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Transforming the Construction Sector in Latin America and The Caribbean

Digitalization, Innovation, and Sustainability as Keys to the Future

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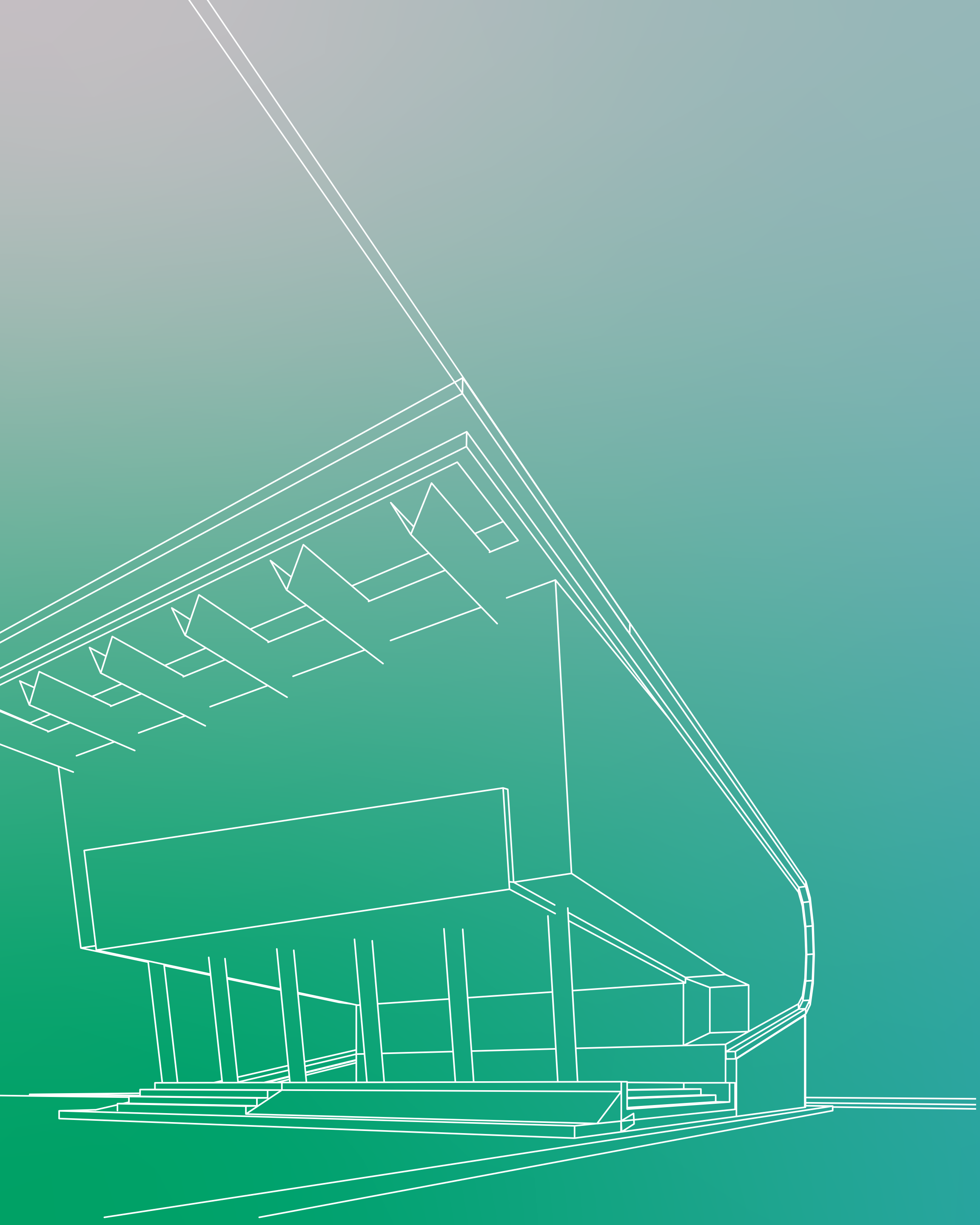
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Keywords: sustainability, digitalization, sustainable construction, sustainable materials, industrialization, advanced digital technologies, building information modeling, climate change, resilience.

¹ Conducted by Belén Baptista (2024).

ACRONYMS AND ABBREVIATIONS

LAC	Latin America and the Caribbean
ANDE	National Development Agency (Uruguay)
ANII	National Agency for Research and Innovation (Uruguay)
ASCC	Sustainability and Climate Change Agency (Chile)
BANHVI	Housing Mortgage Bank (Costa Rica)
IDB	InterAmerican Development Bank
BIM	<i>Building Information Modeling</i>
BIM Gob Latam	Latin American Governments BIM Network
BAECS	Ecological Blue Flag for Sustainable Construction
CAIF	Childhood and Family Care Center (Uruguay)
CBCS	Brazilian Council for Sustainable Construction (Brazil)
CBIC	Brazilian Chamber of the Construction Industry (Brazil)
CCI	Council for Industrialized Construction (Chile)
CCC	Costa Rican Chamber of Construction (Costa Rica)
CDT	Technological Development Corporation (Chile)
CII-BIM	Interinstitutional Commission for BIM Implementation (Costa Rica)
CIPYCS	Interdisciplinary Center for Productivity and Sustainable Construction (Chile)
CND	National Corporation for Development (Uruguay)
CORFO	Production Development Corporation (Chile)
CChC	Chilean Chamber of Construction (Chile)
CCU	Chamber of Construction of Uruguay (Uruguay)
CFIA	Federated College of Engineers and Architects (Costa Rica)
CTeC	Technological Center for Innovation in Construction (Chile)
DEO	Operational Energy Performance of Buildings
FIIC	Inter-American Federation of the Construction Industry

GHG	Greenhouse gases
IC	Construction Institute (Chile)
INA	National Learning Institute (Costa Rica)
INAU	National Institute for Children and Adolescents of Uruguay (Uruguay)
INVU	National Institute of Housing and Urban Planning (Costa Rica)
MA	Ministry of the Environment (Uruguay)
MDIC	Ministry of Development, Industry, Commerce, and Services (Brazil)
MIDEPLAN	Ministry of National Planning and Economic Policy (Costa Rica)
MIDR	Ministry of Integration and Regional Development (Brazil)
MIEM	Ministry of Industry, Energy, and Mining (Uruguay)
MINAE	Ministry of Environment and Energy (Costa Rica)
MINVU	Ministry of Housing and Urban Development (Chile)
MIVAH	Ministry of Housing and Human Settlements (Costa Rica)
MMA	Ministry of the Environment (Chile)
MME	Ministry of Mines and Energy (Brazil)
MOP	Ministry of Public Works (Chile)
MVOT	Ministry of Housing and Territorial Planning (Uruguay)
NDC	Nationally Determined Contribution
RCD	Construction and Demolition Waste
RECEPETi	Santa Catarina Innovation Network (Brazil)
RESET	Sustainable Building Requirements for the Tropics
RELAMAD	Latin American Structural Wood Network
SC	Secretariat of Cities (Brazil)
SIDAC	Environmental Performance Information System for Construction
VUIS	Inclusive and Sustainable Urban Housing Model

EXECUTIVE SUMMARY

Latin America and the Caribbean (LAC) have significantly advanced in incorporating sustainability measures into infrastructure projects. There are notable examples in some countries that demonstrate that the construction sector and the public and academic sectors have the potential and interest to move towards more sustainable construction. However, the initiatives are still developing and require a more significant push to achieve scalability and sector transformation. The digitalization of the construction industry is a key tool for enhancing this transformation. While there are initiatives, and the sector also moves towards incorporating more digital tools, a more significant push from the public sector is required. As these initiatives extend in a coordinated and complementary manner, the region can move towards more broadly sustainable construction with the impetus of digital tools. This Technical Note focuses on establishing how digitalization and innovative construction methods are an opportunity to foster sustainable construction in LAC.

The document is organized into four main sections. Following an introduction, the second section categorizes different types of current solutions that facilitate and promote sustainable construction. The third section analyzes the initiatives, challenges, obstacles, and factors that promote best practices in sustainable construction in Brazil, Chile, Costa Rica, and Uruguay based on interviews with key sector actors. Finally, the fourth section presents a series of conclusions and recommendations for these opportunities to enable and facilitate the transformation of the LAC construction sector into a sustainable, digitalized, and resilient industry.

I. I. Types of Enabling Solutions² for Sustainable Construction

The different initiatives are classified into six categories:

- ◆ **Advanced Digital Technologies:** Methodologies and technologies such as Building Information Modeling (BIM), artificial intelligence, data analytics, extended reality, the Internet of Things, and blockchain optimize resource efficiency, minimize waste, and facilitate informed decision-making. BIM is a key example and gateway to other digitalization opportunities.
- ◆ **Sustainable Design Focus:** Also known as eco-design, it focuses on developing projects that are efficient in resource and energy use, adapted to climatic conditions, have low environmental impact, and are healthy for users. It affects the entire life cycle of the infrastructure.

² In this context, enabling solutions will be understood as methodologies, systems, products, or services that accelerate, facilitate, promote, and/or provide the capacity, ability, or means to achieve a specific goal; in this case, facilitating sustainable construction.

- ◆ **Sustainable Materials:** generate less environmental impact throughout their lifecycle. These include materials with low carbon emissions, recyclable and reusable materials, and local materials to minimize transport emissions.
- ◆ **Industrialized Construction Systems:** Alternatives to traditional systems, such as prefabrication, light construction, modular construction, and 3D printing systems, allow for reduced construction time, debris, and environmental impact and facilitate circularity.
- ◆ **Measurement and Verification of Environmental Impact:** This involves quantifying and certifying the environmental impact of construction assets using tools such as carbon footprint measurement and sustainable certifications, such as Leadership in Energy and Environmental Design (LEED), Excellence in Design for Greater Efficiencies (EDGE), and Building Research Establishment Environmental Assessment Method (BREEAM).

- ◆ **Efficient Management Approaches:** Management methods that enhance efficiency in construction, reduce delays and minimize environmental impact, including waste management and adopting approaches such as LEAN Construction or Advanced Work Packaging.

II. Experiences, Challenges, and Opportunities for Sustainable Construction in Latin America and the Caribbean

Through interviews with key stakeholders in Brazil, Chile, Costa Rica, and Uruguay, 44 initiatives focused on sustainable construction were identified, two-thirds of which are led by the government sector. These initiatives have emerged steadily since 2015, coinciding with the signing of the Paris Agreement.

Among the highlighted similarities is the governmental drive to implement sustainable housing policies and the adoption of advanced digital technologies such as BIM. However, there is low integration of these solutions aimed at sustainable construction, suggesting significant opportunities for improvement.

- ◆ **Obstacles and Challenges:** Cognitive gaps and significant barriers were highlighted, as well as institutional weaknesses and the perception of incompatibility between environmental and economic sustainability. Additionally, challenges were identified in the articulation and synergy of initiatives, the limited demand for sustainable infrastructure, and informality in the construction sector.

- ◆ **Promoting Factors:** The positive impact of the COVID-19 pandemic and climate change on raising awareness of the relevance of sustainable construction was noted. National climate commitments and international organizations' technical and financial support were also mentioned.

- ◆ **Best Practices:** Best practices were identified, such as the development of international benchmarking strategies, technical cooperation, the creation of communities of practice, the training of technical teams, and the formalization of inter-institutional articulation mechanisms. Furthermore, promotion mechanisms such as innovative public procurement and the design of financial and non-financial incentives were highlighted.

III. Keys to the Future to Transform the Sector

This Technical Note identifies key aspects to promote digitization and the use of innovative construction systems and materials to advance sustainable construction within the social, economic, and climatic context of LAC.

Long-term public sector leadership is crucial to driving digitization and productivity and promoting sustainable construction in LAC. To achieve the sector's transformation, all stakeholders must be involved through a consensus-based strategy and a detailed roadmap with clear objectives and progress measurement mechanisms. Effective and widespread communication of the strategy and roadmap is necessary to generate awareness and long-term support.

Strengthening collaboration between the public, private, and academic sectors is also fundamental. Establishing collaborative frameworks that facilitate the implementation of digitization and innovative solutions for sustainable construction is essential.

Financial and non-financial incentives must be established for companies in the sector to adopt sustainable practices and invest in digitization and efficient, innovative construction methods. Strategic public procurement, including innovation and green procurement, is an essential catalyst for boosting the demand for sustainable technologies and materials and transforming the sector.

Driving digitization is a key factor as it optimizes and integrates processes throughout the entire construction lifecycle, improving the sector's transparency, efficiency, and productivity. Similarly, implementing efficient and sustainable construction methods and ensuring widespread adoption should be prioritized.

These actions accelerate the development of a sustainable, resilient, and competitive construction industry that addresses the region's environmental and social challenges.

1

INTRODUCTION

The construction sector accounts for 13% of the gross domestic product (GDP) (McKinsey & Company, 2020) and 7.7% of jobs (250 million)³ worldwide. Latin America and the Caribbean (LAC)⁴ plays a crucial role in the economy, representing 6% of the regional GDP, equivalent to \$300 billion, and generating over 20 million jobs.

However, it faces significant productivity and digitization gaps compared to other economic sectors. According to a McKinsey & Company report (2017), construction productivity has grown by only 1% annually over the last two decades, compared to 3.6% in manufacturing and 2.8% in agriculture. Nevertheless, adopting new technologies is beginning to transform the construction

sector. Methodologies such as Building Information Modeling (BIM), drones, the Internet of Things (IoT), and artificial intelligence are improving efficiency, reducing costs, and increasing project accuracy. According to Deloitte (2021), construction companies adopting advanced technologies have reported a 10% to 15% increase in productivity and a 5% to 10% reduction in operating costs.

Additionally, the construction sector is one of the largest emitters of greenhouse gases (GHGs) and consumers of natural resources. According to the latest data provided by the World Green Building Council (WGBC) (2023), the construction sector consumes 50% of globally extracted resources for materials and 15% of freshwater used, and it is responsible for 37% of global CO₂ emissions related to energy. Moreover, 34% of global

energy is consumed by buildings during their operation. Furthermore, 35% of the solid waste generated annually worldwide comes from construction materials (Menegaki et al., 2018). A strong growth trajectory for the sector is projected globally in the coming years. For vertical infrastructure, it is estimated that 60% of the buildings projected by 2050 have yet to be constructed, and 20% of existing structures will need renovations to achieve the net-zero emissions target by 2030 (UNEP & GLOBAL ABC, 2024).

Adopting a series of measures is essential to addressing these challenges and transforming the construction sector. These measures should drive the implementation of new digital methodologies and innovative solutions to achieve sustainable construction and climate change mitiga-

³ International Labour Organization (ILO), 2020.

⁴ Presentation by the Inter-American Federation of the Construction Industry based on data from the Mexican Chamber of the Construction Industry, the International Monetary Fund, and the Economic Commission for Latin America and the Caribbean (ECLAC).

tion and adaptation (see Information Box 1), which aligns with the Paris Agreement. It involves governmental, business, and civil society actions, such as defining strategies and roadmaps to develop capacities and enablers for digitization and innovative systems and materials for sustainable construction that contribute to low-carbon and climate-resilient construction.

Key measures include adopting efficient digital methodologies and technologies, strengthening involved teams' digital competencies and capabilities, incorporating efficient construction systems and sustainable materials, specifying sustainable construction standards, and implementing policies for circularity, decarbonization, and climate resilience within the sector.

Information Box 1. Sustainable Construction

Sustainability in the construction sector has been addressed for three decades through various definitions that have evolved over time. In 1993, the World Wildlife Fund (WWF) introduced one of the first definitions, which included not only buildings but also their surroundings and their impact on city planning (Alavedra et al., 1997). The following year, at the First International Conference on Sustainable Construction, Charles Kibert^a defined sustainable construction as an environmental responsibility throughout all stages of the construction process, aiming to minimize resource depletion and provide a healthy environment.

Since then, numerous definitions of sustainable construction have been proposed without reaching a global consensus (Gordano, Torchia, and Corazza, 2023; Liu et al., 2022). These definitions vary in focus, ranging from general aspects to specific considerations regarding energy, resources, and quality of life. In 2019, the Inter-American Development Bank (IDB) established that "sustainable infrastructure refers to infrastructure projects

that are planned, designed, constructed, operated, and dismantled, ensuring economic, financial, social, environmental (including climate resilience), and institutional sustainability throughout the project lifecycle." This definition integrates two main statements: i) that infrastructure sustainability must consider the entire project lifecycle, and ii) that infrastructure sustainability must take into account four relevant dimensions: environmental, economic/financial, social, and institutional.^b Furthermore, it details the attributes that constitute each of the four dimensions of infrastructure sustainability (Bhattacharya, 2019). This Technical Note focuses on the environmental dimension, which includes four main subdimensions: i) sustainable and efficient use of natural resources (energy, water, materials, etc.); ii) preservation of the natural environment (biodiversity, natural capital, soil management, ecological connectivity, and environmental services, among others); iii) low pollution levels (water, air, soil, hazardous materials), and iv) resilience to natural disasters and climate change.

For simplification purposes, this document will use the term "sustainable construction" to refer to sustainable infrastructure in its environmental dimension, including greenhouse gas (GHG) emission reduction and resilience to natural disasters and climate change.

In this context, for this Technical Note, resilience (to both climate change and natural disasters) will be understood as the capacity of systems and natural environments to face and absorb disturbances without significantly altering their structural and functional characteristics and to recover to their original state.^c Similarly, the term "construction" encompasses activities such as the planning, design, construction, renovation, operation, maintenance, and demolition of housing, buildings, and civil engineering works (transportation, water, sanitation, and energy, among others).

^a Charles Kibert—organizer of the First International Conference on Sustainable Construction—was the director of the Center for Construction and the Environment at the University of Florida and the coordinator of the international working group 16 of the Conseil International du Batiment (CIB) on sustainable construction, and later, of working group 39 on deconstruction.

^b While several definitions of construction/infrastructure sustainability integrate the environmental, economic/financial, and social dimensions, the 2019 publication by the Inter-American Development Bank (IDB) adds the institutional sustainability dimension, given its importance for the other three dimensions and the long-term effectiveness and impact of projects.

^c According to the Center for Climate and Energy Solutions (C2ES), climate resilience involves the ability to adapt to changes and recover quickly from extreme climate-related events while maintaining system functionality. See <https://www.c2es.org/content/climate-resilience-overview/>

In this context, the Inter-American Development Bank (IDB) is collaborating with public institutions in LAC to promote digital transformation policies in the construction sector, including adopting methodologies such as BIM and improving information quality on emissions from construction processes. Additionally, it should be noted that over the past twenty years, there has been sustained growth in global scientific and technological production related to enabling solutions for sustainable construction. Between 2005 and 2022, the production of articles on this topic in the region had an average annual growth rate of 23%, although it only accounts for 3.6% of the global yearly production (Baptista, 2024).

This Technical Note is based on a consultancy commissioned by the IDB (see Information Box 2). It aims to establish relationships between applications, digital tools, and innovative construction systems and materials as an enabling platform for sustainable construction in LAC. It is organized into four sections: (i) introduction; (ii) enabling solutions for sustainable construction, which includes a section on the generation of scientific and technological knowledge; (iii) analysis of experiences, challenges, and opportunities from the main findings of the qualitative survey con-

ducted in Brazil, Chile, Costa Rica, and Uruguay,⁵ and (iv) keys to the future to transform the construction sector. Additionally, it presents five annexes (Annex I: List of interviewees; Annex II: Interview guidelines; Annex III: Initiatives identified by country; Annex IV: Types of solutions promoted by country; and Annex V: Generation of knowledge on sustainable construction). This structure allows for identifying initiatives, challenges, and best practices associated with the sustainable development of the construction sector in the region.

⁵ These countries were selected for the study due to the identification of ongoing initiatives and their accessibility to information during the study period.

Information Box 2. Methodology of the Study: *Mapping Digital Tools and Innovative Construction Methods for a Sustainable Construction Sector*

This document summarizes the findings of the consultancy commissioned by the Inter-American Development Bank (IDB), *Mapping Digital Tools and Innovative Construction Methods for a Sustainable Construction Sector*. Its methodology combined the identification, systematization, processing, and analysis of various secondary sources, along with a qualitative survey based on semi-structured interviews with relevant stakeholders in the sector across the region.

The process of systematizing secondary information included the review and analysis of relevant documentary and statistical sources related to methodologies and digital and construction tools to improve sustainability in the construction sector. This process made it possible to identify global trends, best practices, and the state of the art in the development of sustainable solutions for construction.

The collection of primary information was carried out through semi-structured interviews with relevant stakeholders in four countries of Latin America and the Caribbean (LAC): Brazil, Chile, Costa Rica, and Uruguay. Representatives of governmental, business, academic, and professional organizations linked to the construction sector were identified and interviewed. A total of 20 interviews were conducted between December 2023 and January 2024 to gather perceptions, approaches, initiatives, challenges, and best practices associated with implementing sustainable solutions in the construction sector in the region.



2

ENABLING SOLUTIONS FOR SUSTAINABLE CONSTRUCTION

The analysis made it possible to identify six categories of solutions and methodologies that contribute to the development of sustainable construction: (i) advanced digital technologies; (ii) sustainable design focus; (iii) sustainable materials; (iv) industrialized construction systems; (v) measurement and verification of the environmental impact of constructions; and (vi) efficient management approaches (Figure 1). In particular, advanced digital technologies act as the common factor, serving as a robust enabler across the different identified categories and driving the sector's transformation toward sustainable construction.

In this regard, two groups of enablers are distinguished. The first, **digital enablers**, facilitate decision-making and make project management and performance more efficient for sustainable construction through methodologies, standards, and the use of digital platforms and tools. Furthermore, they enable the integration and enhanced benefit of the second group, the **technical enablers**, which involve materials, construction systems, design criteria, and management methodologies.

Figure 1. Categories of Solutions for Sustainable Construction



Source: Final consultancy report by the IDB, *Mapping Digital Tools and Innovative Construction Methods for a Sustainable Construction Sector* (Baptista, 2024).

The following section describes each category and how Latin America and the Caribbean (LAC) have advanced in recent years in generating scientific and technological knowledge associated with each category.

2.1. ADVANCED DIGITAL TECHNOLOGIES

Advanced digital technologies, classified as enabling technologies for transforming the sector toward sustainable construction throughout its value chain, allow, among other things, the organization and structuring of data to provide transparent, traceable, reliable, and accurate information; optimize decision-making, asset, and project management; develop simulations of different scenarios; facilitate the measurement of indicators; enhance resource use; contribute to minimizing construction waste; and reduce construction time. In general, advanced digital technologies are enablers for the different types of solutions presented, maximizing benefits and increasing opportunities for operational efficiency, productivity, and the sector's transformation toward a more sustainable construction industry.

This section presents some of the leading enabling technologies for sustainable construction, for example, (i) the Building Information Modeling (BIM) methodology facilitates and efficiently integrates and evaluates various sustainable solutions; (ii) artificial intelligence (AI) can contribute to intelligent management throughout the entire asset lifecycle; (iii) blockchain technology can be used to verify environmental sustainability certifications; (iv) virtual reality (VR) and augmented reality (AR) aid in visualizing and analyzing alternatives for sustainable design; and (v) recyclable or recycled materials can be incorporated into construction through digital or additive manufacturing. Additionally, AI-driven simulations allow the evaluation of infrastructure resilience and adaptation to climate change effects. Furthermore, using advanced digital tools enables the examination of threats and risks and guides decision-making regarding construction site selection.⁶ These advanced digital technologies enable and facilitate the implementation of methodologies and tools to promote sustainable construction.

⁶ Some digital tools of this type are Think Hazard, Climate Change Knowledge Portal, GeoNode, Building Resilience, VI-GEA, and the Observatory of Threats and Natural Resources (Fischel et al., 2023).

2.1.1. Building Information Modeling Methodology

BIM⁷ is a set of methodologies, technologies, and standards that enable collaborative design, construction, and operation of an asset in a virtual space.⁸ It organizes, structures, defines, and captures valuable data and information (geometric and alphanumeric) that stakeholders can manage throughout the project's lifecycle. The BIM methodology can be applied to projects of different types, regardless of their complexity or scale. However, its implementation should be proportional and adapted to the scale and complexity of the asset or project.⁹

Managing and handling three-dimensional parametric models and incorporating multiple data sets (such as time, costs, energy consumption, environmental conditions, and carbon footprint, among others) allow users to manage information efficiently and centrally. It enables the automation of processes and tasks for planning, conceptual design, simulation and analysis, documentation, manufacturing, construction logistics, operation, maintenance, renovations, and/or demolition of the asset, among others. An example is the Materials Passport initiative,¹⁰ a digital platform that integrates parametric 3D models (BIM) with data and functionalities, enabling the registration, traceability, characterization, verification, and validation of technical, sustainability, toxicity, and circularity information for the various materials and products used in construction.

Additionally, three-dimensional digital models allow the management of the physical and functional characteristics of the asset, as well as the integration and collaboration of professionals, technicians, and stakeholders, to define a precise and detailed project. This reduces the need for adjustments and/or rework during the construction phase.

The BIM methodology, being standards-based, enables and facilitates the structured and organized sharing of information among the various actors involved in the project, thereby fostering collaborative work.

BIM is a key enabler for applying advanced digital technologies in construction (WEF, 2016). By integrating with other advanced digital technologies presented, BIM constitutes a powerful digital platform that is highly valuable for planning, designing, constructing, and operating infrastructure with a reduced environmental impact. Studies show that the BIM methodology increases productivity by 13%, reduces costs and timelines by 4%, and decreases on-site information requirements by 6% (Dodge Data & Analytics, 2017) while contributing to environmental sustainability throughout the entire infrastructure lifecycle.

⁷ Shared digital representation of a built asset (an item, object, or entity that has potential or real value to an organization) to facilitate design, construction, and operation processes, forming a reliable basis for decision making, based on ISO 19650-1 (2018).

⁸ Based on the BIM Standard for public projects, Planbim by CORFO (2019).

⁹ Based on ISO 19650-1 (2018).

¹⁰ Section 3, subsection 3.1, provides further details on this tool.

Information Box 3. Example of Integration of Building Information Modeling and LEAN Construction Solutions: Impact Assessment of the CAIF Aeroparque Project in Uruguay

The National Development Corporation (CND) of Uruguay, through the trust fund of the Uruguayan Institute for Children and Adolescents (INAU), managed a pilot project for the construction of the CAIF Aeroparque between 2019 and 2021 using the Building Information Modeling (BIM) methodology in the design and construction phases, alongside the LEAN Construction methodology during project management. This project stood out for the integration of both methodologies, aiming to improve efficiency and reduce costs and execution times.

The evaluation of the pilot project results, based on quantitative and qualitative research techniques, demonstrated greater efficiency in the construction process of the CAIF Aeroparque compared to five control groups. In terms of time, the project performed better on construction timeline indicators and response times to construction observations, particularly excelling compared to projects built during the COVID-19 pandemic. This superior performance suggests that the CAIF Aeroparque project had better organizational and operational condi-

tions to address challenges arising from the health emergency. The pilot project also showed significantly improved response times to construction issues, with variations approximately 50% better than the control averages and superior performance at least within the control group of CAIF centers with similar budgets.

In terms of costs, the pilot project registered a cost overrun 63% lower than similar projects executed during the pandemic, falling more than three standard deviations below the mean. This outcome highlights the significant impact of the pandemic on construction costs and underscores the relative success of the BIM-LEAN Construction approach in mitigating the crisis's negative effects on the budget. An analysis of unforeseen costs as a percentage of the total contract cost showed variations of around 90% compared to the average of the five control groups, confirming the pilot project's superior performance in preventing critical budget errors and modifications.

In summary, the evidence suggests that integrating the BIM and LEAN Construction methodologies in the CAIF Aeroparque pi-

lot project effectively reduced both the execution time and relative costs of the construction work. Shorter construction times and fewer unforeseen events imply reduced energy consumption and more precise material usage, which can lead to comparatively lower emissions. The quantitative and qualitative results, along with interviews with the project's key stakeholders, reinforce these findings and highlight the effectiveness of these methodologies in improving efficiency and project management in the construction sector.

2.1.2. Artificial Intelligence

AI¹¹ applied in construction management can contribute to sustainability across different stages of the project lifecycle. During planning and design, it helps define sustainable designs, examine multiple proposals, and iterate more efficiently. It also supports the development of complex simulations and analyses (energy efficiency, solar orientation, energy consumption, carbon footprint, material performance, and behavior under extreme weather conditions). It provides better responses to climate change and/or natural disasters.

During construction, AI facilitates site planning and construction logistics to optimize work areas, construction sequences, and efficient transport routes, reducing resource use and construction time. Additionally, it can support waste management by identifying opportunities to recycle and reduce waste, contributing to calculating the project's carbon footprint, and highlighting areas for improvement and reduction of greenhouse gas (GHG) emissions.

In operation and maintenance, AI can contribute to real-time energy management

¹¹ According to the definition of the Royal Spanish Academy (RAE), "a scientific discipline that deals with creating computer programs that perform operations comparable to those carried out by the human mind, such as learning or logical reasoning."

linked to the Internet of Things (IoT) and monitor and control systems (heating, ventilation, air conditioning, lighting, and other energy systems) to optimize consumption. This also helps with maintenance and improves sensor data and monitoring system analysis by identifying potential failures and prioritizing maintenance activities. Optimal operation extends the asset's lifespan and results in a lower environmental impact. As an example, artificial neural network (ANN) metamodels are used to develop simulations of energy consumption performance in buildings, improving design definition, as the simulation's accuracy is highly reliable, and the relationship between the obtained precision and computational cost is very favorable (Roman et al., 2020).

2.1.3. Big Data Analytics

Big data analytics¹² is a digital tool capable of processing large volumes of data to find patterns, trends, and relationships through advanced statistical and mathematical techniques. In construction, data analytics allows for better-informed decision making and contributes to continuous optimi-

¹² It originally comes from the field of computer science and refers to a set of data whose size exceeds what standard software and hardware can handle (Rodríguez et al., 2017). See <http://dx.doi.org/10.18235/0000893>. Its technology was developed based on five pillars: volume, velocity, variety, veracity, and value, and can be applied to both structured and unstructured data.

zation and improvement of environmental performance over time. Big data analytics¹³ and AI are complementary; they increase efficiency in processing structured and unstructured data and identifying patterns, trends, and relationships. This can be highly valuable in defining project locations and their operation and maintenance.

2.1.4. Virtual Reality and Augmented Reality

Extended reality enables professionals and all stakeholders to better visualize and understand projects, facilitating decision making and communication. It simplifies interactions with clients and project users and identifies adjustments prior to construction, reducing the likelihood of rework and, consequently, reducing the environmental impact of construction. Furthermore, integrating virtual reality¹⁴ (VR), augmented reality¹⁵ (AR), and AI facilitates the creation of digital twins¹⁶ and enables remote col-

¹³ The analysis of big data often requires techniques and technologies to efficiently process large volumes of data, and artificial intelligence (AI), particularly in the field of natural language processing, can help increase the efficiency of processing unstructured datasets. In turn, machine learning algorithms—a branch of AI—rely on data analytics to train and improve their performance in identifying patterns, trends, and relationships.

¹⁴ Computer system that generates real-time representations of reality.

¹⁵ Technology that combines virtual elements with the physical environment for information visualization.

¹⁶ It involves replicating a physical building or infrastructure in a digital environment.

laboration and decision-making, reducing the need for travel and emissions. In the operational phase, it can be used for the continuous management of the built asset, improving operational efficiency, energy management, and resource use, thereby increasing its lifespan and reducing emissions.

2.1.5. Internet of Things

IoT¹⁷ involves connecting sensors and devices via the Internet to collect real-time data on the condition, use, and performance of the built asset. This facilitates system monitoring and automated control, improving energy efficiency and safety. For example, IoT devices and sensors can be used to monitor and control energy consumption, ambient temperature, lighting systems, and occupancy sensors. These devices allow for automatic adjustments to optimize usage and reduce energy waste.

2.1.6. Blockchain

Blockchain¹⁸ can contribute to supply chain traceability, track provenance, and ensure materials come from sustainable

¹⁷ A term that describes the network of physical objects equipped with sensors, software, and other technologies to connect and exchange data with other devices and systems over the Internet.

¹⁸ Blockchain, or chain of blocks, is a shared or distributed database where information is stored in blocks, linked to one another, and validated in a decentralized manner through a common protocol.

sources. It also allows for tracking materials' carbon content, facilitating informed decision-making. Additionally, it can be used to store and verify sustainability certifications, such as Leadership in Energy and Environmental Design (LEED) or Building Research Establishment Environmental Assessment Method (BREEAM). It can also optimize waste management by tracking the quantity and destination of construction and demolition waste (CDW).

2.1.7. Cloud-Based Project Management

This technology offers efficiency, collaboration, and real-time data access. It enables teams and stakeholders to collaborate effectively in real-time, reduces travel and in-person meetings, and decreases emissions associated with travel. It also promotes using electronic documents instead of printed copies, reducing paper and ink usage and the need to dispose of waste. Cloud-stored documentation and data enhance long-term accessibility, improve traceability and transparency of information, and facilitate sustainable management throughout the asset's lifecycle phases.

2.1.8. Advanced Robotics

Robots can play a significant role in improving sustainability in construction projects throughout the entire lifecycle. During

the construction phase, masonry robots or climbing robots can accelerate the building process, reducing construction time and energy consumption. They can also perform tasks precisely and repetitively, minimizing errors and reducing the need for corrections. Autonomous robots and unmanned vehicles can also optimize logistics and material transport, thus mitigating environmental impact, fuel consumption, and carbon emissions. Specialized robots can selectively dismantle structures, recover materials, and minimize demolition waste during deconstruction. They are also equipped to perform dangerous tasks, such as working in contaminated environments or extreme conditions, without exposing workers to risks, thereby improving safety and sustainability on the job site.

2.1.9. Digital/Additive Manufacturing (3D Printing)

3D printing is used to manufacture construction components directly on-site or in a factory. This accelerates construction, reduces energy consumption, and minimizes waste compared to traditional methods. Additionally, by allowing the production of components on the construction site or nearby locations it reduces the need for transportation and associated carbon emissions. Another benefit is that it can incorporate recycled or recyclable materials,

promoting sustainability by reducing the demand for new resources.

2.2. SUSTAINABLE DESIGN APPROACH

Sustainable design, also known as eco-design, involves considering the environmental impact from the conception of a product to improve its environmental performance throughout its lifecycle. In the context of construction, sustainable design focuses on creating buildings and structures that are efficient in using natural resources and energy, adapted to climatic conditions, and with minimal environmental impact and greenhouse gas emissions (GHG). To achieve sustainability, in addition to complying with building codes and local technical standards, it is crucial to incorporate features such as efficient use of energy and water, integration of renewable energy, reduction of pollution and waste, indoor air quality, use of sustainable and non-toxic materials, consideration of the environment in design, construction, and operation, enhancement of occupants' quality of life, and adaptation to a changing environment (Alvear et al., 2022).¹⁹ These sustainable design approaches are complementary and contribute to creating more

¹⁹ While sustainable design has initially been associated with buildings (architectural design), these considerations have gradually been transferred to the design of infrastructure in general.

environmentally responsible built environments. Below are some sustainable design approaches.

2.2.1. Bioclimatic Design

Bioclimatic design, also known as eco-architecture or green design, focuses on utilizing environmental, climatic, and surrounding conditions to benefit users by using locally available resources and seeking comfort with minimal energy consumption and environmental impact. A variant of this design is "passive" buildings,²⁰ which follow energy efficiency²¹ criteria and aim for low energy demand for heating and cooling so that they can be "passively" conditioned (Feist, 1993),²² thereby reducing the need for active systems. These buildings are based on strategies such as thermal insulation, ventilation with heat recovery or cooling, and orientation to take advantage of external environmental conditions. Other relevant

²⁰ The concept of the "passive house" became popular in architecture schools in the early 1980s, following the publication of the book *The Passive House: Climate and Energy Savings* by the American Institute of Architects.

²¹ Energy efficiency enables the optimization of the energy performance of buildings throughout their lifecycle by reducing energy demand compared to conventional buildings; this translates into economic resource savings, among other associated benefits (Fischel et al., 2023).

²² To be considered "passive," buildings must adhere to strict standards, such as those of the Passive House Institute, which are presented in section 3.4.

elements include the building's volumetrics, solar protection, and natural solutions such as urban gardens and green roofs (Fischel et al., 2023), which help reduce the heat island effect, improve runoff control, decrease pollution and energy consumption, and restore habitat and well-being for people and ecosystems.²³

2.2.2. Energy Efficiency and Generation

In addition to bioclimatic design measures, it is possible to work on improving the energy efficiency of the building. This allows for optimizing energy performance throughout its lifecycle by reducing energy demand, compared to conventional buildings, which translates into savings of economic resources, among other associated benefits (Alvear et al., 2022).

Various techniques are applied to reduce energy needs and increase the building's capacity to absorb, store, and generate energy. These techniques include installing high-efficiency HVAC systems, using efficient equipment and Light-Emitting Diode (LED) lighting systems, and integrating renewable energy generation technologies, such as photovoltaic solar panels. Combining these measures can lead to a carbon-neutral or even a positive building if

²³ See <https://www.minvu.gov.cl/ditec/infraestructura-verde-y-espacios-publicos-sustentables/>.

the renewable energy generated exceeds the energy consumed (Fischel et al., 2023).

2.2.3. Flexible Architectural Design

Flexible architectural design is intended to adapt to changes by incorporating movable and interactive components that respond to external stimuli and modify their configuration. This approach helps avoid oversized spaces and allows buildings to adapt to different uses and needs over time. Flexibility in design can reduce the need to demolish and construct new buildings, contributing to sustainability and energy savings. Current examples include the combined use of spaces for both housing and work, which presents new opportunities and challenges for flexible design.

2.2.4. Resilient Construction Design

Resilient construction design combines durable materials and construction methods aimed at increasing the strength of assets, especially in areas prone to threats such as hurricane-force winds and flooding, among others. It includes improvements in foundations, slabs, roofs, exterior and interior walls, window frames, roof fastenings, and reinforced connections in finishes, with criteria that must be adapted according to the characteristics of each location. In urban areas, resilience extends to infrastructures such as drainage systems,

sewers, dikes, retaining walls, and slope stabilization systems to reduce the risk of flooding, erosion, and landslides (United Nations, 2012). These measures are crucial in high-risk areas, such as those affected by hurricanes (Bailey et al., 2021) or other natural disasters.

2.3. SUSTAINABLE MATERIALS

Various studies have shown that sustainable materials can significantly reduce construction's environmental impact. Thormark (2006) demonstrated that an appropriate selection of materials can reduce embedded energy from 40% to 17% of a building's total energy demand over 50 years.²⁴ In Chile, approximately one-third of the carbon emissions from a residential building come from construction materials,²⁵ with concrete accounting for more than half (54%) of these emissions (GBC Chile, 2023).

Industrialized construction materials have a high environmental impact due to the energy required for their production. For example, producing one cubic meter of

²⁴ There is a direct relationship between the embodied energy in materials and CO₂ emissions during their production process. According to Cabeza et al. (2013), the carbon footprint is approximately 0.08 per energy consumption.

²⁵ For the evaluated building, 12% of the total carbon emissions in the lifecycle of the project is attributed to the transportation of materials.

concrete requires 100 times more energy than producing the same amount of compacted earth bricks,²⁶ and producing one cubic meter of asphalt requires two to four times more energy than concrete.²⁷ Cement production consumes large amounts of energy in processes such as burning, grinding, packaging, and transportation, while earth bricks require less energy and transportation (Houben, 1994).

In addition to energy costs, the extraction of mineral resources and the disposal of construction and demolition waste²⁸ represent significant environmental impacts. Over 10 billion tons of construction waste are generated globally each year (Chen et al., 2021), with more than 80% of this waste consisting of concrete, bricks, and decorative elements, among other materials (Kong and Ma, 2020).

To minimize the damage associated with the use of construction materials, three main strategies can be followed: (i) conser-

²⁶ The production of one cubic meter of concrete consumes between 400 and 800 kWh, whereas the production of earth bricks requires only up to 5 kWh per cubic meter (Houben, 1994).

²⁷ Lifecycle Assessment (LCA) Data.

²⁸ Construction waste is the waste generated in the process of construction, maintenance, and demolition of buildings. According to its source, construction waste can be divided into five categories: excavation waste; road removal waste; demolition waste from old buildings; construction work waste; and construction material production waste (Kong and Ma, 2020).

vation of materials, using fewer materials and recycled materials; (ii) using low-carbon footprint and sustainable materials; and (iii) efficient management to reduce waste during construction, operation, and demolition of buildings (Fischel et al., 2023).

Sustainable materials come from renewable resources, have low carbon emissions, are durable, are designed for climate resilience, generate minimal waste, and are recyclable or reusable. Additionally, using local materials can minimize energy consumption associated with transportation. Below is a summary of some sustainable materials currently available.

2.3.1. Certified Wood

Certified wood is one of the sustainable materials that can be used in construction due to its multiple environmental and structural benefits. Sourced from sustainably managed forests, wood absorbs carbon, is renewable, and generates fewer greenhouse gas (GHG) emissions during industrialization. Its construction process is faster²⁹ and has a lower environmental impact. Additionally, wood has a high insulation capacity, requiring less energy con-

²⁹ The Stadthaus building in London, a nine-story structure, was completed in 49 weeks, and it is estimated that the project took five months less compared to concrete construction (TRADA Technology 2009, cited by Gallardo, 2020).

sumption during operation. It³⁰ generates less waste and is recyclable. Wood's carbon footprint is very low or even negative.³¹

Wood is beneficial in terms of resilience to natural disasters due to its good seismic performance and flexibility, which make it less prone to structural collapses (Gallardo, 2020). Moreover, recent studies have highlighted the warmth and well-being that wood provides in built environments (Lowe, 2020).

Innovation in engineered wood³² products has enabled their use in high-rise construction. These products present an alternative to traditional materials to address housing shortages and mitigate climate change. Construction based on engineered wood products implies a shift in material and construction system, as the process is based on a modular construction system.

30 Wood contributes to energy efficiency due to its heat conduction capacity. This characteristic makes it a superior insulator compared to other materials. It is 400 times better than steel and 15 times better than concrete (Gallardo, 2020).

31 The production of one ton of wood absorbs 1.8 tons of CO₂eq, in contrast to the emission of 0.9 tons of CO₂eq and 1.24 tons of CO₂eq from the production of one ton of concrete and steel, respectively (MVOT and IDB, 2022).

32 Wood engineering products for construction can be classified into two main categories: those made with sawn lumber, known as Mass Timber, and structural composite lumber (SCL), which is manufactured by bonding layers of veneers or flakes using adhesive, pressure, and temperature. See <https://www.naturallywood.com/topics/mass-timber/>.

2.3.2. Bamboo

Bamboo, especially popular in tropical areas, is a natural, high-strength, and eco-friendly material. Due to its rapid growth, it is renewable and has a limited environmental impact. Bamboo offers ecological benefits by capturing carbon dioxide and possesses structural properties similar to steel bars in concrete (Hernández-Zamora, Jiménez-Martínez, and Sánchez-Monge, 2021), making it a robust and versatile material.

2.3.3. Natural Insulation Materials

Natural insulation materials, such as cork, wool, cellulose, and hemp, are sustainable construction options. These materials are renewable, recyclable, and biodegradable, helping reduce energy consumption in buildings and decreasing GHG emissions.

Cork, used as thermal and acoustic insulation, is biodegradable, recyclable, and requires little energy for transformation. Additionally, cork's thermal insulation properties are competitive with modern insulating materials (Yay et al., 2024). However, it must come from responsibly managed forests to ensure its sustainability. Cellulose, with low thermal conductivity, is an excellent acoustic insulator and can be treated with fire-resistant, insecticidal, and antifungal properties. Hemp, used to manufacture building blocks (Cannabric), does not require pesticides, and its culti-

vation has a low environmental impact. It is also porous, promotes ventilation, regulates humidity, and purifies the air; it is recyclable and does not contribute to GHG emissions during its manufacturing, as it consumes very little energy (Hernández-Zamora, Jiménez-Martínez, and Sánchez-Monge, 2021).

2.3.4. Clay

Clay, used in the form of adobe and compressed or compacted earth, is an abundant and eco-friendly material. Adobe, made from raw clay dried in the sun, contains no toxic substances, is recyclable, and has a low carbon footprint due to its local sourcing and low energy consumption.³³ Additionally, it has excellent thermal and acoustic insulating properties, promotes moisture regulation in environments, is non-flammable, economically affordable, and allows for self-construction. However, it has limitations for high-rise construction and is vulnerable to water and seismic activity (CDT, 2022); moreover, there may be barriers in regional building codes (Alvear et al., 2023).

33 Adobe requires 2,000 BTUs of energy to be produced (most of the time completely renewable, clean, and natural), while brick requires 15 times more energy (30,000 BTUs) and, in addition to its production, involves burning fuels that emit CO₂ (CDT, 2022).

Fired clay, used for bricks, tiles, blocks, slabs, and coatings, is recyclable, and its production consumes less energy than other materials. Due to its production process, which involves heating clay to temperatures below 950 °C, retains properties such as hygroscopicity, insulation, low radioactivity, and good thermal inertia. Stabilized compressed clay blocks are environmentally friendly and energy-efficient alternatives to fired bricks, saving up to 70% of the energy used in their production (Reddy, 2009), and can store industrial waste, such as quarry dust, fly ash, etc.

2.3.5. Stone Materials

Natural stone is a durable, low-maintenance material with good insulating properties and a lower carbon footprint than other materials. However, the carbon emissions associated with its use depend on the proximity of its source to the construction site. Granite production has an embodied carbon of 93 kgCO₂ per ton, cement production generates 830 kgCO₂, and steel bars generate 1,710 kgCO₂ (Crishna, Banfill, and Goodsir, 2011). However, due to its weight and volume, as well as the energy consumed in its transportation, the carbon emissions from the stone will only be lower than those of other construction

materials when the material's origin is near the construction site (Crishna, Banfill, and Goodsir, 2011).³⁴

2.3.6. Innovations in Concrete Production

Concrete has a significant environmental impact due to the clinker used in it, which releases one ton of CO₂ per ton produced. However, approaches are being developed to reduce its environmental impact (Cabeza et al., 2013). These include replacing clinker with supplementary cementing materials and industrial byproducts, using plant-based aggregates (rice, corn, or sunflower) (Grădinaru et al., 2019), and using recycled materials (plastic resins, polystyrene, and rubber) (Bailey et al., 2021).

Eco-friendly concrete can include fly ash, silica fume, and recycled materials like plastics and rubber, which improve its thermal performance (Maddalena, Roberts, and Hamilton, 2018) and reduce carbon emissions by 20% to 50%. Incorporating biochar provides greater strength and durability, better thermal properties, and carbon capture potential (Barbhuiya, Bhusan Das, and Kanavaris, 2024).

³⁴ For example, according to Crishna, Banfill, and Goodsir (2011), in the case of UK stone delivered within the country, the carbon footprint of sandstone, granite, and slate is 77, 107, and 251 kgCO₂eq per ton, respectively. However, when imported from Spain, the cradle-to-site footprint increases to between 134 and 318 kgCO₂eq per ton.

Other strategies include reducing the volume of concrete required and using prefabricated components that enhance construction efficiency and minimize waste, such as (i) using molds or fillers to decrease the volume of concrete, (ii) replacing elements with prefabricated or industrialized components, and (iii) solutions that combine in-situ, prefabricated, and industrialized concrete (Bailey et al., 2021). Another alternative is the development of self-healing concrete, which extends the life of structures and reduces the need for external interventions, which is critical for sustainability and energy efficiency (Baque-Campoano, Pino-Tarragó, and Delgado-Mendoza, 2023). Currently, there are four techniques to promote self-healing in concrete: i) mixing with microcapsules, ii) latent bacteria, iii) shape-memory polymers, and iv) vascular systems,³⁵ all of which have great potential to address sustainability challenges in construction. However, significant challenges remain, such as training in handling materials and construction techniques, as well as developing safety standards and testing protocols (Baque-Campoano, Pino-Tarragó, and Delgado-Mendoza, 2023).

³⁵ See <https://www.dconstruccion.cl/?p=42273>.

2.3.7. Aggregates

Aggregates can be recycled, and their use would reduce emissions, debris generation, and environmental impact. Recycled aggregates can be used to restore degraded areas, build road bases, construct drainage systems, and produce mortars and concrete.

Construction waste recycling is technically feasible and widely used in developed countries such as Spain and the United Kingdom. Denmark, the Netherlands, and Japan have the highest recycling rates for construction waste (Kong and Ma, 2020), which contributes significantly to sustainable construction.

2.4. INDUSTRIALIZED CONSTRUCTION SYSTEMS

Industrialized construction systems are coordinated sets of methods, techniques, materials, and processes used in construction. To be sustainable, they must consider environmentally responsible alternatives throughout all stages. Advanced systems based on industrialization and standardization exist, such as modern construction methods (MMC) (United Kingdom, Spain) (see box 4), industrialized construction systems (ISB) (Malaysia, Thailand), off-site manufacturing (OSB) (Australia), prefabrication, pre-assembly, modularization, and

off-site manufacturing (PPMOF) (United States), off-site construction (OSC) (China), prefabricated and prefinished volumetric construction (PPVC) (Singapore) (see box 5), integrated modular construction (MIC) (Hong Kong), off-site production (OSP) (Germany), industrialized construction (Sweden, Finland, Denmark), industrialized housing (Netherlands), prefabricated housing (Japan, Philippines), and modular construction (Canada), among others (Sánchez-Garrido et al., 2023), all of which offer alternatives and can contribute to sustainability.

Industrialization of construction involves applying industrial production systems from conception to dismantling. This includes the industrial production of construction elements, an efficient execution process on-site, and the industrial production of spatial units assembled on-site (Monjo Carrió, 2005). The fundamental criterion is that the system should leave the factory as fully completed as possible, with optimized dimensions and minimal joints, facilitating quick assembly and solid construction. The goal is to produce integrated and standardized units but with the flexibility to allow some customization in finishes and dimensions (López, 2017).

Industrialized construction offers numerous environmental benefits, including reducing construction waste, promoting the recovery and recycling of materials, and minimizing the use of resources such as energy and water. It also requires less labor and shortens execution times. Studies such as those by Krug and Miles (2013) have shown significant reductions (60%) in traffic movements and energy consumption (80% on-site and 20% during construction), while Deloitte (2023) reports a 15% reduction in project costs, a 70% reduction in CO₂ emissions, and a 40% reduction in delivery times. Additionally, life-cycle assessments, such as those conducted by Hernández, Ossio, and Silva (2023)³⁶ on the system, show substantial improvements in labor productivity (47% higher), reduction in annual energy consumption (53%), and a 51% reduction in carbon emissions. In this regard, applying off-site construction has led to a 68% reduction in construction waste and a 49% and 54% reduction in energy and carbon emissions associated with waste, respectively. However, industrialized construction faces challenges such as a lack of skilled labor, supply shortages, and existing regulations (Rahman,

36 The Beam + Insulation + Pillar (VAP, for the Spanish acronym) system incorporates wood, plywood, and expanded polystyrene components.

2014, cited by Yepes, 2020). In the region, regulations of this kind are still emerging, although Chile has made notable progress in this area.

2.4.1. Prefabrication

Prefabrication is a "closed" construction system where components, such as wall panels and roofs, are fabricated off-site and assembled on-site. This method streamlines processes by modularizing elements and ensuring a high level of finish and quality. Off-site fabrication reduces construction times and minimizes waste, especially when using materials like metals and wood, which have high recyclability. These materials are easily joined and allow for clean, easily recoverable structures, which are ideal for reversible housing. Prefabrication also simplifies maintenance, as this activity focuses on the joints between the elements. It is also used for rapid response to climate emergencies or natural disasters.

2.4.2. Light-Frame Construction Systems

Light-frame construction systems, also known as dry construction, are based on galvanized steel profiles and are fast, cost-effective, and clean due to their assembly planning. These systems employ lightweight materials, such as lightweight steel, wood, and drywall, which significantly reduce the weight per square me-

ter (18 kilograms per m²) compared to conventional concrete construction (300 kilograms per m²). Their main advantage lies in the speed of assembly, as they can reduce construction time by up to 70% compared to traditional methods. This efficiency also implies lower energy and resource consumption during the process and generates less waste. Furthermore, these systems are characterized by their easy transportability and maintenance, and their environmental impact is lower in terms of CO₂ emissions incorporated into the materials, according to a study by Hacker et al. (2008).

2.4.3. Modular Construction

Modular construction involves manufacturing modules in an industrial plant and their assembly on the construction site and stands out among sustainable construction systems. It offers advantages such as reduced construction timelines, lower materials and energy consumption, reduced waste, and high energy efficiency. Prefabricated modules allow for a time savings of up to 50%, as they are produced under controlled conditions. Once they reach the site, they are assembled and minimize on-site work since, on average, 80% of the construction activity has been completed elsewhere. Additionally, they enable manufacturing with strict tolerances, reducing

errors and improving safety. Despite its benefits, proper supply chain management and reducing carbon emissions are significant challenges (Sanchez-Garrido, 2023).

2.4.4. 3D Printing Systems

The construction system based on 3D printing uses additive manufacturing technology to create building components layer by layer, on-site and off-site. It is highly versatile and allows the creation of a wide range of components and complex structures, from houses or living spaces, offices, bridges, walls, modular structures, reinforcement molds, and columns to urban furniture and decorative elements. Its advantages include minimizing waste, optimizing construction time, increased safety on-site, and design customization (Leles da Silva et al., 2024).³⁷ However, it faces significant challenges, such as the cost of machinery, staff training (designers, operators, and maintenance personnel), and the weakness or lack of an appropriate regulatory framework.³⁸

37 In a recent study, Leles da Silva et al. (2024) developed and validated a bench-scale 3D printer prototype coupled with a pumping subsystem capable of extruding and supporting overlapping layers. They demonstrated the feasibility of replacing traditional methods with 3D printing, as well as its benefits in terms of efficiency and waste reduction.

38 See <https://www.cemexventures.com/es/impression-3d-en-la-construccion/>.

Information Box 4. Modern Construction Methods in the United Kingdom

Prefabricated housing in the United Kingdom has been used during periods of high demand, such as after the world wars; however, due to issues with material quality and labor qualifications, it generated a negative perception. In 2003, faced with a significant housing shortage, the UK government launched the Sustainable Communities Plan, which focused on modern construction methods (MMC). This plan aimed to radically transform the construction industry to produce housing in the required quantity and quality (Lovell, 2012). Since 2004, one-quarter of publicly funded social housing projects had to use MMC. This initiative was followed by public policies encouraging the use of MMC, such as best practices programs, informational guides, the development of standards, and capacity building, among others.^a

MMC encompasses a variety of construction approaches, including prefabrication, process improvements, and technological applications, both off-site and on-site, offering alternatives to traditional methods with the potential to significantly improve productivity, efficiency, and the quality of the industry (Yepes, 2020). In 2019, the Housing Corporation defined MMC in seven categories (MHCLG MMC, 2019): i) prefabricated 3D volumetric modules; ii) prefabricated flat panels; iii) prefabricated structural components; iv) additive manufacturing (structural or non-structural); v) prefabricated non-structural components; vi) use of improved traditional construction materials, and vii) on-site processes that improve productivity, reduce labor, and increase safety.

The benefits of using MMC compared to traditional construction are well documented in more than 600 publications on the topic.^b These include improved delivery times and product quality, higher material productivity and efficiency, reduced occupational risks, and lower environmental impact (including reductions in air and noise pollution as well as waste generation). According to a recent study by Sánchez-Garrido et al. (2023), sustainability is precisely one of the drivers of MMC use.

^a The policy promoting modern construction methods (MMC) in the United Kingdom continues to this day, and according to recent data, 7% of the total housing in this country was built using MMC (Sánchez-Garrido et al., 2023).

^b A systematic literature review using machine learning can be found in Sánchez-Garrido et al. (2023).

Information Box 5. Regulations for Buildability and Prefabricated and Pre-Finished Volumetric Construction in Singapore

In 1999, the government of Singapore established the Building and Construction Authority (BCA) with the aim of developing regulations for construction to improve productivity in the sector and reduce labor usage. In 2001, the BCA introduced the Buildable Design Score (BDS), which evaluates the design of a building in terms of labor usage and promotes the adoption of construction methods using prefabricated, modular, and standardized components, as well as efficient construction processes for projects over 5,000 m² (BCA, 2000).

In 2019, the BCA raised the minimum BDS scores and incorporated a new regulation that highlights Design for Manufacturing and Assembly (DfMA). This method involves designing for off-site fabrication in a controlled environment before assembly on-site. DfMA encompasses various technologies and methodologies for external fabrication, from prefabricated components to fully integrated assemblies across different disciplines.

One of the components of DfMA is prefabricated and prefinished volumetric construction (PPVC), the most efficient method for improving construction productivity (BCA, 2020). PPVC involves manufacturing independent three-dimensional modules with complete finishes, which are then transported and assembled on-site. PPVC is particularly suitable for buildings with multiple rooms, such as residential units, institutions, and hotels. Early coordination between the manufacturer and the main contractor during the design phase is crucial to incorporate effective technical solutions, as is the logistics for managing the transportation of modules from the factory to the construction site.

The PPVC system, compared to traditional methods, improves labor productivity by up to 40% and saves more than 20% of time. Furthermore, off-site manufacturing minimizes pollution, reduces construction waste, and lowers the impact on surrounding neighborhoods. Manufacturing in a controlled environment also results in more reliable products of higher quality (BCA, 2020).

2.5. MEASUREMENT AND VERIFICATION OF ENVIRONMENTAL IMPACT

Measuring, reporting, and certifying the environmental impact of construction assets is essential to improving their sustainability. This involves generating and monitoring information throughout the assets' lifecycle, using carbon footprint measurement as a key tool. Sustainable certification systems assess environmental performance in design, construction, and operation, establishing standards and providing a framework for continuous improvement. These systems significantly contribute to the sustainability of the construction sector.

2.5.1. Environmental Impact Measurement

The decarbonization of construction requires understanding its impacts, such as operational energy consumption and carbon emissions, through reliable accounting (Peregalli, 2023; GBC Chile, 2023). Monitoring and analyzing this data is essential to identify opportunities for emission reductions (GBC Chile, 2023). The carbon footprint is crucial for measuring this impact, but verification is key to ensuring data accuracy. In Latin America and the Caribbean (LAC), the lack of sector-specific

data and omissions regarding incorporated and operational carbon in the life cycle creates inconsistencies (GBC Chile, 2023).³⁹ Furthermore, emission factors are often based on data from developed countries, which do not reflect the region's reality (IDB, 2023).

There are various methodologies for calculating the carbon footprint that covers all stages of the construction life cycle, such as those proposed by the Royal Institution of Chartered Surveyors (RICS, 2017), the Carbon Leadership Forum (CLF, 2018), and the Building Research Establishment (BRE), Centre for Sustainable Products (BRE, 2016). In addition, several programs, online calculators, and tools are capable of measuring the carbon footprint in buildings (GBC Chile, 2023) (see information box 6).

According to a pilot assessment in Chile, a traditional residential building of 130 units emitted 826.8 kg of CO₂eq/m² during its life cycle (60 years). Of these emissions, 69%

corresponds to incorporated carbon and 31% to operational carbon. Approximately one-third of the total emissions come from the materials used, followed by operational energy (31%), replacements (18%), material transportation (12%), and waste processing (4%) (GBC Chile, 2023).

³⁹ Although CO₂ emission calculation methodologies vary from one country to another, the basic framework is usually the lifecycle assessment process. The lifecycle considers all stages of a construction project, from cradle (raw material extraction), product manufacturing, transportation, and on-site installation to operation, maintenance, and eventual disposal of the material (grave). More precisely, the lifecycle stages are as follows: i) raw material production; ii) building construction; iii) building operation; iv) end of the building's life; and v) reuse, recycling, and energy recovery.

Information Box 6. Carbon Footprint Calculation Methodologies

Royal Institution of Chartered Surveyors (RICS, 2017)

- ◆ **Developer:** Royal Institution of Chartered Surveyors (RICS), an international organization based in the UK that sets professional standards in property management, valuation, and construction.
- ◆ **Main objective:** RICS' methodology focuses on providing clear and practical guidelines for measuring the carbon footprint of buildings and real estate assets. It aims to facilitate the comparison and improvement of buildings' environmental performance throughout their lifecycle.
- ◆ **Relevant features:** It is notable for its practical applicability and integration with international carbon measurement standards.^a It provides detailed guidelines for data collection, emissions calculation, and result presentation,

and adapts to various project scales and types of buildings.

Carbon Leadership Forum (2018)

- ◆ **Developer:** Carbon Leadership Forum, a network of professionals and academics dedicated to reducing the carbon footprint in the construction industry, based in the United States.
- ◆ **Main Objective:** This methodology aims to promote more sustainable construction practices by measuring and reducing carbon emissions associated with materials and construction processes.
- ◆ **Relevant Features:** It stands out for its focus on the complete life cycle assessment of construction materials and structural systems. It incorporates advanced modeling and evaluation tools to quantify emissions throughout the entire life cycle of buildings, from raw material extraction to deconstruction.

Building Research Establishment, Centre for Sustainable Products (BRE, 2016)

- ◆ **Developer:** Building Research Establishment (BRE), Centre for Sustainable Products, based in the United Kingdom, a center specialized in sustainability research and consulting for the construction industry.
- ◆ **Main objective:** Its methodology focuses on analyzing and improving the sustainability of products used in construction, including the measurement of the carbon footprint as an integral part of its sustainability assessments.
- ◆ **Relevant features:** It is distinguished by its focus on detailed research of specific products used in construction, and applies life cycle assessment (LCA) methodologies to calculate the associated carbon emissions. It provides tools for selecting more sustainable materials and optimizing manufacturing processes.

These methodologies are designed to provide construction professionals with robust tools to examine and manage carbon emissions, improve transparency and environmental management in the construction sector, and facilitate informed decision-making aimed at reducing the carbon footprint and promoting more sustainable construction practices, thereby contributing to global climate change mitigation in the construction sector.

^a The stages of the project life cycle use the modular structure provided in the standards EN 15978, EN 17472, EN 15804, EN 15643, ISO 21931, parts 1 and 2, and ISO 21930.

2.5.2. Certification and Standards

Sustainable standards verification systems have been developed in response to environmental challenges, establishing minimum criteria for sustainable features and assigning scores based on compliance. A seal indicates compliance with specific standards, while certification results from a formal independent evaluation process. Certification is more valued when a third-party independent verifies and grants compliance (Alvear et al., 2023). It should also be noted that certifications are typically voluntary and are only considered mandatory when the requester specifies it in their contract terms. As organizations establish these requirements in their contracts or regulations and set criteria for their requirement based on project typologies or amounts, the market will be encouraged to accelerate adoption.

Among the international certifications for sustainable buildings currently available, the following stand out:

- ◆ LEED (Leadership in Energy and Environmental Design) was developed by the U.S. Green Building Council (USGBC). It is available for a wide range of projects, from new construction to operation and maintenance, and evaluates various aspects such as energy efficiency, water

management, material selection, and indoor environmental quality (USGBC, 2020).

- ◆ EDGE (Excellence in Design for Greater Efficiency) was developed by the International Finance Corporation (IFC) of the World Bank. It focuses on resource efficiency (energy, water, and materials) and requires a 20% reduction in energy consumption, water use, and embodied energy in materials.
- ◆ BREEAM (Building Research Establishment Environmental Assessment Method) is driven by BRE Global Ltd. of the United Kingdom. It evaluates the sustainable performance of any new or existing building, considering environmental aspects such as land use, transportation, energy, water, materials, pollution, and waste management.
- ◆ Green Globes, similar to LEED, was initially implemented in Canada and is used in several countries. It evaluates aspects such as energy, water, emissions, materials, and environmental management.
- ◆ Passive House focuses on extreme energy efficiency and indoor comfort. Originating in Germany, it seeks to minimize energy consumption for heating and cooling.

- ◆ WELL Building Standard, focused on the health and well-being of building occupants, evaluates indoor air quality, lighting, thermal comfort, and other aspects.
- ◆ The Green Star, established by the Green Building Council of Australia (GBCA), evaluates sustainable attributes across several categories, including management, environmental impact, and emissions.

Some countries in Latin America and the Caribbean have national sustainable certifications and labels, such as AQUA-HQE, PROCEL EDIFICA-Energy Efficiency in Buildings, Sello Casa Azul and Sello EDIF (Brazil), Sustainable Building Certification and Sustainable Housing Certification (Chile), Casa Colombia (Colombia), Sustainable Building Requirements in the Tropics (RESET) (Costa Rica), Casa Guatemala (Guatemala), and Sisevive-Ecocasa (Mexico), among others (Alvear et al., 2022).

In Latin America and the Caribbean, the countries with the highest number of sustainable certified construction projects per million inhabitants are Costa Rica, Panama, Chile, Peru, Colombia, and Mexico, with values higher than the regional average (Alvear et al., 2023).

2.6. EFFICIENT MANAGEMENT STRATEGIES

Construction projects often experience delays that result in time and resource loss. According to global estimates, 70% of projects experience cost overruns, and 61% suffer delays (Barbosa et al., 2017). These issues negatively impact sector productivity and increase its environmental footprint. They prolong the construction phase, generating higher pollutant emissions and noise and harming local ecosystems and quality of life. This highlights the need for more efficient management methods to reduce environmental impact.

The key components of construction project management are (i) proper planning; (ii) coordination, collaboration, and alignment of the involved parties; (iii) definition of roles and responsibilities; (iv) establishment of key performance indicators; and (v) continuous monitoring and improvement of processes. There are specific management approaches for construction, such as LEAN Construction, Advance Work Packaging, and Design & Build, which optimize costs, schedules, and quality and reduce environmental impacts during project execution.

2.6.1. LEAN Construction

LEAN Construction is a management methodology that focuses on continuous improvement, minimizing waste, and maximizing the value of the final product. It aims to eliminate non-value-adding activities, reduce waste, manage variability, maintain a steady workflow, and decrease inventories, transportation, and costs through efficient and adaptable processes. Some inefficiencies that LEAN Construction focuses on minimizing include waiting times due to (i) shortages of equipment, tools, or materials; (ii) incomplete or poorly performed activities; (iii) lack of clear instructions; (iv) accumulation of material and labor inventory; and (v) tasks that do not add value to the project.

The Last Planner System is a collaborative tool of LEAN Construction that involves field managers in planning each phase of work. It considers the best available alternatives and manages constraints to anticipate conflicts between teams and avoid time losses.

The results of applying LEAN Construction include lower costs, higher quality, reduced delivery times, and a lower environmental impact due to reduced construction times, efficient use of resources, and less waste.

2.6.2. Advanced Work Packaging

Advanced Work Packaging (AWP) is a project management approach for construction that optimizes the planning and execution of specific tasks throughout the project's lifecycle. Defined by the Construction Industry Institute (CII, 2021), AWP organizes the process into work packages for construction, engineering, and installation, from initial planning through detailed design and execution. This method provides a productive and progressive construction framework and ensures a construction execution plan.

The benefits of AWP include a 25% increase in productivity, a 10% reduction in construction times, and an improvement in safety during the process. While AWP does not directly focus on sustainability, its implementation can contribute to sustainable construction through increased efficiency and reduced execution times.

2.6.3. Design & Build

Design & Build is a contractual method aimed at optimizing execution and improving the quality of construction projects by integrating the design and construction phases under a single responsibility. Unlike the traditional model of separate

contracts, in the Design & Build method, a firm assumes the design development and construction execution as a complete package. This allows the different roles in the process (main contractor, designer, and builder) to collaborate from the design phase, proposing technical, economic, and schedule solutions to meet the client's needs. Changes are managed by this integrated team, fostering collaboration and innovation in project execution. This method contrasts with the conventional approach, where design is separate from construction, making it challenging to integrate construction experience in the early phases and reducing the contractor's ability to assume responsibility for deficiencies in the project.

Design & Build offers comparative advantages, such as greater efficiency and speed of delivery, more precise distribution of responsibilities, better risk management, cost and budget control, higher quality and customer satisfaction, and reduction of conflicts and claims due to early and continuous collaboration among the involved parties. These advantages are directly linked to the contractual model used and the collaboration it promotes among the parties.

Opportunities for improvement in construction management include not only the design and execution phases but also operations, such as monitoring infrastructure and performing corrective, preventive, and predictive maintenance supported by advanced digital technologies. This also allows for proactive and efficient management of design, logistics, and assembly in construction, which reduces waste, rework, and overtime, while also reducing the demand for energy and resources and potentially lowering emissions.

Properly managing construction and demolition waste (C&D waste) and promoting recycling and material reuse can reduce environmental impact during construction and at the end of the infrastructure's useful life (decommissioning). Currently, landfills are the primary method for disposing of these wastes, which causes environmental impacts such as the consumption of land space and resources, landfill depletion, and contamination of air, water, and noise (Akanbi et al., 2018, cited by Chen et al., 2021).

2.7. INTERRELATION OF SOLUTIONS FOR SUSTAINABLE CONSTRUCTION

Six categories of solutions that enable sustainable construction have been presented, and it has been observed that they can be interconnected to enhance their ability to reduce negative environmental impacts in general. Digitalization, in its broadest sense, is identified as the fundamental platform that will allow these solutions to be integrated more efficiently and effectively, contributing to the sector's transformation toward more sustainable construction. Figure 2 presents some examples and a diagram of the relationships between different types of solutions.

- ◆ Bioconstruction combines the sustainable design approach with the use of eco-friendly materials that have a low environmental impact. Bioclimatic design criteria linked to BIM models and measurement and validation processes facilitate the verification of energy efficiency standards and the acquisition of certifications.

- ◆ Wood engineering products—such as Mass Timber and Laminated Timber (CLT or GLULAM), among others—combine sustainable materials and industrialized construction. The use of BIM is key in the production process, as it facilitates the communication of information between design teams, suppliers, and manufacturing lines.
- ◆ Industrialized construction and BIM enable control over the manufacturing, construction, and assembly processes, simplify iteration, and provide flexibility during the design process of construction solutions. In addition, they can provide guides or codes for a quick, easy, and error-free assembly process.
- ◆ Applying efficient management methods, such as LEAN Construction, together with the incorporation of AI and machine learning, will enable the design of predictive systems and early warning alerts for delays and deviations from the schedule. This will reduce execution times and lower the projects' carbon footprint. Integrating LEAN Construction methodologies and BIM enhances their benefits to improve management and shorten project timelines while reducing environmental impact (see information box 3).

Figure 2. Examples of Interrelationships Between Types of Solutions for Sustainable Construction



Source: Final consultancy report from the IDB, *Mapping of Digital Tools and Innovative Construction Methods for a Sustainable Construction Sector* (Baptista, 2024).

- ◆ The use of BIM models, digital data capture (drones and scanners), and AI-based analysis enables behavior analysis and progress verification. This contributes to predictive maintenance planning and improving project or asset performance and lifespan.
- ◆ The BIM methodology for lifecycle analysis allows for the quick and efficient calculation of embedded energy and measuring construction's carbon footprint.
- ◆ The combination of digital parametric models and circularity criteria allows for estimating the potential reduction of project impacts. It links the carbon footprint with the use of sustainable materials, thus facilitating the efficient management of construction waste.
- ◆ Integrating Material Passports (or similar initiatives) with technologies such as BIM and AI, alongside efficient management methods like LEAN Construction, will facilitate the implementation of near-real-time waste management systems. This will optimize the segregation and recycling of construction waste and address one of the industry's main challenges: inefficient material segregation and limited waste storage capacity. This innovation will improve sustainability practices and promote a circular economy within the sector.

As noted in the introduction, within the framework of this Technical Note, the concept of sustainable construction also incorporates the dimensions of climate adaptation and resilience. In this regard, the different identified categories contribute to improving infrastructure performance in the face of the effects of climate change and natural disasters. Some of them, in particular, enable access to better information for defining and evaluating adaptation criteria. This is especially important in Latin America and the Caribbean (LAC), as the effects of climate change are triggering an increase in the frequency and intensity of extreme weather events, which exacerbate other high-impact events such as floods, landslides, wildfires, and avalanches (Fischel et al., 2023). Some examples and a diagram are presented in Figure 3 below.

- ◆ The analysis of parametric models and performance simulation facilitates designs that feature structures capable of withstanding and mitigating damage associated with extreme events (floods, storms, hurricanes, or earthquakes) while ensuring the long-term safety and sustainability of the infrastructure, that is, strengthening its climate resilience.

- ◆ Some construction materials have physical, mechanical, thermal, and/or environmental properties, making them naturally resilient to climate change. Examples include fire-resistant solid wood (Mass Timber), insulation such as treated cellulose, which has thermal and fire-resistant properties, and low-carbon permeable concrete, which allows water drainage in pavements during heavy storms, runoff, and floods.
- ◆ Construction systems that use structural joints and anchors to improve the ability to transfer lifting forces caused by hurricane winds from the roof through the building structure to the foundation (Bailey et al., 2021).
- ◆ Parametric digital models (BIM) and AI to assess risks related to infrastructure location and urban development in the context of climate change.

- ◆ Parametric digital models (BIM) that allow (i) the simulation and planning of infrastructure management against climate emergency risks and/or natural disasters and (ii) the simulation and evaluation of scenarios to plan disaster management and post-emergency recovery.
- ◆ Testing and certification of adaptive capacity to climate change, including assessing compliance with existing international construction codes and technical standards to address threats that, according to projections, will be exacerbated by climate change, such as wind, hurricanes, and floods.

Figure 3. Examples of Interrelation between Types of Solutions for Sustainable Construction, Climate Resilience, and Natural Disaster Response

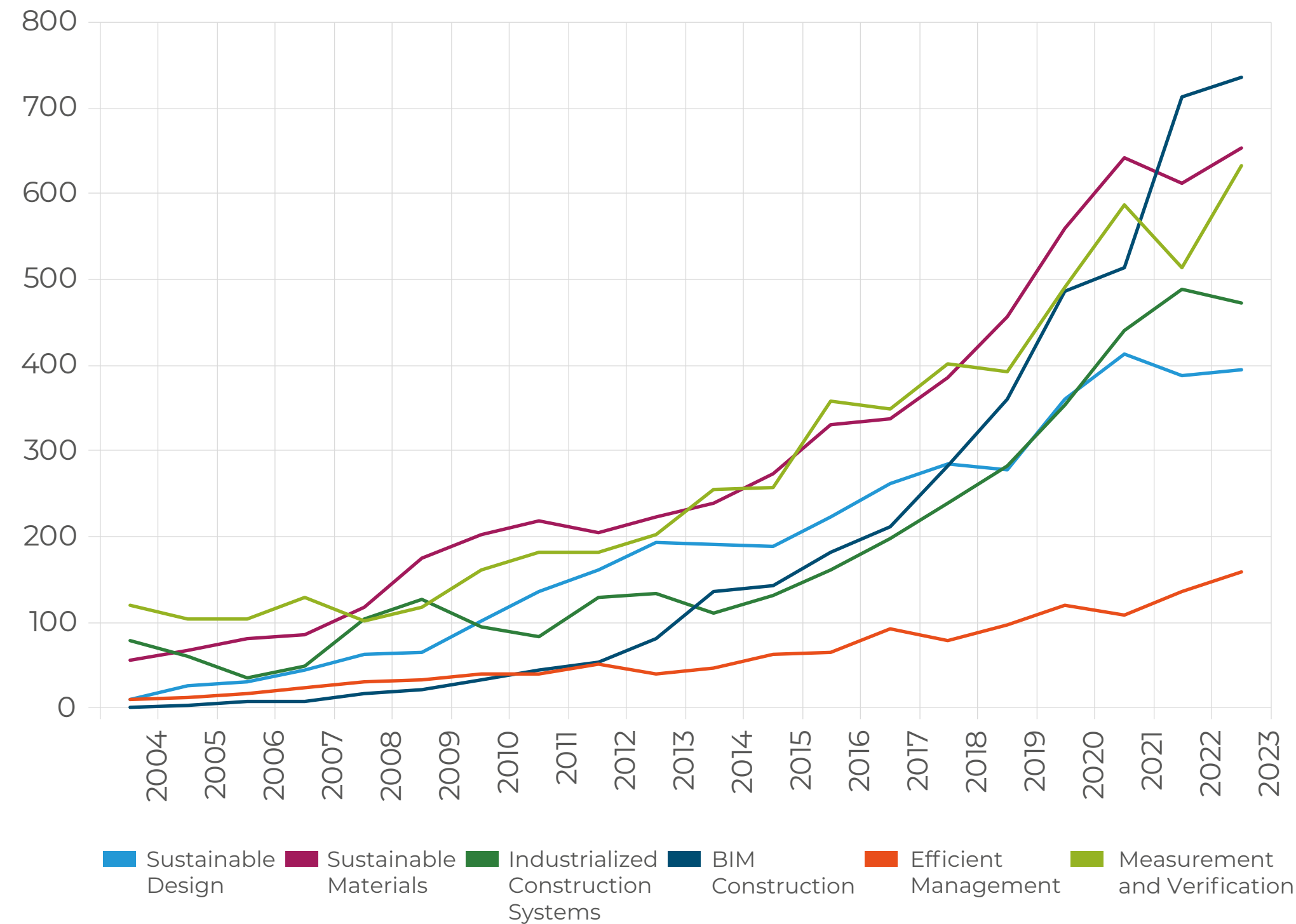


Source: Final consultancy report by the IDB, *Mapping of digital tools and innovative construction methods for a sustainable construction sector* (Baptista, 2024).

2.8. KNOWLEDGE GENERATION ON TYPES OF SOLUTIONS

In the past twenty years, there has been strong and sustained growth in global scientific-technological production related to the categories presented, with average annual growth rates ranging from 9% to 37% between 2004 and 2023. The highest annual production is recorded for the categories of advanced digital technologies (BIM, with an average of 37%), sustainable construction materials, environmental impact measurement and verification of construction projects, and industrialized construction systems, in this order, as shown in Figure 4. In Latin America and the Caribbean (see Figures A5.3 and A5.4 in Annex V), between 2005 and 2022, the production of articles on these topics had an average annual growth rate of 23%. However, it only represents 3.6% of the annual production. Annex V analyses scientific-technological production associated with sustainable construction topics in general.

Figure 4. Scientific-Technical Publications in Scopus by Type of Solution for Sustainable Construction (2004-2023)



Source: Scopus (Portal Timbó, ANII), consulted in March 2024.

3

EXPERIENCES, CHALLENGES, AND OPPORTUNITIES FOR SUSTAINABLE CONSTRUCTION IN LATIN AMERICA AND THE CARIBBEAN

This study conducted a qualitative analysis through semi-structured interviews with relevant actors from governmental, business, academic, or professional organizations in four Latin American and Caribbean (LAC) countries: Brazil, Chile, Costa Rica, and Uruguay. The objective of the survey was to gather perceptions, approaches, and evidence on initiatives, obstacles, and challenges, the factors that promote, and the best practices for the implementation of digitalization and innovative solutions for sustainable construction in the region. Table 1 summarizes the organizations that participated in the survey, classified by type of institution and country.

Box 1. Distribution of Surveyed Organizations by Type and Country

Country	Type of Organization		
	Government	Business	Academy/Professional
Brazil	Secretariat of Cities (SC)		Federal University of Santa Catarina (UFSC) Brazilian Council for Sustainable Construction (CBCS)
Chile	Ministry of Public Works (MOP) <i>Construye2025</i>	Chilean Chamber of Construction (CChC) Council for Industrialized Construction (CCI)	Technology Center for Innovation in Construction (CTeC)
Costa Rica	Ministry of Environment and Energy (MINAE)		National Learning Institute (INA) Federated College of Engineers and Architects (CFIA) International University of the Americas (UIA)
Uruguay	Ministry of Housing and Territorial Planning National Development Corporation (CND)	Chamber of Construction of Uruguay (CCU)	ORT University
Regional	Latin American Governments BIM Network (BIM Gob Latam)	Inconet - Inter-American Construction Industry Federation (FIIC)	Latin American Network of Structural Timber (RELAMAD)

Source: Own elaboration based on the list of interviewees (Annex I).

The following sections present the main results of the interviews conducted, organized according to the different aspects addressed in the survey: i) initiatives; ii) type of solutions promoted; iii) obstacles and challenges; iv) promoting factors; and v) identification of best practices.

3.1. INITIATIVES THAT CONTRIBUTE TO SUSTAINABLE CONSTRUCTION

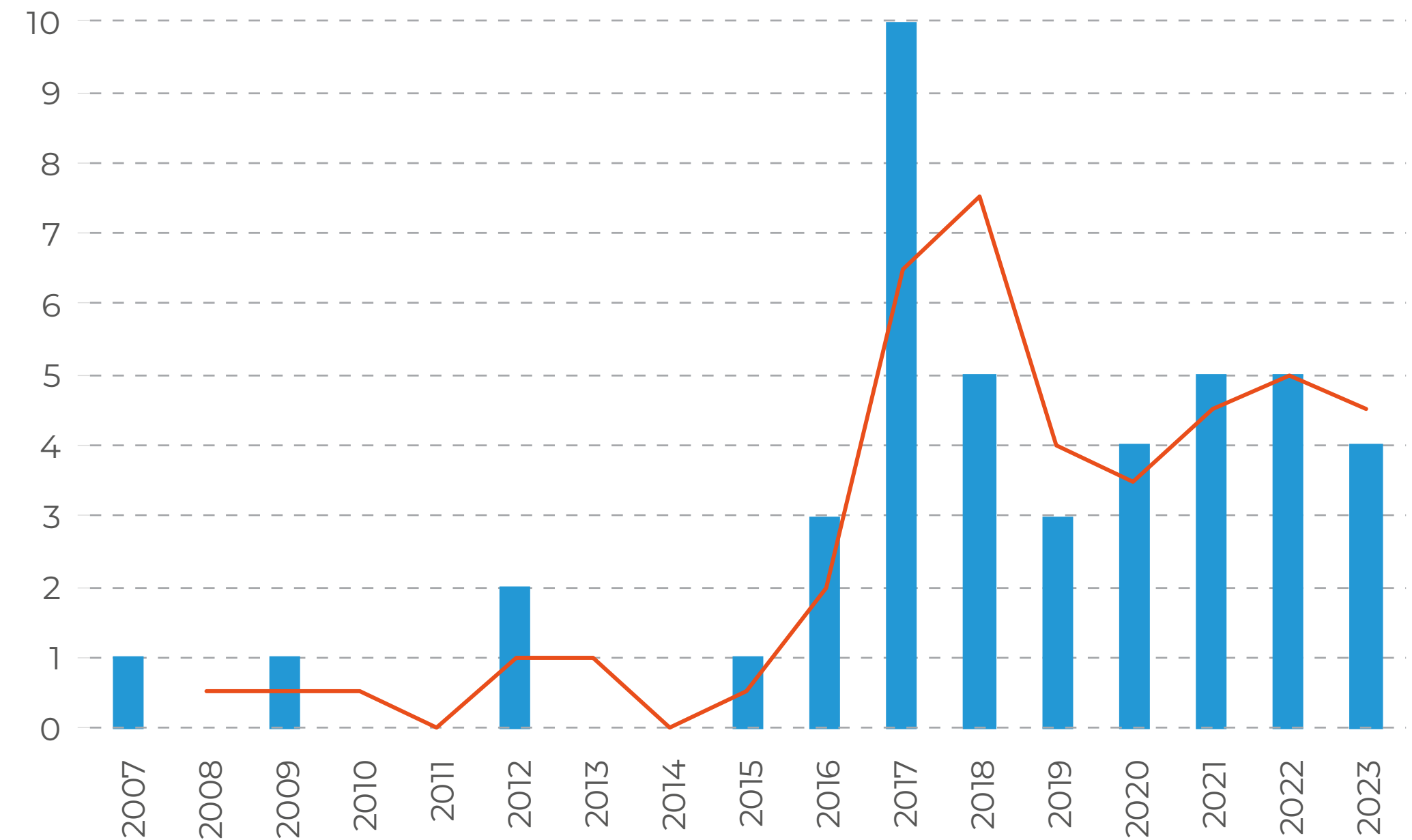
This section synthesizes information on the main initiatives and/or practices that contribute to developing a sustainable construction sector in Brazil, Chile, Costa Rica, and Uruguay, as identified from the interviews. It also analyzes how these initiatives have directly involved organizations from different institutional sectors.

From the interviews, it was possible to identify at least 44 initiatives in the analyzed countries that contribute directly or indirectly to developing a sustainable construction sector. It is important to mention that the survey was not exhaustive and aimed at approximating the practices related to the topic. With this consideration, Figure 5 presents the development of the initiatives over time.

Since 2015, sustained efforts have emerged to promote sustainable construction in the analyzed countries. This period coincides with the signing of the Paris Agreement of the United Nations Framework Convention on Climate Change, which sets targets for the decarbonization of the global economy and climate resilience by 2050 and generates a global sense of urgency about environmental sustainability and the climate crisis. The development of the initiatives, as shown in Figure 5, reflects the emergence and positioning of sustainable construction as a new policy area at the national or institutional level in the analyzed countries. However, this process presents specific particularities in each country.

In Annex III, "Initiatives Identified by Country," Tables A3.1, A3.2, A3.3, and A3.4 present the initiatives identified from the interviews in the four countries. The tables contain synthetic information about the organizations involved in these initiatives and the organization's institutional sector (governmental, business, or academic/professional) that took on the leadership role.

Figure 5. Number of Initiatives Contributing to Sustainable Construction



Source: Own elaboration based on interviews (2023-24).

3.1.1. Summary of Identified Initiatives

The qualitative survey identified at least 44 initiatives to develop a sustainable construction sector, of which the governmental sector leads two-thirds. The temporal evolution of these initiatives gained momentum in 2015, with a notable rise in 2017. They then established a somewhat

homogeneous trend between 2018 and 2023, reflecting a growing interest in and positioning of sustainability in national and institutional policies.

There is considerable heterogeneity among the countries regarding inter-institutional articulation strategies at two levels: i) among governmental sector organizations

and ii) among government, business, and academic or professional sector organizations. In Chile, greater public-public coordination is observed, favored by an early cooperation mechanism and a deliberate strategy to involve the business and academic or professional sectors. Many government initiatives in Brazil and Costa Rica have strong support from academic and professional organizations. In Uruguay, the business sector, mainly the Chamber of Construction of Uruguay (CCU), frequently engages in public initiatives, but participation from the academic or professional sector is more limited to specific projects.

At a general level, some convergences between the countries were identified:

1. All countries have promoted sustainable construction focused on housing for low-income populations.
2. The construction chambers of the four countries have incorporated sustainability into their work agenda⁴⁰, covering environmental, economic-financial, and, in some cases, social dimensions.

40 The institutionalization of specific work streams related to the environmental sustainability of construction is also evident in institutions within the governmental, academic, and professional sectors of several analyzed countries.

3. The business sector has led initiatives to incorporate advanced digital technologies, especially the BIM methodology, with efforts for public-private articulation at national and regional levels.

3.2. TYPES OF SOLUTIONS PROMOTED

This section analyzes the connection of initiatives aimed at sustainable construction in Brazil, Chile, Costa Rica, and Uruguay with the six categories of solutions presented in section 2 of this document.

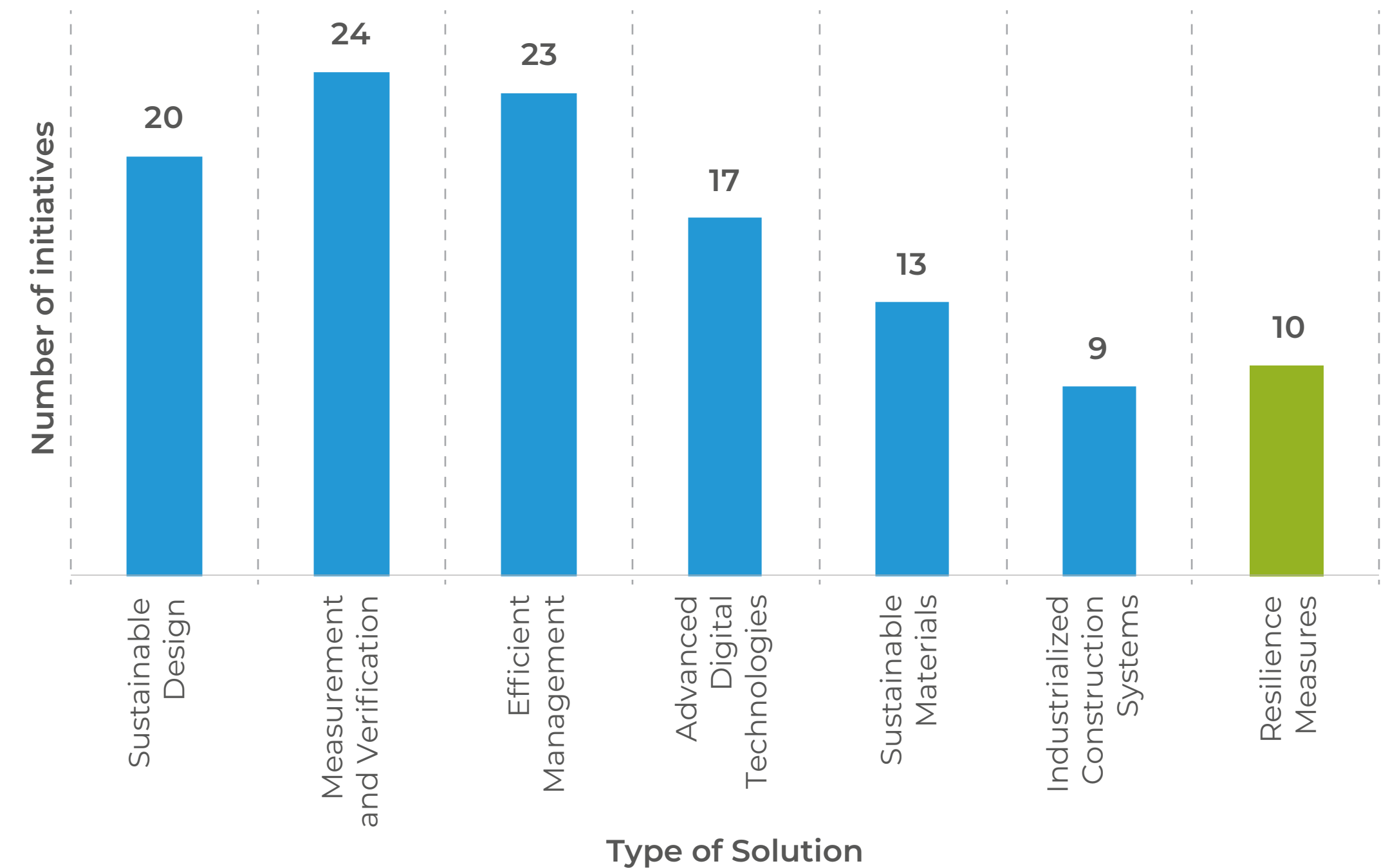
Figure 6 classifies the 44 identified initiatives according to the type of solution they promote. More than half of these initiatives relate to measuring and verifying construction sustainability and efficient management approaches. Next, those that encourage sustainable design strategies are identified. However, the number of people who promote adopting industrialized construction systems and using sustainable materials is notably lower.

This last result is significant because leading countries in sustainable construction, such as the United Kingdom or Singapore, are focusing their efforts precisely on solutions linked to industrialized construction and the incorporation of advanced digital technologies as enablers throughout the asset life cycle. It should also be noted that

the relationship between initiatives can increase results, and one of the most impactful is that of advanced digital technologies, as they enable more efficient and standardized processes. This suggests significant opportunities to advance in these areas in the region's countries.

Annex IV, "Types of Solutions Promoted by Country," analyzes the types of solutions promoted in initiatives that contribute to sustainable construction, identified from a qualitative survey at the country level.

Figure 6. Initiatives Identified by Type of Solution



Source: Own elaboration based on interviews conducted (2023-24).
 Note: see section 2 for more information on each type of solution.

3.2.1. Integrated Analysis

The analysis reveals limited integration of different solutions in the initiatives promoting sustainable construction in the countries considered. 34% of these initiatives focus on a single type of solution, while approximately one-third (32%) cover two different solution categories. The remaining 34% address three or more solutions, and only four (9%) encompass all solutions. This lack of integration suggests opportunities for improvement in the design of policies to promote sustainable construction in the region (for more detail, see Tables A4.1, A4.2, A4.3, and A4.4 in Annex IV).

When analyzing how different types of solutions are combined in these initiatives, Table 2 shows a significant association between promoting sustainable architectural design, measuring and verifying its sustainability, and using efficient management approaches. Initiatives that encourage using sustainable materials often integrate with these measures and approaches. Those that promote industrialized construction systems tend to cover all the proposed solution categories.

Box 2. Interrelationship Between Different Types of Solutions and the Initiatives Identified in Brazil, Chile, Costa Rica, and Uruguay

Solution Type		Sustainable Design	Measurement and Verification	Efficient Management Approaches	Advanced Digital Technologies	Sustainable Materials	Industrialized Construction Systems	Resilience
Sustainable Design	N	20	12	10	6	10	7	9
	%	100%	60%	50%	30%	50%	35%	45%
Measurement and Verification	N	12	24	17	7	11	5	4
	%	50%	100%	71%	29%	46%	21%	17%
Efficient Management Approaches	N	10	17	23	9	10	6	5
	%	43%	74%	100%	39%	43%	26%	22%
Advanced Digital Technologies	N	6	7	9	17	5	6	2
	%	35%	41%	53%	100%	29%	35%	12%
Sustainable Materials	N	10	11	10	5	13	6	4
	%	77%	85%	77%	38%	100%	46%	31%
Industrialized Construction Systems	N	7	5	6	6	6	9	1
	%	78%	56%	67%	67%	67%	100%	11%
Resilience	N	9	4	5	2	4	1	10
	%	90%	40%	50%	20%	40%	10%	100%

Source: Own elaboration based on interviews conducted (2023-24). Note: N=44.

However, initiatives to encourage the use of advanced digital technologies in con-

struction are poorly integrated with other solutions for sustainable construction.⁴¹

⁴¹ In fact, with a few specific exceptions, advanced digital technologies are not spontaneously perceived by the interviewees as a tool that can contribute to sustainable construction.

In the interviews, some stakeholders expressed institutional interest in advancing certain areas related to sustainable and climate-resilient construction. In Uruguay, they pointed out an interest linked to measuring the carbon footprint and industrialized construction. Costa Rica mentioned a commitment to continue developing the Ecological Blue Flag for Sustainable Construction Initiative (BAECS) and eventually share this tool with other countries in the region, especially Central America.

3.3. OBSTACLES AND CHALLENGES

In the context of the qualitative survey, respondents were asked to indicate what they considered the main challenges associated with implementing initiatives to promote sustainable-focused construction in their respective countries, as well as the factors that hindered the implementation of these initiatives. The most frequently mentioned challenges are related to (i) the existence of information and knowledge gaps, (ii) institutional weaknesses in the governmental sector, and (iii) the perception of incompatibility between environmental and economic sustainability. The analysis of these challenges is elaborated further below.

3.3.1. Information and Knowledge Gaps

Key stakeholders from the four analyzed countries highlighted significant cognitive gaps that hinder the promotion of sustainable construction development in the region. These knowledge and information gaps affect various key agents in the construction process and value chain, including industry workers, technical teams, decision-makers in the business and government sectors, and civil society as potential purchasers of sustainable infrastructure.

Interviewees from all countries and institutional sectors emphasized the need to incorporate topics of environmental sustainability, infrastructure resilience, and available solutions into the training plans for sector professionals such as architects, engineers, builders, designers, and project managers. Some stakeholders suggest that sustainable construction in the region can only advance if these subjects are fully integrated into universities, not just as a specialization but as mandatory content in professional training. Although there have been training and professional technical updating programs on sustainable construction in recent years, the offering remains limited and does not constitute a central part of professional training.

Additionally, several interviewees highlighted the need for more in-depth training on specific topics, such as the asset life cycle approach. Currently, there is a focus on the resources and energy consumed during operation. Still, it is less common to consider the embedded energy in construction materials throughout the entire life cycle, up to their dismantling and final disposal. This approach also poses challenges in terms of training in carbon footprint measurement and in the management of information systems that span from production and transport to the potential recycling or reuse of construction materials.

Another specific training requirement that spontaneously emerged during the interviews is using the BIM methodology. Interviewees agreed on the need for more comprehensive university training on BIM, which teaches modeling and 3D visualization and delves into construction project management and its use during the design, construction, operation, and maintenance phases of buildings.

Besides professional training, some stakeholders highlighted the importance of providing training to all sector workers (technicians, operators, and subcontractors) in sustainable construction and different solutions. Workforce preparation

throughout the value chain is especially critical when working with unconventional solutions and materials, industrialized construction systems, BIM, or efficient management approaches.

Another significant challenge is closing information gaps between different agents in the construction sector and society, in general, to create greater environmental awareness and dismantle myths that inhibit progress in this area. For example, in Uruguay, the widespread belief that wooden houses have low quality is an obstacle to developing construction with this component. The general public and industry professionals also misunderstand the advantages of wood as a construction material.

Generating greater environmental awareness is key for society to demand sustainable buildings and infrastructure, which would contribute to increasing the supply of such constructions in the region.

Finally, the importance of creating communities of practice at the national, regional, and international levels to exchange knowledge, information, and experiences about sustainable construction, climate change adaptation, and different available solutions was emphasized as a key action to close information and knowledge gaps.

3.3.2. Institutional Weaknesses at the Governmental Sector Level

Promoting environmentally sustainable construction requires strong leadership and management capabilities from the governmental sector. This includes (i) the ability to mobilize and coordinate efforts among various actors, assume strategic roles in public-public, public-private, and international articulation; (ii) generate enabling conditions for the development of sustainable construction (such as capacity development, regulations, operational tools, infrastructure, material and process certifications, and streamlining procedures and permits), and (iii) stimulate the demand for sustainable construction through public purchasing and innovative public procurement.

Most interviewees pointed out institutional weaknesses at the governmental level that present significant challenges for successfully promoting environmentally sustainable construction in their respective countries. These weaknesses affect the sustainability of currently implemented policies. The observations come from business, academic, professional, and governmental representatives.

Several interviewees highlighted that state organizations often strongly depend on the personal and/or professional profile of some public servants to drive initiatives for construction with a sustainable focus and adopt solutions. This represents a considerable weakness, especially with the turnover of individuals in the technical teams of these organizations, which is exacerbated by changes in authorities.

Additionally, some stakeholders noted that public interventions aimed at promoting sustainable construction often depend on political cycles. This creates a constant risk of discontinuity or inconsistency in implementing initiatives, thus reducing their effectiveness.

Other interviewees opined that the measures and resources allocated by the government to promote sustainable construction do not seem to be part of a planned and monitored strategy that allows for meeting national commitments to decarbonize the economy. At least six interviewees mentioned that, to advance in this line, the State should move from indicative strategies to binding strategies and develop adequate capacities for their oversight. This view is less common among business sector stakeholders.

3.3.3. Perception of Discrepancy Between Environmental and Economic Sustainability

The opinions collected suggest that businesses and governmental organizations face a learning curve when first engaging in sustainable construction projects. This learning curve and the necessary investments to adopt this new business model generate higher initial costs for the various actors.

Most interviewees agreed that these initial costs are offset in the medium and long term by gains in terms of productivity, efficiency, and associated savings, even without considering the social benefits. For public or private agents to decide to undertake such projects, they must be evaluated from a medium and long-term economic perspective, and the returns and associated externalities must be adequately accounted for. In addition, they must have the necessary financing to make the initial investments. This logic also applies to the end consumer, who might pay more for a building with energy efficiency criteria, although savings during operation compensate for the initial investment.

The interviews revealed specific cases, both in the business and governmental sectors, where a short-term view hinders the development of sustainable construction projects. At least four interviewees expressed that building sustainably is perceived as more costly, highlighting an apparent incompatibility between environmental and economic sustainability.

Therefore, one of the identified challenges is promoting a long-term vision among public and private agents when assessing the cost-benefit relationship of sustainable construction. Additionally, it is crucial to facilitate access to financing on favorable terms so that the necessary initial investments can be made in these types of projects.

3.3.4. Other Challenges and Obstacles

Although less frequently, interviewees mentioned other challenges and obstacles to advancing construction development with a sustainable approach in their respective countries.

Among these challenges, the following stand out:

- ◆ **Recognition and visibility of success stories:** Develop strategies that allow visibility for both public and private projects that incorporate best practices in sustainable construction.
- ◆ **Limited demand:** In the countries analyzed, the final demand for environmentally sustainable infrastructure is still very limited or in its early stages.

Among the obstacles mentioned, the following are included:

- ◆ **Informality in the construction sector:** Informal work in the construction sector creates unfair competition that allows for significantly lower costs than formal activity. This misinforms the final consumer about the characteristics and environmental sustainability of the final product and the construction process.
- ◆ **Resistance to change:** There is resistance to change both in the conservative business sector and within the state. Many interviewees believe that without the state's promotion, obligation, and oversight of the development of sustainable practices, agents are less likely to step out of their comfort zones and voluntarily adopt sustainable construction.

3.4. FACTORS PROMOTING SUSTAINABLE CONSTRUCTION

As part of the survey, stakeholders were also asked about the factors that facilitate or favor implementing actions to promote sustainable construction. Below are the factors identified at a general level and those specific to each analyzed country.

3.4.1. General Factors

- ◆ **COVID-19 Pandemic:** The construction industry's halt during the pandemic demonstrated the relevance of accelerating the sector's digitization and increasing the use of prefabricated components. Digitization allows projects to continue in a virtual environment during the planning and design stages. At the same time, prefabricated components require fewer on-site personnel, which is advantageous in contexts of physical distancing.
- ◆ **Climate Change:** The growing evidence of climate change in the region has raised socio-environmental awareness and favored implementing measures to promote sustainable construction.
- ◆ **Climate Commitments:** Each country's climate commitments and the need to meet nationally determined contribu-

tions (NDCs) have driven state-led initiatives to promote sustainable construction.

- ◆ **International Support:** The availability of technical and financial support from international organizations, such as the Inter-American Development Bank (IDB) and the German Technical Cooperation (GIZ), facilitates the development of sustainable construction initiatives.
- ◆ **Technical Cooperation Among Countries:** Technical cooperation among countries is seen as a significant support element. It involves identifying best practices and lessons learned. Examples of this type of collaboration include Japan, Canada, Finland, Singapore, England, and Chile.
- ◆ **New Generations:** Newer generations are more aware of environmental care, which could facilitate progress toward sustainable construction in the future.

3.4.2. Country-Specific Factors

- ◆ **Brazil:** The country's significant housing deficit (UN-Habitat, 2015) and the state's purchasing power for social housing construction are important opportunities to promote sustainable construction. Technical support from the academic sector is also a favorable factor.

- ◆ **Chile:** The Construye2025 program of the Corporation for the Promotion of Production (CORFO) and the support for the creation of technological centers have been fundamental in promoting the productivity and sustainability of the sector. Chile also has a national production of high-quality wood for sustainable construction.

- ◆ **Costa Rica:** The high sensitivity of citizens towards environmental issues and the emerging demand for sustainable housing, especially among high-income families in coastal areas, are significant factors.

- ◆ **Uruguay:** The national production of wood suitable for construction and the reputational value of construction companies specialized in sustainability facilitate access to international markets. The emerging demand for sustainable buildings, associated with multinational companies and foreigners with high purchasing power, is also a relevant factor.

These factors and challenges reflect the complexity and opportunities associated with the development of sustainable construction in the region and highlight the need to implement integrated and collaborative strategies to overcome obstacles and leverage the identified scenarios.

3.5. IDENTIFICATION OF BEST PRACTICES

The qualitative analysis conducted in this study allowed for the detection of best practices related to promoting sustainable construction in the region. Some of the practices implemented in the analyzed countries include:

i. International Benchmarking and Knowledge Transfer:

- **Strategies:** Develop international benchmarking strategies and knowledge transfer mechanisms from leading institutions and countries.
- **Technical Cooperation:** Establish technical cooperation among countries and create communities of practice at national and international levels focused on sustainable construction.

These actions, based on previous experiences from other organizations or countries, help to close information and knowledge gaps and accelerate institutional processes.

ii. Capacity Building and Empowerment of Technical Teams:

- **Training:** Train the technical teams responsible for driving and responding to sustainable construction initiatives.
- **Empowerment:** Integrate new specialized professional profiles to empower these teams.

This enhances the teams' understanding and alignment with the objectives. It also accelerates the adoption and application of criteria and solutions for sustainable construction in institutional processes and improves the market response to the needs of sustainable construction.

iii. Inter-institutional Coordination Mechanisms:

- **Public-Public Domain:** Formalize inter-institutional coordination mechanisms through agreements or joint strategies, define roles and responsibilities, and establish the allocation of specific resources.
- **Public-Private Domain:** Actively involve the business, academic, and professional sectors in government initiatives to achieve greater commitment and effectiveness in implementing these actions.

Ensuring the sustainability and coordination of the ecosystem will facilitate inter-institutional coordination, promote the development of medium—and long-term policies, and implement national sustainable construction strategies that are less susceptible to changes in political guidelines between governments.

iv. Innovation Promotion:

- **Promotion:** Engage national organizations that promote new productivity and competitiveness initiatives to foster digitalization and innovation as enablers for sustainable construction.
- **Academic Sector:** It also positively impacts the creation of research and technological development lines and the adaptation of training programs related to digitalization and innovation as enablers for sustainable construction.

This enables the development of technological capabilities that facilitate progress, support sustainable and efficient initiatives, and encourage collaboration on specific projects.

These best practices contribute significantly to developing the sustainable construction sector and promote a collabo-

orative approach based on digitalization, innovation, and knowledge transfer.

The survey also identified effective government strategies to encourage sustainable construction, which were highlighted as best practices by the respondents. These strategies include:

i. Public Procurement and Innovative Public Procurement:⁴²

Use public procurement as a driver for the demand for sustainable construction, including innovative public procurement to address technological challenges, generate demonstrative prototypes, and promote green public procurement (Salazar Cota, Fernández, and Dalaison, 2018).

ii. Financial Incentives: Link the attainment of sustainability certifications with monetary benefits, such as access to bank credit lines with preferential interest rates.

iii. Non-Financial Incentives: Offer additional benefits to certified sustainable construction projects, such as increasing allowable square footage, building height, or density.

⁴² The Inter-American Development Bank (IDB) has developed a tool to promote and implement innovative public procurement. See <https://innovationprocurementcom-pass.com/>.

iv. Technological Centers: Encourage the creation of technological centers that facilitate innovation in sustainable construction and provide infrastructure, prototype development services, pilot validation, and specialized consultancy. This is particularly relevant in regions where the local production of technological knowledge in this field is limited.⁴³

A reflection arising from the analysis of the best practices identified in the interviews is that to foster the implementation of more effective interventions promoting sustainable-focused construction in the countries of the region, the governmental sector must, with a long-term perspective, assume a leadership role at the national level in this emerging policy area and promote the coordination of the ecosystem for collaboration.

Finally, although the present study focused on the environmental dimension of sustainability, the analysis revealed a strong interrelationship between this dimension and the other three defined by the IDB (2019): economic-financial, institutional, and social. Specifically, these latter three dimensions can either constrain or enable

the development of environmentally sustainable construction. At the same time, environmental sustainability, in turn, can facilitate or hinder progress in the other dimensions of infrastructure sustainability.

⁴³ See Table A3.2 in Annex III, "Initiatives Identified by Country," and Table A4.2 in Annex IV, "Types of Solutions Promoted."

4

KEYS TO THE FUTURE FOR TRANSFORMING THE SECTOR

This research identifies relevant aspects to drive the future development of actions focused on promoting and increasing digitalization, innovative construction systems, and materials. These actions will transform the construction sector in the region and enhance the opportunities for sustainable construction in LAC. It is key to address the limitations and barriers identified through the interviews to achieve this and reach the expected benefits.

In this regard, long-term public leadership is essential to promote the transformation of the sustainable construction industry in LAC. This leadership must be capable of navigating political cycles, articulating and communicating the urgency of digital transformation, and promoting the adoption of innovative construction systems and materials as key enablers of sustainable construction, decarbonization, and

climate resilience. This leadership must establish a comprehensive strategic vision acknowledging the region's environmental and economic challenges and driving a transition toward more sustainable and resilient practices.

Effective communication of the strategy, action plan, and broad dissemination are fundamental to raising awareness and securing the necessary support to build strong commitment among the public, private, and academic sectors. Developing a binding, clear, and consensual strategy, along with a flexible action plan with achievable short- and medium-term objectives and goals, is crucial.

Both the strategy and its action plan must create the conditions and address the identified limitations. In this regard, four areas must be tackled in parallel: (i) managing knowledge, skills, and competencies

within the value chain; (ii) driving supply through demand and implementing public procurement instruments; (iii) updating regulations and generating incentives; and (iv) measuring and communicating the performance and progress of initiatives.

To achieve this, it is essential to enhance the skills, competencies, and tools of those responsible for public procurement to integrate sustainability and digitalization criteria into contracts. Likewise, it is vital to strengthen the capacities and competencies of companies, the workforce, and operators to reinforce supply. Collaboration with the academic sector is also necessary to update technical and professional training programs and provide continuous education for the sector throughout the value chain. Promoting cooperation and knowledge exchange by establishing collaborative work frameworks, communities

of practice, and disseminating success stories that spread knowledge, debunk myths, and facilitate the implementation of digitalization and innovative solutions is key to transforming the sector toward sustainable construction.

Additionally, strategically using public procurement as a fundamental lever to accelerate digital transformation and adopt construction systems, innovative materials, and sustainable practices in the construction sector is crucial. This involves employing public procurement, particularly innovative and green public procurement, as a driver to pull and accelerate large-scale adoption by the industry.

Promoting the updating of regulations and certifications to reflect international best practices and encouraging the development of subsidies and other financial and non-financial incentive mechanisms is essential to motivate companies to adopt these practices, offering benefits such as tax incentives and access to preferential financing.

The success of these initiatives must be monitored through robust measurement mechanisms to evaluate progress in implementing new practices and their actual impact on reducing the carbon footprint, increasing climate resilience, and other key

sustainability indicators. Results should be disseminated to ensure long-term commitment and that adopted policies and strategies effectively contribute to more sustainable and resilient construction in the region.

Driving digitalization will optimize and integrate processes throughout the entire construction cycle. It will also improve transparency, efficiency, and productivity in the sector, facilitating the implementation of efficient and sustainable construction methods. This must be a priority to ensure that new practices are widely adopted. This way, the sector will transform into a sustainable, resilient, and competitive construction industry capable of addressing the region's environmental, social, and economic challenges.

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ANNEX I.

LIST OF INTERVIEWEES

Box A1.1. List of Interviewees

#	Name	Organization	Position	Country	Interview Date
1	Clarice Degani	Brazilian Council for Sustainable Construction (CBCS)	Executive Director	Brazil	12/20/2023
2	Amanda Olalquiaga	Secretariat of Cities	General Coordinator for Strategic Affairs	Brazil	12/12/2023
3	Roberto Lamberts	Federal University of Santa Catarina, Department of Civil Engineering	Full Professor	Brazil	12/13/2023
4	Marcos Brito	Construye2025	Manager	Chile	12/13/2023
5	Conrad Von Igel	Chilean Chamber of Construction (CChC)	Innovation and Sustainability Manager	Chile	12/18/2023
6	Tatiana Martínez	Council for Industrialized Construction	President	Chile	12/13/2023
7	Katherine Martínez/ Marisol Cortez	Chilean Chamber of Construction / President of the Environmental Commission of the CChC	Secretary/ Executive	Chile	12/11/2023
8	Carolina Briones	Technological Center for Innovation in Construction	Executive Director	Chile	12/27/2023
9	Daniel Bifani	Ministry of Public Works, General Directorate of Public Works	Head of the Sustainable Infrastructure Division	Chile	12/19/2023
10	Silvia Campos Zárate	National Learning Institute (INA), National Node for Materials	Researcher	Costa Rica	12/13/2023
11	Guillermo Carazo	Federated College of Engineers and Architects (CFIA)	CFIA Executive Director/ President of the Sustainable Construction Forum	Costa Rica	12/14/2023
12	Rodrigo Martínez	Inter-American Development Bank	Director of the Innovation School	Costa Rica	12/08/2023
13	Daniel Viquez/Olman Mora	Ministry of Environment and Energy (MINAE)	Director of Adaptation, Climate Risk, and Environmental Management/ Coordinator of the Sectoral Decarbonization Policy	Costa Rica	01/10/2024
14	Marcia Croci	Ministry of Transport and Territorial Planning (MOT)	Advisor	Uruguay	12/14/2023
15	Florencia Seré	Chamber of Construction of Uruguay, Sustainable Construction Forum	President	Uruguay	12/12/2023
16	Andrés Eliseo Cabrera	ORT University	Professor	Uruguay	12/12/2023
17	Rafael Laureiro	National Corporation for Development (CND)	Executive Director	Uruguay	12/08/2023
18	Sebastian Orrego	Intendancy – FIIC	Executive	Regional	12/18/2023
19	Pablo Guidos	Latin American Network for Structural Modeling (RELAMAD)	Coordinator	Regional	01/04/2023
20	Andrea Paladin	Latin American BIM Governmental Network (BIM Gob Latam)	Network Coordinator	Regional	12/02/2023

ANNEX II.

INTERVIEW GUIDELINES

Below are the interview guides used during the primary data collection process with key representatives from public institutions, the private sector, as well as academia and professional associations, as part of the Inter-American Development Bank (IDB) consultancy titled “*Mapping of Digital Tools and Other Innovative Construction Methods for a Greener Construction Sector.*”

I. General Introduction

Present the objective of the study and of the interviews in particular.

- ◆ The interviews aim to gather perceptions, approaches, and evidence from qualified interviewees regarding practices, interests, requirements, available solutions, lessons learned, and challenges associated with implementing innovative digital and construction methodologies and solutions for the sustainable construction sector. The ultimate goal of the study is to generate inputs that will help define the IDB’s position on this topic.

- ◆ Include open-ended questions on key topics of interest. Estimated duration: maximum 30 minutes.
- ◆ Clarify that responses are provided in a personal capacity (not as an official institutional position).
- ◆ Request permission to record the interview.

II. Interview Guidelines for Representatives of Public Institutions

1. To begin, could you please describe the main activities carried out by the department or area of the institution where you work? *(This question aims to understand the interviewee’s role and provide context for the interview.)*
2. As you are likely aware, there is extensive evidence indicating that the construction sector is highly polluting. Based on the information and knowledge available to you, could you name some methodologies, materials, and/or technological or construction solutions currently available that could help reduce the sector’s environmental impact? *(This question*

assesses the interviewee’s familiarity with the topic and explores their understanding of sustainable construction practices.)

3. Has your institution implemented any initiatives aimed at promoting a more sustainable and/or climate-resilient construction sector? If so, please specify.
4. What are the primary motivations for implementing sustainability measures in the country’s construction sector? *(If not mentioned spontaneously, follow up by asking, for example, whether their area is aligned with a national plan.)*
5. Has your organization developed any strategy to build or strengthen institutional and/or system-level competencies on these topics, whether through training or awareness-raising? If so, please specify which ones and indicate whether they involved collaboration with other stakeholders.

6. What do you consider to be the main challenges—past or present—associated with implementing the actions mentioned above? *(If multiple challenges are identified, follow up on each one separately.)*
7. Do you believe there have been any factors that have hindered the implementation of these actions? If yes, could you list and explain them? *(Only if multiple obstacles are mentioned: If you had to prioritize them, which one would you consider the most significant during the process?)*
8. On the other hand, do you believe there have been any factors that facilitated or supported the implementation of these actions? If so, please specify and explain.
9. In your opinion, and based on the information available to you, have the actions implemented had any effects to date—whether positive or negative? Please specify and explain.
10. What would you highlight as the key lessons learned and overall learning processes from these experiences?
11. Are you aware of any institutional interest in advancing—or continuing to advance—workstreams to promote sustainable construction in the country? If yes: please specify the areas of interest. *(If not mentioned spontaneously, probe specifically about interest in: i) BIM adoption; ii) timber construction; and iii) developing methodologies and/or capacities for measuring the carbon footprint in construction.)*
12. *(Only if not previously addressed:)* Are you aware of any other organizations in the country—public or private—undertaking initiatives to advance a more sustainable construction sector? Have any efforts been coordinated with these entities? If yes, please provide specific examples.
13. What do you consider to be the main future challenges to advancing a more sustainable and resilient construction sector in the country?
14. *(Only if not addressed earlier:)* In your view, what are the main institutional and system-wide competency needs to support the growth of more sustainable construction?

15. Would you like to share any other reflections or suggestions that could contribute to the objectives of this study?

(Before concluding, the interviewer will ask whether the interviewee is aware of any documents containing information on greenhouse gas (GHG) emissions from the construction sector in the country.)

Thank you very much
for your collaboration!

End of interview

III. Interview Guidelines for Private Sector Representatives

The formulation of questions is tailored depending on whether the interviewee belongs to a business chamber or a company with experience in one of the practices of interest.

A. For Business Chambers

1. To start, could you describe how many members the organization has, what types of companies it brings together, and what its main activities are? *(This question is intended to understand the interviewee's institutional context and provide background for the interview.)*
2. As you are likely aware, there is extensive evidence indicating that the construction sector is highly polluting. Based on the information and knowledge available to you, could you name some methodologies, materials, and/or technological or construction solutions currently available that could help reduce the sector's environmental impact? *(This question assesses the interviewee's familiarity with the topic and explores their understanding of sustainable construction practices.)*

3. Based on your knowledge, how widespread are these practices in the country? And specifically, among your organization's members? *(Focus on each of the practices mentioned by the interviewee in their previous response. If possible, ask to provide examples).*
4. To what extent are these initiatives driven by market demand? Where does the demand mainly come from? How do you perceive the balance between supply and demand in sustainable construction?
5. Has your organization taken any actions to promote a more sustainable and/or climate-resilient construction sector? If so, please specify. Did these actions involve collaboration with other stakeholders?
6. *(Only if the answer to the previous question is yes:)* What are the main motivations for implementing sustainability measures in the construction sector?
7. *(If not previously addressed:)* Are you aware of any public initiatives or national plans aimed at advancing sustainable construction in the country?
8. Has your organization developed any strategies to build or strengthen institutional or member-level competencies on these topics—for example, through training or awareness-raising? If yes, please specify and indicate whether these efforts involved collaboration with other stakeholders.
9. Do you perceive any obstacles or limitations to advancing sustainable construction in the country? If so, please specify them. Who do you think could take action to address them?
10. On the other hand, are there any factors that could facilitate or support progress toward a more sustainable construction sector? If so, please specify which ones and why.
11. Based on your knowledge of specific cases where sustainable construction practices were applied (please specify which ones), are there any key lessons learned from these experiences?
12. Beyond environmental benefits, do you see any business advantages for companies participating in sustainable construction projects? If yes, please specify which ones. *(If not mentioned spontaneously, probe about economic and reputational benefits.)*
13. Is your organization interested in advancing or continuing to advance workstreams aimed at promoting sustainable construction? If yes, please specify which areas. *(If not mentioned spontaneously, probe about interest in: i) BIM adoption; ii) timber construction; and iii) developing methodologies and/or capacities to measure the carbon footprint in construction.)*
14. What do you consider to be the main future challenges for developing a more sustainable and climate-resilient construction sector in the country?
15. *(Only if not mentioned previously:)* What do you consider to be the main requirements for developing competencies—at both the institutional and sector levels—to promote the expansion of sustainable and resilient construction?
16. Would you like to share any additional reflections or suggestions that you believe could contribute to the objectives of this study?

(Before concluding, the interviewer will ask whether the interviewee is aware of any documents containing information on greenhouse gas (GHG) emissions from the construction sector in the country.)

Thank you very much
for your collaboration!

End of interview

B. For Companies

1. To start, could you describe the company's core activities, target market, and number of employees? *(This question aims to understand the interviewee's position and provide context for the interview.)*
2. As you are likely aware, there is extensive evidence indicating that the construction sector is highly polluting. Based on the information and knowledge available to you, could you name some methodologies, materials, and/or technological or construction solutions currently available that could help reduce the sector's environmental impact? *(This question assesses the interviewee's familiarity with the topic and explores their understanding of sustainable construction practices.)*

3. Has your company developed or participated in construction projects that incorporate a sustainable and/or resilient approach? If yes, please specify.
4. To what extent are these initiatives driven by market demand? Where does the demand mainly come from? How do you perceive the balance between supply and demand in sustainable construction?
5. Has your company developed any strategies to build or strengthen institutional and/or system-level competencies on these topics, whether through training or awareness-raising? If so, please specify which one and indicate whether they involved collaboration with other stakeholders.
6. What do you consider to be the main challenges—past or present—associated with implementing the actions mentioned above? *(If multiple challenges are identified, follow up on each one separately.)*
7. Do you believe there have been any factors that have hindered the implementation of these actions? If yes, could you list and explain them? *(Only if multiple obstacles are mentioned: If you had to prioritize them, which one would you consider the most significant during the process?)*
8. On the other hand, do you believe there have been any factors that facilitated or supported the implementation of these actions? If so, please specify and explain.
9. In your opinion, and based on the information available to you, have the actions implemented had any effects to date—whether positive or negative? Please specify and explain.
10. What would you highlight as the key lessons learned and overall learning processes from these experiences?
11. Beyond environmental benefits, do you see any business advantages for companies participating in sustainable construction projects?
12. Is your company interested in advancing or continuing to advance workstreams aimed at promoting sustainable construction? If yes, please specify which areas. *(If not mentioned spontaneously, probe about interest in: i) BIM adoption; ii) timber construction; and iii) developing methodologies and/or capacities to measure the carbon footprint in construction across the asset's life cycle and certifying green buildings.)*
13. *(If not previously addressed:)* Are you aware of any public initiatives

or national plans aimed at advancing sustainable construction in the country?

14. What do you consider to be the main future challenges for developing a more sustainable and climate-resilient construction sector in the country?
15. *(Only if not mentioned previously:)* What do you consider to be the main requirements for developing competencies—at both the institutional and sector levels—to promote the expansion of sustainable and resilient construction?
16. Would you like to share any additional reflections or suggestions that you believe could contribute to the objectives of this study?

Thank you very much
for your collaboration!

End of interview

IV. Interview Guidelines for Representatives from the Academic Sector or Professional Associations

The formulation of the questions is tailored according to the type of interviewee.

A. For the Academic Sector

1. To start, could you describe the type of academic offering, both educational and research-related, provided by the institution in relation to the construction sector? *(This question aims to understand the interviewee's institutional role and provide context for the interview.)*
2. As you are likely aware, there is extensive evidence indicating that the construction sector is highly polluting. Based on the information and knowledge available to you, could you name some methodologies, materials, and/or technological or construction solutions currently available that could help reduce the sector's environmental impact? *(This question assesses the interviewee's familiarity with the topic and explores their understanding of sustainable construction practices.)*

3. Does the institution offer educational programs—including degree courses within study plans or continuing education activities—that are aimed at or contribute to the development of a more sustainable and/or resilient construction sector? Please specify. *(If not explicitly mentioned, follow up specifically on training in BIM use, timber construction, and methodology for measuring carbon footprint across the construction life cycle.)*
4. *(Only if the answer to the previous question is yes:)* Since when have these programs been offered, and approximately how many participants are trained annually?
5. *(Only if applicable:)* What strategies has your institution implemented to develop or strengthen its own competencies in sustainable and resilient construction, whether through training or awareness-raising? If yes, please specify and indicate whether these efforts included collaboration with other stakeholders.
6. Does your institution conduct specific research on sustainable construction? *(If not mentioned spontaneously, probe about studies related to climate resilience, sustainable materials, sustainable design, innovative construction systems, digitalization, and environmental impact measurement/verification.)*
7. *(If not previously addressed:)* Are you aware of any public initiatives or national plans aimed at advancing sustainable construction in the country?
8. Do you perceive any obstacles or limitations to advancing sustainable construction in the country? If so, please specify them. Who do you think could take action to address them?
9. On the other hand, are there any factors that could facilitate or support progress toward a more sustainable construction sector? If so, please specify which ones and why.
10. Is your organization interested in advancing or continuing to advance workstreams aimed at promoting sustainable construction? If yes, please specify which areas. *(If not mentioned spontaneously, probe about interest in: i) BIM adoption; ii) timber construction; and iii) developing methodologies and/or capacities to measure the carbon footprint in construction.)*

11. What do you consider to be the main future challenges for developing a more sustainable and climate-resilient construction sector in the country?
12. *(Only if not mentioned previously:)* What do you consider to be the main requirements for developing competencies—at the level of construction professionals—to promote the expansion of sustainable and resilient construction?
13. Would you like to share any additional reflections or suggestions that you believe could contribute to the objectives of this study?

(Before concluding, the interviewer will ask whether the interviewee is aware of any documents containing information on greenhouse gas (GHG) emissions from the construction sector in the country.)

Thank you very much
for your collaboration!

End of interview

B. For Professional Associations

1. To begin, could you please describe the number of members in your organization, the types of professionals it represents, and its main activities? *(This question aims to understand the interviewee's position and provide context for the interview.)*
2. As you are likely aware, there is extensive evidence indicating that the construction sector is highly polluting. Based on the information and knowledge available to you, could you name some methodologies, materials, and/or technological or construction solutions currently available that could help reduce the sector's environmental impact? *(This question assesses the interviewee's familiarity with the topic and explores their understanding of sustainable construction practices.)*
3. Based on your knowledge, how widespread are these practices in the country? And specifically, among your organization's members? *(Focus on each of the practices mentioned by the interviewee in their previous response.)* If possible, please provide examples.

4. To what extent are these initiatives driven by market demand? Where does the demand mainly come from? How do you perceive the balance between supply and demand in sustainable construction?
5. To what extent do you believe professionals in the sector possess the training and skills required to develop construction activities with a sustainable and resilient approach?
6. Has your organization taken any actions to promote a more sustainable and/or climate-resilient construction sector? If so, please specify. Did these actions include collaboration with other stakeholders?
7. *(If not previously addressed:)* Are you aware of any public initiatives or national plans aimed at advancing sustainable construction in the country?
8. Do you perceive any obstacles or limitations to advancing sustainable construction in the country? If so, please specify them. Who do you think could take action to address them?
9. On the other hand, are there any factors that could facilitate or support progress toward a more sustainable construction sector? If so, please specify which ones and why.
10. Based on your knowledge of specific cases where sustainable construction practices were applied (please specify which ones), are there any key lessons learned from these experiences?
11. Is your organization interested in advancing or continuing to advance workstreams aimed at promoting sustainable construction? If yes, please specify which areas. *(If not mentioned spontaneously, probe about interest in: i) BIM adoption; ii) timber construction; and iii) developing methodologies and/or capacities to measure the carbon footprint in construction.)*
12. What do you consider to be the main future challenges for developing a more sustainable and climate-resilient construction sector in the country?
13. *(Only if not mentioned previously:)* What do you consider to be the main requirements for developing competencies—at both the institutional and sector levels—to promote the expansion of sustainable and resilient construction?
14. Would you like to share any additional reflections or suggestions that you believe could contribute to the objectives of this study?

(Before concluding, the interviewer will ask whether the interviewee is aware of any documents containing information on greenhouse gas (GHG) emissions from the construction sector in the country.)

Thank you very much
for your collaboration!

End of interview

ANNEX III.

INITIATIVES IDENTIFIED BY COUNTRY

I. Brazil

The interviews revealed at least nine initiatives in Brazil aimed at advancing sustainable construction. The first one, launched in 2007, was the establishment of the Brazilian Council for Sustainable Construction (*Conselho Brasileiro de Construção Sustentável*, CBCS), a national technical organization that has supported several government initiatives. These include the Operational Energy Performance Platform for Buildings (*Plataforma Desempenho energético operacional em edificações*, DEO) and the Efficient Cities Project (*Projeto Cidades Eficientes*), both launched in 2018, as well as the Environmental Performance Information System for Construction (*Sistema de Informação do Desempenho Ambiental da Construção*, SIDAC) created in 2022.

From the public sector, two major lines of intervention have been identified:

- 1. Indirect Promotion Through Public Procurement:** Initiatives led by the State Secretariat for Cities (Secretaria das Cidades, SC) with strong sup-

port from academic institutions. It is important to note that Brazil has one of the highest housing deficits in Latin America. One of its flagship social housing programs is *Minha Casa, Minha Vida* (2009), launched with the goal of building 2 million homes within four years. Another one is *ProMorar Brasil* (2023), developed in collaboration with the IDB, which focuses on sustainable and climate-resilient housing retrofitting for low-income populations.

- 2. Projeto Construa Brasil:** Promoted by the Ministry of Development, Industry, Commerce and Services (*Ministério do Desenvolvimento, Indústria, Comércio e Serviços*, MDIC) and the Santa Catarina Innovation Network (*Rede Catarinense de Inovação*, RECEPETi), this 2022 initiative seeks to modernize the construction industry through: (i) the harmonization of building codes and improvements in the construction permitting process; (ii) the

widespread adoption of BIM; and (iii) the promotion of industrialized construction methods. The program enhances the environmental sustainability of the construction industry by supporting innovation and optimizing operational processes.

From the private sector, the Brazilian Chamber of the Construction Industry (*Câmara Brasileira da Indústria da Construção*, CBIC) launched a project in 2017 to map sustainability-related actions and practices that show positive financial returns. This initiative highlights the importance of linking environmental and financial sustainability.

The BIM Forum Brazil, active since 2017, promotes the broad adoption of BIM across the construction industry, involving businesses, government, and academic entities. Additionally, academic groups in Brazil are engaged in research and training related to sustainable construction and climate resilience.

Table A3.1. Brazil: Initiatives That Contribute to Sustainable Construction

Initiative	Start Year	Main Organizations Involved	Institutional Sector		
			Public	Private	Academic/Professional
Brazilian Council for Sustainable Construction (CBCS)	2007	Academic sector, companies and business associations, government representatives, professionals			
<i>Minha Casa Minha Vida</i> housing program	2009	Secretaria das Cidades (State Secretariat for Cities), Caixa, supported by academic institutions			
BIM Forum Brasil	2017	Business, governmental, academic, and professional organizations			
Mapping of Business Opportunities in Sustainability	2017	Brazilian Chamber of the Construction Industry (CBIC)			
<i>Projeto Cidades Eficientes</i>	2018	Brazilian Council for Sustainable Construction (CBCS), municipalities			
Operational Energy Performance Platform for Buildings (DEO)	2018	CBCS, Eletrobras, among others			
Environmental Performance Information System for Construction (SIDAC)	2022	Ministry of Mines and Energy (MME), CBCS, Ministry of Integration and Regional Development (MIDR), Energy Research Office, Eletrobras, Procel, GIZ, business associations, among others			
<i>Projeto Construa Brasil</i>	2022	Ministry of Development, Industry, Commerce and Services (MDIC), Santa Catarina Innovation Network (RECEPETi)			
<i>ProMorar Brasil</i> housing program	2023	MCid, supported by academic institutions, financial support from IDB			

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

Note: The darkest blue indicates the leading institutional sector for each initiative (public, private, or academic/professional).

II. Chile

In Chile, at least 18 initiatives have been identified to promote sustainable construction. As shown in Table A3.2, the public sector stands out for its leadership, structured around two main pillars:

Inter-ministerial Initiatives: Following the 2012 Inter-ministerial Agreement for Sustainable Construction—initially signed by the Ministry of Housing and Urban Development (*Ministerio de Vivienda y Urbanismo*, MINVU), Ministry of Public Works (*Ministerio de Obras Públicas*, MOP), and Ministry of the Environment (*Ministerio del Medio Ambiente*, MMA), with later participation from other ministries—Chile has developed several key initiatives: i) National Sustainable Construction Strategy (2013); ii) National Sustainable Construction Plan 2050; iii) Climate Change Plan for Infrastructure and Public Buildings (2017); iv) Roadmap for the National Strategy on Carbon Footprint in Construction (2018); v) Sustainable Construction Standards (2018); vi) Roadmap for Construction and Demolition Waste and Circular Economy in Construction (2020); vii) Green Building Certification (2014) and Sustainable Housing Certification (2020); viii) Innovation competitions, including Industrialized Housing (2022).

CORFO Initiatives: Production Development Corporation (*Corporación de Fomento de la Producción*, CORFO) has played a key role, particularly through its strategic program *Construye2025* (launched in 2016). This program has promoted: i) Plan-BIM (2016); ii) Council for Industrialized Construction (2017); iii) Roadmap for Construction and Demolition Waste and Circular Economy in the Construction Sector (2018); iv) Public design competitions for carbon-neutral housing prototypes (2023).

CORFO also spearheaded the creation of two technology centers in 2017: the Interdisciplinary Center for Productivity and Sustainable Construction (*Centro Interdisciplinario de Productividad y Construcción Sustentable*, CIPYCS) and the Technological Center for Innovation in Construction (*Centro Tecnológico para la Innovación en Productividad y Sustentabilidad en la Construcción*, CTEC). Both centers offer services including prototyping, technology monitoring, BIM and Lean Construction consulting, and training courses. In 2023, CTEC developed the *Pasaporte de Materiales* platform, a tool for recording and validating sustainability information for construction materials.

The Chilean private sector has played an active role, particularly in waste management and BIM promotion. Notable initiatives include the Clean Production Agreements and BIM Forum Chile. Additionally, the Chilean Chamber of Construction (*Cámara Chilena de la Construcción*, CChC) promoted the PRO Commitment and Label, which focuses on a sustainable business management model that incorporates economic, social, and environmental aspects.

Finally, the academic sector in Chile is also engaged in education and research related to sustainable and climate-resilient construction, thereby complementing public and private sector efforts.

Table A3.2. Chile: Initiatives that Contribute to Sustainable Construction

Initiative	Start Year	Main Organizations Involved	Institutional Sector		
			Public	Private	Academic/Professional
National Sustainable Construction Strategy	2012	Ministry of Housing and Urban Development (MINVU), Ministry of Public Works (MOP), Ministry of the Environment (MMA), Ministries of Economy, Development and Tourism; Ministry of Social Development and Family			
BIM Forum Chile	2015	Technological Development Corporation (CDT) of the Chilean Chamber of Construction (CChC), business, governmental, academic and professional organizations			
<i>Construye2025</i>	2016	Production Development Agency (CORFO), CChC, MOP, Construction Institute (IC), universities			
PlanBIM	2016	CORFO, supported by public, private, and academic institutions			
Council for Industrialized Construction (CCI)	2017	<i>Construye2025</i> , Technology Center for Innovation in Construction (CTeC), CChC			
Technological Centers for Innovation in Construction (CTeC)	2017	CORFO (funder), companies, academia (executors)			
Development and updating of regulations	2017	<i>Construye2025</i> , National Institute of Standardization, IC, MINVU			
Model Building Code for Latin America and the Caribbean	2017	IC (Coordinator), MINVU, ACHISINA, AICE, SOCHIGE, organizations from 16 LAC countries			
Sustainable Construction Standards	2018	MINVU, other public entities, business sector, academic sector			
Roadmap for the National Carbon Footprint Strategy in Construction	2018	MINVU and related ministries, IC, CChC, CTeC, private universities, among others			
Clean Production Agreements	2020	CChC, CORFO, MOP, Sustainability and Climate Change Agency (ASCC), regional governments, among others			
Roadmap for Construction and Demolition Waste and Circular Economy in the Construction Sector	2020	<i>Construye2025</i> , MINVU, MOP, MMA, IC, CChC			
PRO Commitment and Label	2021	CChC			
Net Zero Challenge (<i>Desafío Net Zero</i>)	2023	<i>Construye2025</i> , CORFO, College of Architects of Chile			
Sustainable Housing and Building Certification	2022	MINVU, IC, University of Chile, Chilean Association of Architecture Firms, College of Architects of Chile			
Material Passport initiative	2023	CTeC, Chile <i>Green Building Council</i>			
Innovation Contest: Industrialized Housing in Chile	2022	CChC, MINVU, CTeC			
Climate Change Plan for Public Infrastructure and Buildings	2017	MOP, supported by IDB			

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

Note: The darkest blue indicates the institutional sector leading the initiative (public, private, or academic/professional).

III. Costa Rica

In Costa Rica, at least eight initiatives have been identified to promote sustainable construction, with the leadership of the Federated College of Engineers and Architects (*Colegio Federado de Ingenieros y Arquitectos*, CFIA). Since 2017, the CFIA has overseen the Ecological Blue Flag certification in Sustainable Construction (*Bandera Azul Ecológica de Construcción Sostenible*, BAECS), which rewards good environmental, economic, and social practices in infrastructure design and construction. This certification has been linked to financial incentives, such as preferential credit lines from the Bank of Costa Rica, and non-financial benefits such as municipal permits allowing up to 30% additional buildable area.

The CFIA also supports government entities in various initiatives, such as the Requirements for Sustainable Buildings in the Tropics (*Requisitos para Edificaciones Sostenibles en el Trópico*, RESET) (2020),⁴⁴ the Climate Risk Assessment Methodology for Infrastructure (*Metodología de Evaluación de Riesgo Climático para la Infraestructura*, MERCI-CR) (2023), and the

Inclusive and Sustainable Urban Housing model (*Modelo de Vivienda Urbana Inclusiva y Sostenible*, VUIS) (2018).

The Ministry of Environment and Energy (*Ministerio de Ambiente y Energía*, MINAE) issued a directive for Sustainable Construction in the Public Sector (2019), promoting sustainable construction practices in public buildings, based on a guideline document prepared by the CFIA. In addition, MINAE, together with the Ministry of Public Works and Transport (*Ministerio de Obras Públicas y Transportes*, MOPT), developed the Climate Risk Assessment Methodology for Infrastructure (*Metodología de Evaluación de Riesgo Climático para la Infraestructura*, MERCI) and the National Urban-Environmental Agenda (*Agenda Nacional Urbano-Ambiental*, ANUA), which includes a focus on decarbonization and sustainable construction.

The Housing Directorate of the Ministry of Housing and Human Settlements (*Ministerio de Vivienda y Asentamientos Humanos*, MIVAH), in coordination with CFIA, the National Institute for Housing and Urban Development (*Instituto Nacional de Vivienda y Urbanismo*, INVU), the Housing Mortgage Bank (*Banco Hipotecario de la Vivienda*, BANHVI), and other organizations, has promoted the VUIS model through a national

competition of pilot proposals to strengthen resilient and sustainable cities.

The Ministry of National Planning and Economic Policy (*Ministerio de Planificación Nacional y Política Económica*, MIDEPLAN), with support from the IDB, developed Costa Rica's National BIM Strategy and its roadmap, as well as the Interinstitutional BIM Commission, which promotes adoption of BIM across the sector.

The private sector has also promoted the BIM methodology through the BIM Forum Costa Rica, coordinated by the Costa Rican Chamber of Construction (*Cámara Costarricense de la Construcción*, CCC) since 2017. In addition, various academic institutions have also begun offering technical and professional training programs in sustainable construction.

⁴⁴ Standard developed in compliance with Level 1 and Level 2 requirements of the Standards Council of Canada (SCC), based on a document prepared by the Institute of Tropical Architecture (Instituto de Arquitectura Tropical, IAT).

Table A3.3. Costa Rica: Initiatives that Contribute to Sustainable Construction

Initiative	Start Year	Main Organizations Involved	Institutional Sector		
			Public	Private	Academic/Professional
BIM Forum Costa Rica	2017	Costa Rican Chamber of Construction (CCC)			
Ecological Blue Flag certification in Sustainable Construction (BAECS)	2017	Federated College of Engineers and Architects of Costa Rica (CFIA)			
Inclusive and Sustainable Urban Housing Model (VUIS)	2018	Ministry of Housing and Human Settlements (MIVAH), CFIA, National Institute for Housing and Urban Development (INVU), Housing Mortgage Bank (BANHVI), other public and private institutions			
Guideline for Sustainable Construction in the Public Sector	2019	Ministry of Environment and Energy (MINAE), CFIA, Ministry of Public Works and Transport (MOPT), National Meteorological Institute (IMN)			
Requirements for Sustainable Buildings in the Tropics (RESET)	2020	CFIA, Costa Rican Institute of Technical Standards (INTECO)			
National BIM Strategy Costa Rica	2020	MIDEPLAN, Inter-institutional Commission for BIM Implementation (CII-BIM)			
National Urban-Environmental Agenda (ANUA)	2021	MIVAH, MINAE			
Climate Risk Assessment Methodology for Infrastructure (MERICI-CR)	2023	MINAE, CFIA, MOPT, IMN			

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

Note: The darkest blue indicates the institutional sector leading the initiative (public, private, or academic/professional).

IV. Uruguay

In Uruguay, eight initiatives that are aimed at sustainable construction –led mainly by public institutions, often in collaboration with the private sector, especially the Chamber of Construction of Uruguay (*Cámara de la Construcción del Uruguay*, CCU)– have been identified.

As shown in Table A3.4, various public institutions have launched initiatives that directly or indirectly promote sustainable construction in Uruguay, especially since 2020. These initiatives frequently involve other public organizations, and the private sector (particularly the CCU) in at least half of the cases.

National Energy Efficiency Plan (2015–2024): Led by the Ministry of Industry, Energy and Mining (*Ministerio de Industrias, Energía y Minería*, MIEM), this plan includes the Building Energy Performance Evaluation System (2016), aimed at improving energy efficiency in buildings.

Ministry of Housing and Territorial Planning (*Ministerio de Vivienda y Ordenamiento Territorial*, MVOT): Since 2021, MVOT has promoted the construction of timber social housing, launching public tenders and developing the Roadmap for Social Housing Construction in Timber (2022), with IDB support.

Table A3.4. Uruguay: Initiatives that Contribute to Sustainable Construction

Initiative	Start Year	Main Organizations Involved	Institutional Sector		
			Public	Private	Academic/Professional
Energy Performance Evaluation System for Buildings	2016	Ministry of Industry, Energy and Mining (MIEM)	Public		
BIM Forum Uruguay	2017	Chamber of Construction of Uruguay (CCU), CND, University of the Republic (UDELAR), ORT University	Public	Private	Academic/Professional
BIM Pilot Project – CAIF Aero-parque	2019	CND, National Institute for Children and Adolescents of Uruguay (INAU)	Public		
Assessment of construction circularity	2020	CCU, National Development Agency (ANDE)	Public	Private	
Manual for Calculating GHG Emissions in Infrastructure Projects	2021	CND, CCU, Ministry of Environment (MA), Green Climate Fund	Public	Private	
Montevideo Departmental Plan for Civil Works Waste Management	2021	Municipality of Montevideo, MA, CCU	Public	Private	
Roadmap for Social Housing Construction in Timber	2022	Ministry of Housing and Territorial Planning (MVOT), supported by IDB, with participation of private and academic sectors	Public	Private	Academic/Professional
Public Competitions for Timber Construction	2021	MVOT, National Housing Agency (ANV), MEVIR	Public		

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

Note: The darkest blue indicates the institutional sector leading the initiative (public, private, or academic/professional).

National Corporation for Development (*Corporación Nacional para el Desarrollo*, CND): In partnership with the Ministry of the Environment (*Ministerio de Ambiente*, MA), the CCU, and the Green Climate Fund, the CND developed the

GHG Emissions Calculation Manual for Infrastructure Projects (*Manual para el Cálculo de Emisiones GEI de Proyectos de Infraestructura*) (2023). It has also played a key role in promoting BIM methodology in public infrastructure projects. Between

2019 and 2021, it managed the Childhood and Family Care Center (*Centro de Atención a la Infancia y la Familia*, CAIF) Aero-parque pilot project, which incorporated BIM in its design and construction phases, and applied Lean Construction methods.

Municipality of Montevideo: Launched the Departmental Plan for the Management of Civil Works Waste (*Plan Departamental de Gestión de Residuos de Obras Civiles*) (2021), in coordination with the MA and the CCU.

Chamber of Construction of Uruguay (CCU): In addition to participating in the above initiatives, the CCU developed an assessment of construction circularity (2020) with support from the National Development Agency (*Agencia Nacional de Desarrollo*, ANDE). The CCU also coordinates the BIM Forum Uruguay, alongside the CND and universities.

Academic Initiatives: Various academic institutions in Uruguay have developed research initiatives and professional training programs on sustainable construction.

In addition to the initiatives described before, the 2019 creation of the Latin American Governments BIM Network (*Red BIM de Gobiernos Latinoamericanos*, BIM Gob Latam) should also be noted, which includes Brazil, Chile, Costa Rica, and Uruguay, along with Argentina, Colombia, Mexico, and Peru. Supported by the IDB, this regional network aims to improve productivity in the construction sector through digital transformation, focusing on coordinating national-level government initiatives and facilitating the exchange of knowledge and best practices related to BIM adoption in the region.

ANNEX IV.

TYPES OF SOLUTIONS PROMOTED BY COUNTRY

I. Brazil

Table A4.1 categorizes sustainable construction initiatives in Brazil by type of solution promoted. The country has developed initiatives that cover all six solution types identified in the study, although some have been promoted more frequently than others.

The most common initiatives in Brazil focus on improving management efficiency, measuring and verifying environmental impacts, applying advanced digital technologies, and integrating sustainability criteria in design. Less common are the initiatives that promote the use of sustainable construction materials and industrialized

construction systems. Only a few initiatives incorporate resilience criteria for disasters and climate change.

The following table also shows that one third of the initiatives identified in Brazil tend to focus on a single type of solution, such as promoting sustainable design or the adoption of BIM.

Table A4.1. Brazil: Initiatives Identified by Type of Solution

Initiative	Type of Solutions						Resilience
	Sustainable Design	Measurement and Verification	Efficient Management	Advanced Digital Technologies	Sustainable Material	Industrialized Construction System	
Brazilian Council for Sustainable Construction (CBCS)							
<i>Minha Casa Minha Vida</i> housing program							
BIM Forum Brazil							
Mapping of Business Opportunities in Sustainability							
<i>Projeto Cidades Eficientes</i>							
Operational Energy Performance Platform for Buildings (DEO)							
Environmental Performance Information System for Construction (SIDAC)							
<i>Projeto Construa Brasil</i>							
<i>ProMorar Brasil</i> housing program							

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

II. Chile

Table A4.2 categorizes sustainable construction initiatives in Chile by type of solution promoted. Similarly to Brazil, Chile has developed initiatives that support all six types of solutions identified in this study.

In Chile, at least half of the initiatives focus on measuring and verifying the environmental sustainability of buildings, implementing efficient management approaches, and applying sustainable architectural design measures. Consistent with the overall findings, initiatives promoting industrialized construction systems and the use of sustainable materials are less common, although at least five different initiatives were identified for each of these solution types.

Notably, the qualitative assessment identified several government-led initiatives in Chile that support all six sustainable construction solution types mapped in this study. Key examples include the *Construye2025* program and the Technological Centers for Innovation in Construction, both launched by the Chilean Economic Development Agency (*Corporación de Fomento de la Producción, CORFO*), each with its own dedicated lines of work.

Table A4.2. Chile: Initiatives Identified by Type of Solution

Initiative	Type of Solutions						Resilience
	Sustainable Design	Measurement and Verification	Efficient Management	Advanced Digital Technologies	Sustainable Material	Industrialized Construction System	
National Sustainable Construction Strategy							
BIM Forum Chile							
<i>Construye2025</i>							
PlanBIM							
Council for Industrialized Construction (CCI)							
Technological Centers for Innovation in Construction (CTeC)							
Development and updating of regulations							
Model Building Code for Latin America and the Caribbean							
Sustainable Construction Standards							
Roadmap for the National Carbon Footprint Strategy in Construction							
Clean Production Agreements							
Roadmap for Construction and Demolition Waste and Circular Economy in the Construction Sector							
PRO Commitment and Label							
Net Zero Challenge (<i>Desafío Net Zero</i>)							
Sustainable Housing and Building Certification							
Material Passport initiative							
Innovation Contest: Industrialized Housing in Chile							
Climate Change Plan for Public Infrastructure and Buildings							

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

III. Costa Rica

Table A4.3 categorizes sustainable construction initiatives in Costa Rica by solution type. While the identified initiatives address all categories of solutions included in the study, there is a notable emphasis on sustainable architectural design measures and resilience to climate change or disasters.

In contrast, only one initiative related to industrialized construction systems was identified, developed within the framework of the Requirements for Sustainable Buildings in the Tropics (RESET) standard. Furthermore, initiatives involving the use of advanced digital technologies in construction appear to be weakly integrated with other efforts that promote sustainable building practices.

Table A4.3. Costa Rica: Initiatives Identified by Type of Solution

Initiative	Type of Solutions						Resilience
	Sustainable Design	Measurement and Verification	Efficient Management	Advanced Digital Technologies	Sustainable Material	Industrialized Construction System	
BIM Forum Costa Rica							
Ecological Blue Flag certification in Sustainable Construction (BAECS)							
Inclusive and Sustainable Urban Housing Model (VUIS)							
Guideline for Sustainable Construction in the Public Sector							
Requirements for Sustainable Buildings in the Tropics (RESET)							
National BIM Strategy Costa Rica							
National Urban-Environmental Agenda (ANUA)							
Climate Risk Assessment Methodology for Infrastructure (MERICI-CR)							

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

IV. Uruguay

Table A4.4 categorizes sustainable construction initiatives in Uruguay by solution type. The findings highlight that the main focus areas (in at least half of the initiatives) are strategies for measuring and verifying the sustainability of buildings, and efficient management approaches across design, construction, or operation stages.

Less frequent solutions include industrialized construction systems, mainly promoted through public competitions for timber-based housing. Notable gaps include the absence of initiatives that incorporate climate resilience or disaster risk criteria in infrastructure; most of the initiatives (6 out of 8) integrate no more than two types of solutions, and none of the initiatives address all six solution types mapped in the study.

Table A4.4. Uruguay: Initiatives Identified by Type of Solution

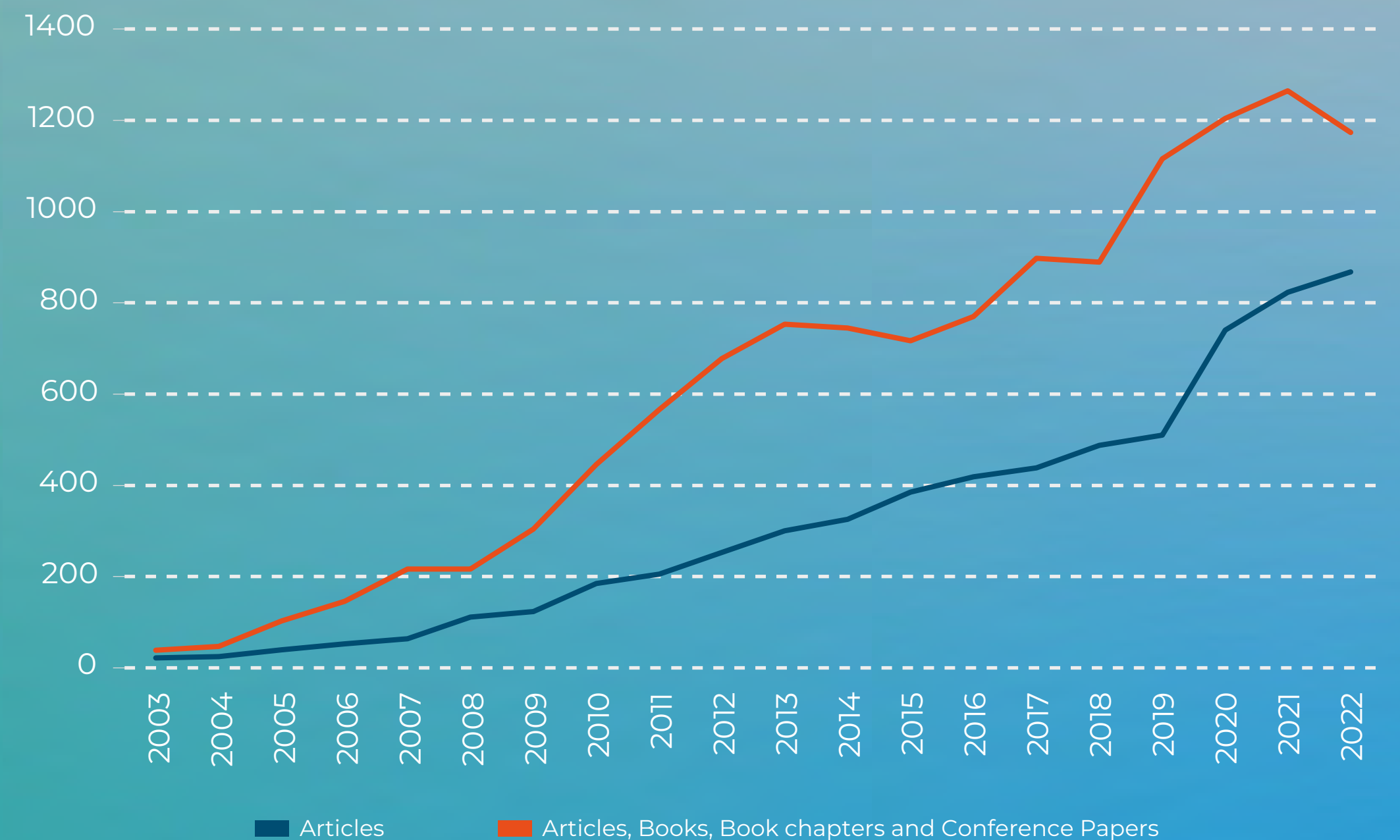
Initiative	Type of Solutions						Resilience
	Sustainable Design	Measurement and Verification	Efficient Management	Advanced Digital Technologies	Sustainable Material	Industrialized Construction System	
Energy Performance Evaluation System for Buildings							
BIM Forum Uruguay							
BIM Pilot Project – CAIF Aeroparque							
Assessment of construction circularity							
Manual for Calculating GHG Emissions in Infrastructure Projects							
Montevideo Departmental Plan for Civil Works Waste Management							
Roadmap for Social Housing Construction in Timber							
Public Competitions for Timber Construction							

Source: Own elaboration, based on interviews conducted between 2023 and 2024.

ANNEX V. GENERATION OF KNOWLEDGE ON SUSTAINABLE CONSTRUCTION

Increasing concern over the environmental impact of construction has been accompanied by strong and sustained growth in global scientific-technological output related to sustainable construction over the past two decades (Graph A5.1). Between 2003 and 2022, both scientific articles and the broader bibliographic production –including articles, books, book chapters, and conference papers– increased at an average annual rate of 20%, according to data from the Scopus repository. Currently, approximately 900 articles and 1,200 scientific-technological documents on sustainable construction are produced worldwide each year.

Graph A5.1. Scientific-Technological Publications on Sustainable Construction Worldwide, Between 2003 and 2022



Source: Scopus (Timbó Portal, ANII), accessed November 2023.

Note: Includes publications containing any of the following keywords: green construction, sustainable construction, eco-friendly construction, environmentally responsible construction, green buildings, environmentally sustainable construction, low-impact building, sustainable building, carbon-neutral construction, zero-emission building, net-zero building, energy-efficient building.

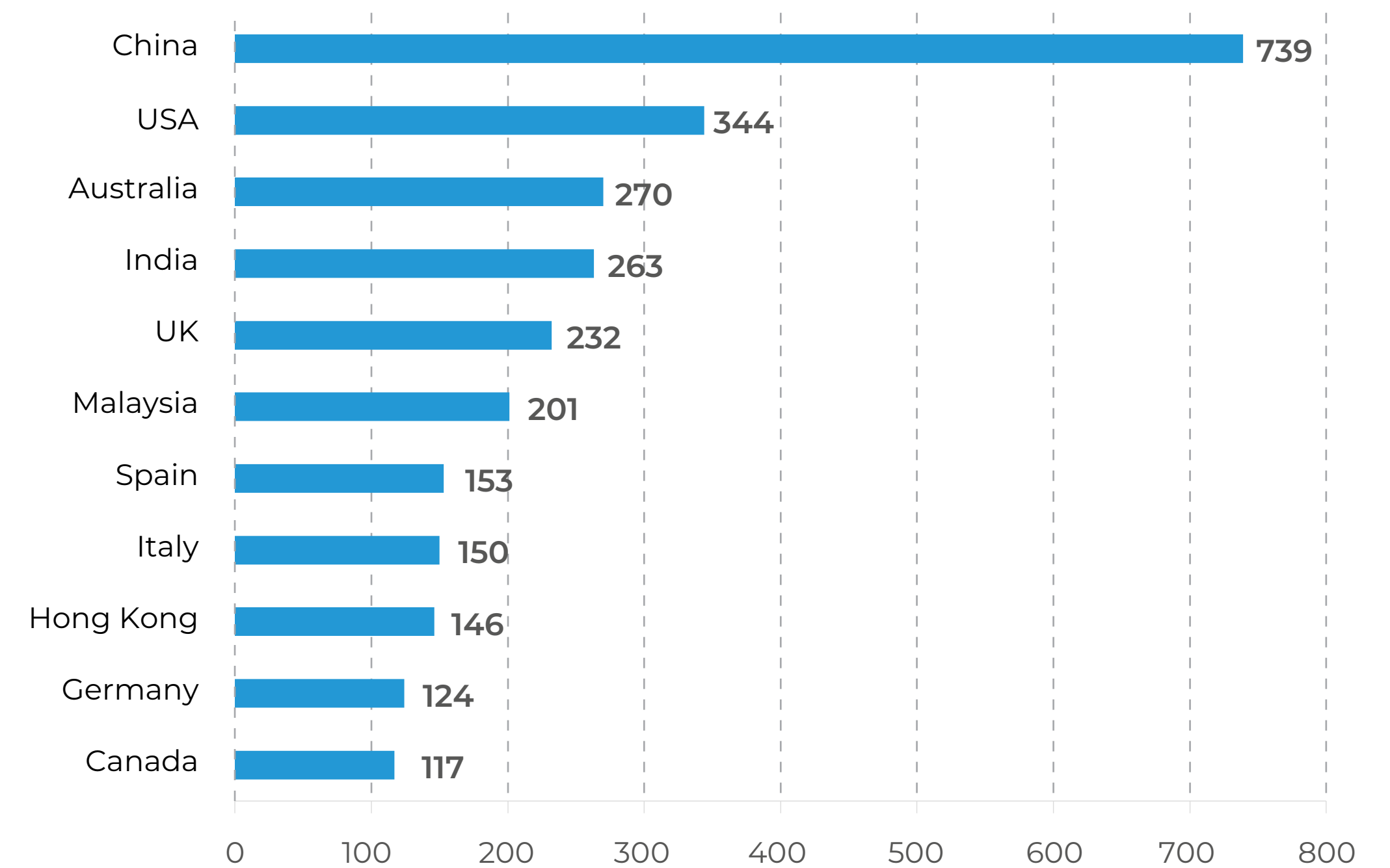
The academic study of sustainable construction spans multiple fields of knowledge, including engineering and architecture (66% of scientific-technological publications), environmental sciences (32%), energy (25%), social sciences (21%), materials science (15%), management and business (12%), and computer science (9%), among others (Scopus publications analysis, 2023).

China leads scientific-technological production on sustainable construction, accounting for more than one-fifth (22%) of all publications on the topic over the past five years (2018–2022) (Graph A5.2). It is followed –albeit with significantly lower output– by the United States, Australia, India, and the United Kingdom, as well as other developed countries in Asia, Europe, and North America. Ranked fifteenth is Egypt, the only country in the top group located outside these regions; Brazil, in the seventeenth place, is the first South American country on the list.

The scientific research and technological development activities that resulted in publications on sustainable construction over the past five years have, in more than half of the cases, been supported by national and/or regional governments. Particularly noteworthy are the number of publications funded by the National Natural Science Foundation of China, China's National Key Research and Development Program, the Australian Research Council, the European Regional Development Fund, the United States National Science Foundation, the European Commission, the National Research Foundation of Korea, Malaysia's Ministry of Higher Education, and the Horizon 2020 Framework Program, among others (Scopus, 2023).

In line with the global trend, Latin America and the Caribbean (LAC) have also experienced growth in scientific-technological production related to the sustainability of the construction industry over the past decades. However, this development began later (starting around 2005) and has

Graph A5.2. Scientific-Technological Publications on Sustainable Construction. Countries with the Highest Global Output. Total Production Between 2017 and 2022



Source: Scopus (Timbó Portal, ANII), accessed November 2023.

Note: Publications by authors with institutional affiliation in the respective countries.

occurred on a significantly smaller scale (Graph A5.3). Between 2005 and 2022, the region's output of articles on the subject grew at an average annual rate of 23%, although it accounts for only 3.6% of global annual production.

In addition to being marginal in relation to global output, knowledge production on sustainable construction in LAC is also

geographically concentrated. Brazil alone accounts for nearly half (49%) of the scientific-technological articles produced in the region between 2018 and 2022, positioning itself as the clear regional leader in the field (Graph A5.4).

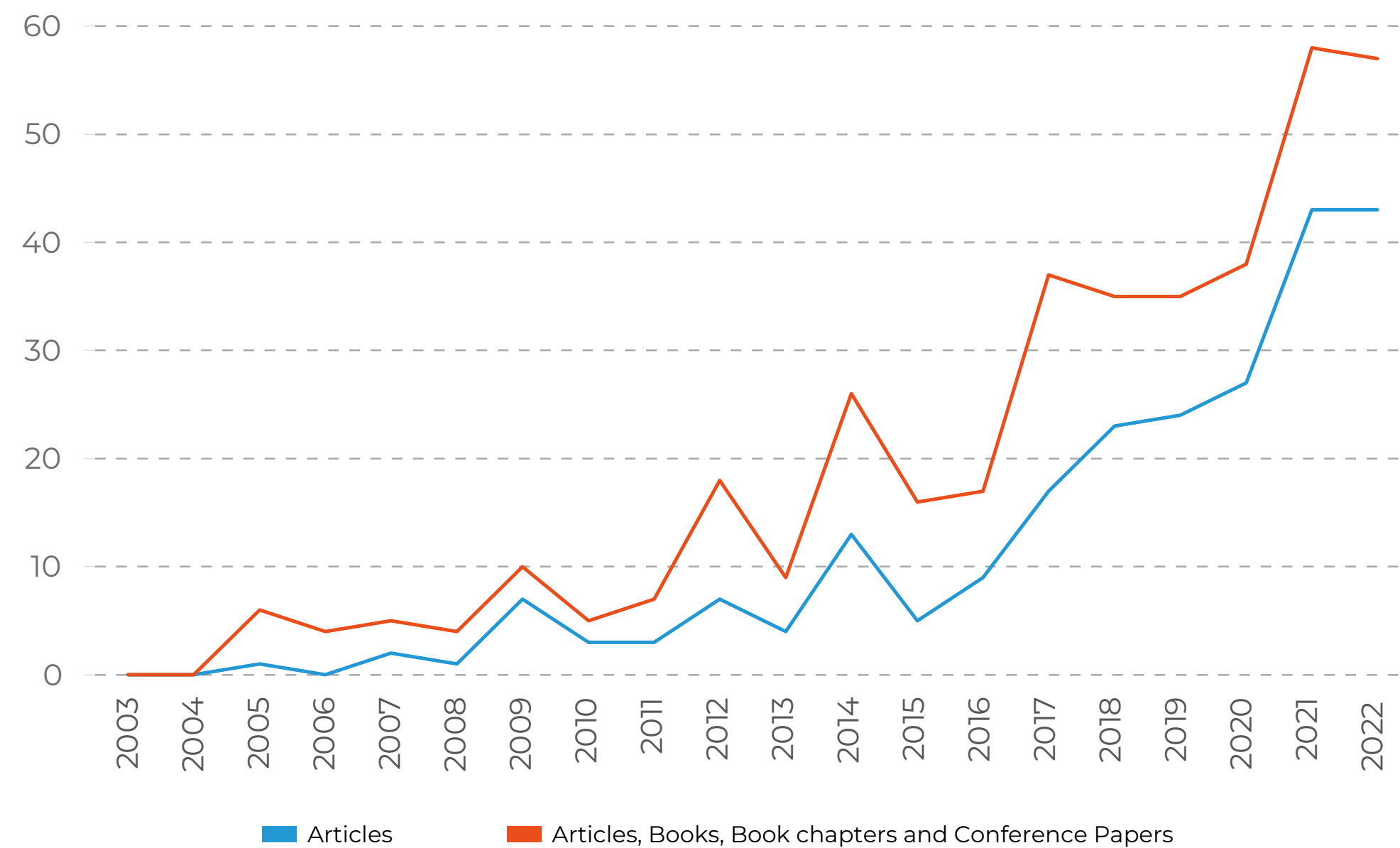
As shown in Graph A5.4, Chile, Mexico, and Colombia form a second-tier group accounting between 11% and 15% of the region's pub-

lications. Ecuador, Argentina, and Peru have produced between six and ten publications over the past five years, while other countries in LAC have either published only sporadic scientific works directly related to the topic or none at all. For reference, in 2022, authors affiliated with LAC countries published a total of 43 scientific articles on sustainable construction –less than one-fifth of China's

output for the same year, and only slightly more than half the number published by India and the United States of America, which published 81 and 72 articles, respectively.

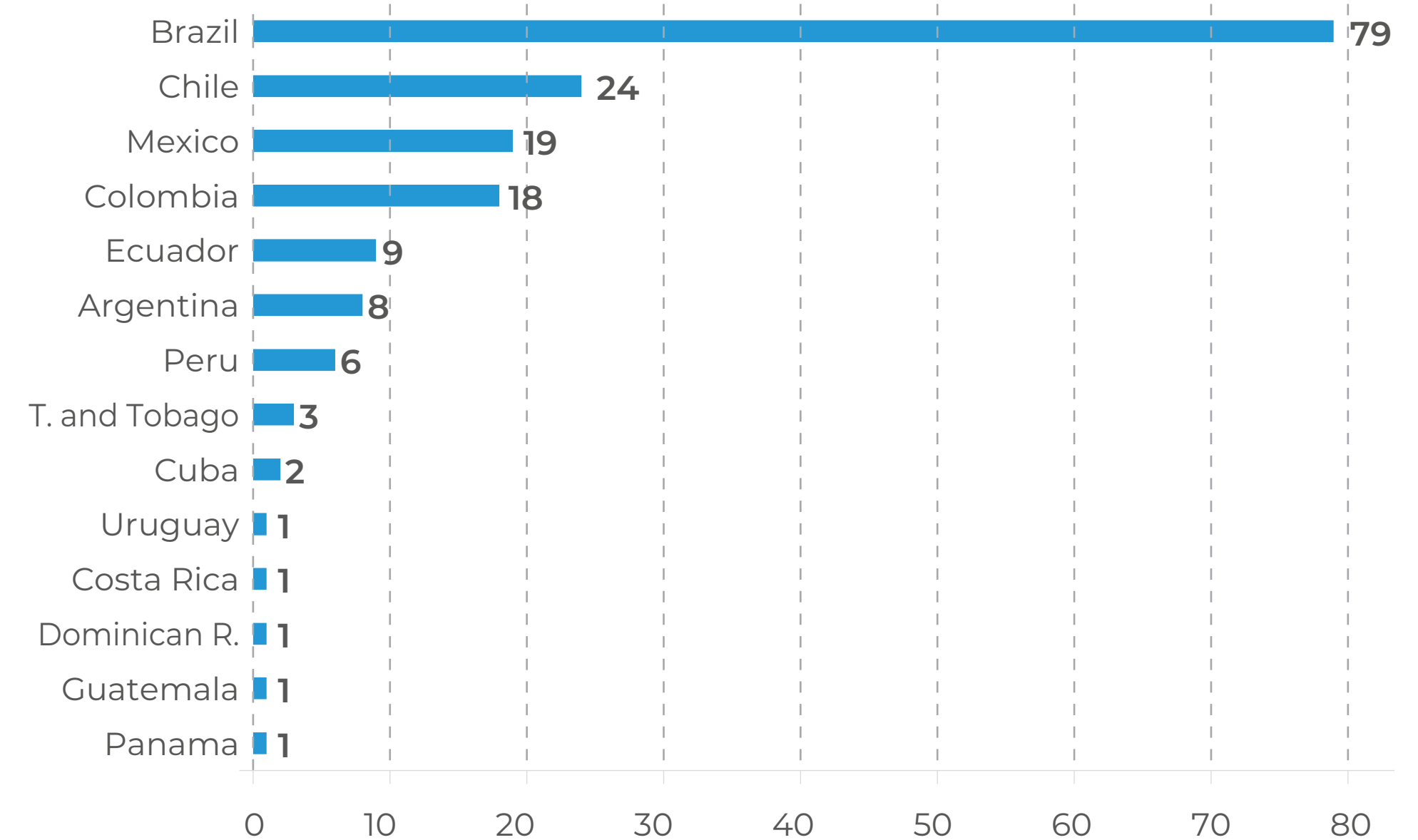
These results suggest that, with the exception of a few countries, there is no critical mass of researchers and technologists in the region who are specialized in sustainable construction and generate original knowledge on the subject.

Graph A5.3. Scientific-Technological Publications on Sustainable Construction in Latin America and the Caribbean, Between 2003 and 2022



Source: Scopus (Timbó Portal, ANII), accessed November 2023.
 Note: Publications by authors with institutional affiliation in countries of the region.

Graph A5.4. Scientific-Technological Publications on Sustainable Construction in Latin America and the Caribbean countries. Total Production Between 2018 and 2022



Source: Scopus (Timbó Portal, ANII), accessed November 2023.
 Note: Publications by authors with institutional affiliation in the respective countries.

