction companies can apply circular-economy principles by presenting waste-reduction, recycling, and material-recovery interventions at every stage of the project. Another way to reduce on-site waste and improve resource utilization is through modular construction and prefabrication. Cooperation is another important aspect. Stakeholders in this case are contractors, suppliers, designers, and policymakers who need to collaborate in order to harmonize their sustainability goals and share knowledge. Cross-country learning, as this study suggests, can help businesses embrace best practices suited to their local contexts. The shift to sustainable construction, in short, must not only be a technological one but also encompass a change in attitude, i.e., a move towards long-term value generation rather than a short-term focus on costs. Sustainable businesses will be better positioned to meet regulatory requirements and market needs, and to participate in international efforts to reduce climate change.

6.3. Limitations and Future Research

There are several limitations to this study that should be considered when interpreting the results. Firstly, the analysis is carried out according to the responses of four countries, China, Malaysia, South Africa, and Peru, which limits the ability to generalize the results to other countries or areas. These are just a few illustrations, helpful as they may be in offering variety in the pattern of development, environmental factors, and construction practice, but they do not represent the full range of construction systems. Second, the study is based on qualitative data and relies mainly on a questionnaire administered by a professional and institutional network. Although this technique is appropriate for identifying thematic patterns and comparative understanding, it also depends on the breadth, depth, and representativeness of the responses elicited. Although thematic sufficiency was achieved for the bounded four-country dataset, this should not be interpreted as evidence of saturation across the wider international construction sector. The results therefore do not reflect informal builders, small construction companies, self-built housing, community-based construction, or builders with vernacular knowledge. These groups can represent a significant amount of construction work, and may employ locally adapted materials, labor, financing, and environmental strategies different from those that are reported by formal professional institutions. Third, direct cross-country comparability can be affected by differences in national standards, institutional arrangements, and interpretations of sustainability. Patterns of analysis, through which the themes found in this research are identified, are useful but not comprehensive performance measures. Furthermore, the questionnaire had predetermined domains and the completeness and detail of the country submissions varied, so the thematic frequencies may be influenced by this reporting intensity and questionnaire structure. It is important to remember that they are an indication of their local priorities, and not a general indicator of the nation's priorities. Fourth, the response to the optional macro indicator module was not included in the formal analysis because only one country (China) provided complete information while others did not. Lastly, the research mostly focuses on the environmental and strategic aspects of sustainable construction. It does not methodically analyze economic feasibility, implementation costs, and policy performance, all of which will presumably contribute to the acceptance and growth of sustainable practices.

These results are applicable to further study in the following ways. Firstly, more comparative studies across a broader range of countries, including low-, middle-, and

high-income settings, would provide a clearer global picture of how sustainable building priorities may vary across institutional and developmental contexts. Second, longitudinal and mixed-method research designs would add to the evidence base by combining qualitative knowledge with project-level performance indicators, life-cycle assessment, and policy analysis over time. Third, the economic and governance features of sustainable construction should be more clearly addressed in future research, including the cost–benefit trade-off, funding challenges, incentives for regulation, and the ability to act on them. Fourth, the social component of sustainable building, including user acceptance, community inclusion, and local knowledge frameworks, should be further addressed to provide a more detailed understanding of sustainability changes in the built environment. Field observations, interviews, and locally administered surveys should therefore directly engage informal builders, small contractors, community groups, craftspeople, and vernacular builders and practitioners. Finally, examples of specific buildings, technologies, and material systems, as well as research on digital twins, AI-driven design tools, and smart construction systems would also clarify how emerging innovations can facilitate the practical implementation of low-carbon, resource-efficient, and climate-resilient construction.

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