The normative evolution of full-culm bamboo structures in Latin America

A evolução das normas de construção com colmos de bambu na América Latina

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Number of the thematic session of the submission – [5]

Abstract

This study addresses the evolution of bamboo construction standards in Latin America, emphasizing the importance of regulatory development in promoting the use of bamboo culms in civil construction. Through a descriptive and qualitative approach, the bamboo construction standards are surveyed, and the evolution of the regulatory framework is discussed. The current standards and codes in Latin American countries such as Brazil, Colombia, Ecuador, and Peru are briefly introduced, in addition to the international ISO norms. The historical analysis, grounded in bibliographic review and normative survey, illustrates the progression and revisions of these regulations over the last 20 years, highlighting their mutual influence and the trends and collaborative initiatives that contributed to the development of the regulatory context. The study underlines the relevance of standardization and normative flexibility for the effective integration of bamboo into contemporary construction practices, aiming for environmental sustainability and innovation.

Keywords: Full-culm bamboo; Norms and Standards; Regulatory Development

Resumo

Este estudo aborda a evolução das normas de construção com bambu na América Latina, enfatizando a importância do desenvolvimento regulatório no fomento do uso do colmo de bambu na construção civil. Através de uma abordagem descritiva e qualitativa, as normas de construção com bambu são levantadas e a evolução do quadro regulatório é discutido. As normas e códigos vigentes em países da América Latina – o Brasil, a Colômbia, o Equador, e o Peru são analisadas, além das normativas internacionais da ISO. A análise histórica, fundamentada pela revisão bibliográfica e levantamento normativo, ilustra a progressão e as revisões dessas regulamentações ao longo dos últimos 20 anos, destacando sua influência mútua, tendências e iniciativas colaborativas que contribuíram para o desenvolvimento do contexto regulatório atual. O estudo sublinha a relevância da padronização e flexibilidade normativa para a integração efetiva do bambu nas práticas de construção contemporâneas, visando a sustentabilidade ambiental e a inovação.

Palavras-chaves: *Colmos de bambu; Normas de Construção; Desenvolvimento Regulatório*

1. Introduction

In this research, the aim is to highlight the importance of developing construction standards that promote the use of bio-based materials, such as bamboo, in the civil construction sector. The standardization of unconventional construction materials seeks to create a common language to facilitate communication among the main stakeholders—technicians, society, and the economy [1]. Furthermore, construction standards play a critical role in encouraging the production of scientific data on the properties of these materials, thereby serving as a tool for dissemination [2].

The standards examined in this study, ABNT NBR 16828 [3-4] and others related to bamboo construction, are specific to structures built with the bamboo culm. According to ABNT NBR 17043 [5], the bamboo culm is defined as the aerial part of the plant, with a slightly conical shape, generally hollow except at the nodes. In accordance with this standard, the culm becomes sufficiently lignified to perform structural functions starting at four years of age. The anatomical characteristics of the culm make it ideal for such functions, as noted by engineer Neil Thomas in 2017: "If we were to design an ideal construction material, it would look like bamboo," referring to the culm [6].

Gauss (2020) describes the bamboo culm as a unidirectional composite, comprising a matrix and a reinforced phase [7]. It is an anisotropic material and, according to Smits et al. (2023), is also orthotropic [8]. This implies that the culm possesses three distinct anatomical axes, each with specific properties in the longitudinal, radial, and tangential directions. Moreover, it is considered a functionally graded composite material, whose properties vary along its length [9]. In addition, the anatomical parameters of bamboo culms differ significantly among species, conferring unique mechanical characteristics to each one [10].

The inherent diversity of the bamboo culm makes it a complex constructive element, which complicates the standardization of its use in construction [11]. On the other hand, an analysis of the Elsevier database using the keyword "bamboo" identifies a significant increase in scientific output on the subject across various fields of knowledge since the 2000s [7]. This rise suggests that, despite the challenges imposed by its heterogeneous nature, bamboo is beneficial due to its environmental qualities and alignment with sustainable development principles.

Bamboo is a fast-growing perennial crop that allows for a continuous extraction cycle. As they grow, the culms capture and store CO_2 in their tissues [11], and when used for long-duration applications, such as in civil construction, the release of CO_2 is delayed [13]. However, Brazilian researchers and professionals agree that the insufficient technical standards—still in their early stages of development—and the lack of consistent scientific production limit the adoption of bamboo in the civil construction sector in the Brazilian context.

This article aims to outline the historical development of bamboo construction standards, focusing on those currently in effect in Latin America, and more specifically, to provide an in-depth understanding of the regulatory context for the use of bamboo culms in structures in Brazil.

2. Methodological Procedures

The approach adopted for this study is descriptive in nature, qualitative, and centers on elucidating the historical development of bamboo construction standards over the past 20 years. The theoretical framework addresses the standards in force in Latin America—particularly in Colombia, Ecuador, Peru, and Brazil—and also takes into account the international ISO standard, which has global applicability. Except for Brazil, these countries stand out for their use of bamboo in civil construction and for their traditional building culture with the material.

The historical analysis is conducted through a bibliographic review and a detailed survey of both the relevant regulatory documents and scientific publications on the subject. A timeline illustrating the development of these standards is created, establishing a chronological sequence of this progression. An introductory description is then provided for each standard deemed relevant, considering its most recent version, which specifically deals with the design of structures using bamboo culms.

At the end of the research, the aim is to systematically analyze the dynamics and interaction among these standards to understand their mutual influence, identify key moments and significant changes, and highlight crucial elements shaping this evolution. Finally, the trends and collaborative initiatives that contributed to the development of the regulatory context over the period in question are identified.

3. Regulatory Framework Evolution

Research on the use of bamboo as a construction material began in the 1950s with Walter Liese's pioneering studies on bamboo fiber anatomy. In the same vein, in the 1970s, Jules Janssen focused on the development of testing methods to determine the mechanical properties of bamboo culms. In Brazil, in 1979, the first studies on using bamboo as a construction element were published by the engineering department of PUC-Rio, under the supervision of Professor Ghavami [13]. Moving into the early 2000s, the Technical Committee on Timber Structures (TC165) of the International Standard Organization (ISO) initiated the process of drafting the international standards for bamboo structures [14].

ISO 22156 – "Bamboo: Structural Design," ISO 22157-1 – "Bamboo: Determination of Physical and Mechanical Properties – Part 1: Requirements," and ISO 22157-2 – "Bamboo: Determination of Physical and Mechanical Properties – Part 2: Laboratory Manual" were published in 2004 and were quickly integrated into the national legislation of Peru, Ecuador, and Colombia. However, these inaugural international standards, referred to as the "Zero Version," had critical shortcomings, particularly regarding the detailing of connectors in structures and the classification of bamboo culm strengths. To address these gaps, subsequent standards were developed in Latin America, focusing on the properties of a single bamboo species, regionally available and widely used in the construction sector—Guadua angustifolia Kunth (GaK) [15].

Researchers highlight the Colombian code "NSR-10 – Reglamento Colombiano de Construcción Sismo Resistente - Título G Estructuras de Madera y Estructuras de Guadua – Capítulo G.12 – Estructuras de Guadua" (NSR-10) as one of the most relevant in terms of developing the structural use of bamboo culms. Considered a milestone in the regulation of bamboo construction, NSR-10 encompasses fundamental aspects such as visual classification, safety factors, characteristic values, mechanical properties, and design procedures for bamboo structures [16]. This code emerged in response to an earthquake in Colombia in 1999, which revealed that 90% of fatalities occurred in buildings that lacked structural bamboo elements. Prior to its publication, between 2006 and 2009, the Colombian Technical Standards (NTCs) were developed by the Colombian Institute of Technical Standards and Certifications (ICONTEC). These technical standards formed the foundation for the code published in 2010 [2].

Similarly to Colombia, notable earthquakes in Peru (2007) and Ecuador (2016) motivated these countries to incorporate elements of the NSR-10 code into their national building regulations. Ecuador made adaptations focusing on material processing, selection, construction, and maintenance, while Peru emphasized bamboo building design and construction processes for earthquake-resistant structures [2]. Unlike the ISO standards, which do not specify the species to be used in bamboo structures, the regulations in effect in Colombia, Ecuador, and Peru are directed specifically toward the use of the GaK species and other species with similar physical-mechanical characteristics.

Between the initial publication of the ISO standards in 2004 and the release of NSR-10 in 2010, efforts to develop international standards diminished. However, in 2013, a new wave of activity was triggered by collaboration between the International Bamboo and Rattan Organization (INBAR) and Coventry University, with support from Colombian, Ecuadorian, and Chinese partners. This partnership led to the creation of Working Group 12 (WG12) within TC165, aimed at reviewing existing standards and proposing new guidelines. Additionally, in 2013, INBAR established the Bamboo Construction Task Force (INBAR TFC) [14].

The collaborative efforts of INBAR, INBAR TFC, and WG12 resulted in the review and updating of the ISO standards on bamboo. In 2018, ISO 19624 – “Bamboo Structures: Grading of Culms – Basic Principles and Procedures” was introduced, providing the first specific guidelines for bamboo culm grading. This was followed by the revised edition of ISO 22157: “Bamboo Structures: Determination of Physical and Mechanical Properties of Bamboo Culms and Test Methods” in 2019, which improved existing test methods. The standard ISO 22156: “Bamboo Structures: Bamboo Culms – Structural Design,” revised and published in 2021, brought significant advances by incorporating innovative approaches to design and structural calculation, as well as offering detailed guidance on connector development [17]. All these standards bear the title “Bamboo Structures” in their names, underscoring the goal of promoting the use of bamboo culms in structural applications.

In July 2017, nearly four decades after the first scientific publications on bamboo in Brazil, the first committee dedicated to creating a Brazilian standard for the structural use of bamboo was formed in São Paulo. This standard, ABNT NBR 16828, was developed by the Brazilian civil construction committee, specifically the committee on Brazilian structural standards. According to Beraldo (2017), the initial draft was written by Engineer Normando Perazzo Barbosa from the Federal University of Paraíba and submitted for discussion among professionals from various fields [18]. The final version of this initial draft underwent a national public consultation in December 2019 and was officially published in December 2020.

4. Normative Timeline

The timeline (Fig. 1) aims to illustrate the historical context of the evolution of bamboo construction standards in Brazil, Colombia, Ecuador, and Peru, as well as the international ISO standards. Based on the analysis of this timeline, it is possible to identify the relevant standards in their most recent versions.

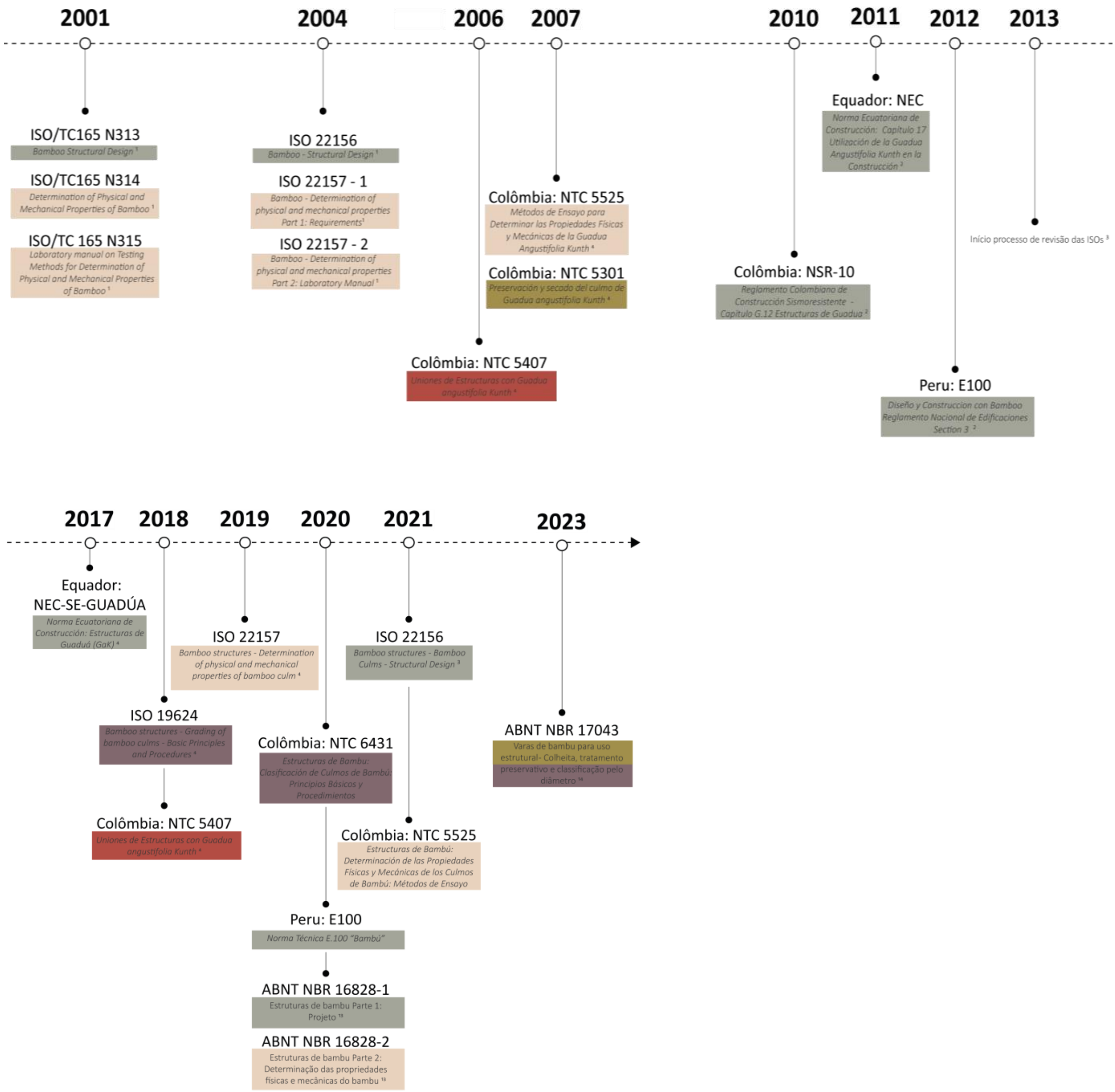

Figure 1: Chronological evolution of standards and codes for construction using bamboo culms identified in the bibliographic review. Source: Prepared by the authors, adapted from Marçal (2017), Gauss (2020), Amede et al. (2021), and Harries (2022).

4.1. NSR-10: Capítulo G.12 Estructuras de Guadua – Colombia (2010)

The NSR-10 code, included in Title G – "Estructuras de Madera y Estructuras de Guadua," is part of Colombia's earthquake-resistant construction regulations created by the Permanent Advisory Committee of the Ministry of Environment, Housing, and Development [16]. The regulation applies to residential, commercial, industrial, or educational buildings of up to two stories. For structures with an area exceeding 2,000 m², load testing is recommended prior to use. These structures, which must use only the Guadua angustifolia Kunth (GaK) species, are to be designed and built to withstand the forces generated by the combination of service loads and the deflection limits specified by the standard. The structural analysis should treat elements as homogeneous and linear, and connections must be considered hinged, with no moment transfer between elements.

4.2. NEC-SE-GUADÚA – Ecuador (2017)

The “Estructuras de Guadúa (GaK)” standard, part of the Structural Safety (SE) chapter of the Ecuadorian Building Code (NEC) formulated by the Ministry of Urban Development and Housing, sets forth basic principles for designing earthquake-resistant structures [20]. It applies to residential buildings, general-purpose facilities, and infrastructure support structures built with GaK and bamboos with similar physical-mechanical characteristics, of up to two stories that support live loads of up to 2.0 kN/m². The structures must be designed and constructed to resist the forces from service load combinations, as well as seismic loads. The allowable-stress design method is employed, and the connections between elements are considered hinged, with no moment transfer.

4.3. Norma Técnica E.100 “Bambú” – Peru (2020)

The Bamboo Technical Standard E.100, part of the “Reglamento Nacional de Edificaciones” (RNE) and developed by the “Servicio Nacional de la Capacitación para la Industria de la Construcción” (SENCICO), sets out technical guidelines for designing and building earthquake-resistant structures that use GaK and other species with similar physical-mechanical characteristics [21]. It is mandatory for buildings of up to two stories with a maximum distributed live load of 250 kgf/m². Bamboo elements must be designed to withstand forces resulting from service-load combinations, in addition to overloads from earthquakes, wind, and rain, using the allowable-stress design method. The structural analysis must align with consistent and acceptable assumptions of sound engineering practice, and permissible limits and stresses are assessed through conventional linear and elastic analysis methods.

4.4. ABNT NBR 16828-1 – Brazil (2020)

The ABNT NBR 16828 standard is specific to structures that use bamboo culms. Its title begins with “Estruturas de Bambu” (Bamboo Structures), and it is currently divided into two parts: “Estruturas de Bambu – Parte 1: Projeto” (Bamboo Structures – Part 1: Design) and “Estruturas de Bambu – Parte 2: Determinação das propriedades físicas e mecânicas do bambu” (Bamboo Structures – Part 2: Determination of the Physical and Mechanical Properties of Bamboo). It adopts the partial safety factor method for limit states, considering two types of limit states: ultimate limit state and service (or usage) limit state. The key concepts presented in the standard include load-bearing capacity, service performance, and durability.

During the design phase, the expected service life of the structure is determined along with its intended use, required performance under specific environmental conditions, material properties and performance, the shape of structural elements, workmanship quality, the level of control over construction materials, special protective measures, and preventive maintenance needed to ensure the structure’s durability.

Structures must be designed to safely resist both usual loads and special loads, which are typically associated with the construction and assembly stages. Structural systems should exhibit a low propensity for progressive collapse, ensuring the integrity and safety of the building. To achieve this, the structural design must ensure continuity among individual components, enabling an efficient distribution of load that prevents isolated failure points. Structural calculations must be carried out using design models and, if needed, supplemented by experimental testing. Connectors, which must be labeled, ensure structural continuity between different elements. At the end of the project, a quality control manual, a quality assurance manual, and records of the quality assurance process must be provided.

4.5. ISO 22156 – Global (2021) [17]

ISO 22156:2021 – "Bamboo Structures: Bamboo Culms – Structural Design" provides guidelines for the structural design of one- and two-story buildings employing bamboo culms in residential, commercial, institutional, and light industrial constructions, with a maximum height of seven meters. It allows the use of allowable-load and/or allowable-stress design methods. The document also recognizes design approaches using partial safety factors and/or load and resistance factors, as well as methods based on established experience or testing approaches.

The standard underscores the concepts of structural redundancy, serviceability, and durability in the design of bamboo structures. Structural redundancy is achieved when four or more structural members are interconnected within a single load-distribution path, allowing forces to be redistributed among remaining members if an element fails, thereby maintaining structural integrity. It also addresses maintenance considerations, particularly principles for identifying culms in the structure that have suffered some form of deterioration, along with the process of replacing them with suitable alternatives.

Connectors must ensure effective transfer of forces between two or more culms or structural members and must meet criteria for stiffness, ductility, and robustness, minimizing the risk of cracking. The design of structures should be carried out by qualified, experienced professionals, ensuring that construction is performed by individuals with specific skills and knowledge in the field. Supervision and quality control are crucial at every stage of the process, from material preparation through to project completion.

5. Discussions

Owing to the anisotropic nature of the biomaterial and the numerous woody bamboo species that can be employed in civil construction, when the development of bamboo standards is carried out by regional authorities, the result is a wide array of diverse standards. For instance, the construction standards in force for bamboo in Colombia, Ecuador, and Peru are specific to the GaK bamboo species and present a structural design methodology that differs from the ISO standards and ABNT NBR 16828-1. Additionally, these are not restricted to the use of a single bamboo species.

A noticeable trend is that standards do not necessarily prescribe the use of a specific bamboo species. This is illustrated by the update to NTC 5525. The revision of the Colombian technical standard, published in 2012, is a direct translation of ISO 22157, which does not specify which woody bamboo species should be used structurally. This change reflects a global movement toward a more generic and comprehensive standardization of structures employing bamboo culms, thereby enabling application to a broader range of species.

Nevertheless, having a standard that targets one specific species offers some advantages. For example, it provides clear guidance for the development of production chains, ensuring that the required material—according to the parameters defined by the standard—is readily available or even in stock at construction material suppliers. Moreover, the mechanical properties are already characterized and ready for structural calculations. This species-specific standardization expedites compatibility processes between architectural and structural designs, eliminating the testing phase.

However, not specifying a species within a regulatory framework allows, above all, the use of various locally available bamboos, fostering a decentralized form of production and enabling bamboo construction to be adapted to local conditions. Furthermore, different bamboo species exhibit distinct mechanical properties, making them more or less suitable for specific structural applications. A standard covering multiple species thus encourages more complex projects, allowing the use of a variety of bamboos, and rendering the design process more creative.

6. Final Considerations

Despite the challenges posed by the anatomical diversity and inherent complexity of bamboo as a construction material, existing standards have evolved to address these issues with increasing effectiveness. This regulatory advancement not only facilitates the use of bamboo culms in structural projects but also encourages research and scientific development regarding its properties and applications.

The study of standards in Latin American countries—specifically Colombia, Ecuador, Peru, and Brazil—as well as the international ISO guidelines, revealed a trend toward standardization. Such standardization is critical for the broader adoption of bamboo, as it provides a common language among technicians, society, and the economy, in addition to ensuring safety and efficiency in construction.

However, it was also observed that the flexibility of these standards to include a variety of bamboo species enhances the use of this resource according to local characteristics and availability, thereby strengthening the ability to address the specific needs of each region. This work contributes to the existing literature by offering a detailed historical and regulatory perspective on the use of bamboo in civil construction in Latin America, highlighting its role as a sustainable and versatile building material.

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