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# Contemporary Bamboo Architecture in China

中国现代竹建筑 (英文版)

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## 内 容 简 介

本书在全球竹建筑发展背景下，从竹资源和建筑用竹种分布，竹建材种类及特点，竹建筑发展历程和研究现状，标准体系，相关国际组织、科研机构和生产加工企业，典型案例等六方面，系统阐释了中国竹建筑产业总体发展情况，分析了机遇和挑战，提出了未来发展指导意见。通过 100 多个案例和 300 多张高清图，深入浅出而又趣味生动地展示了竹建筑的文化内涵和科技成果，启发从业者积极主动、大胆地选择竹子来建设美丽家园。可为全球竹建筑相关研究、设计和施工人员，“一带一路”竹产业政策和标准制定者，发展理念超前的开发商，以及对竹建筑感兴趣的国际读者提供有益参考。

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## Foreword by Ali Mchumo

Bamboo is one of the fastest growing species on earth, and woody bamboos have been used in buildings for thousands of years. For example, in the Sidama Region of southern Ethiopia, the majority of local farmers still live in traditional bamboo houses, commonly known as “Sidama” which account for 1% of the total housing in Ethiopia. Bamboo’s relatively lightweight and high natural strength makes it an excellent construction material, earning it the name “vegetal steel” among architects around the world. In Ecuador, an assessment of the effects of the 2016 earthquake on local buildings emphasized that there was little or no impact on structures built with bamboo and wood. With the development of modern building technology, the application of bamboo in modern construction is gradually increasing, from small dwellings to medium-sized public buildings, as well as large outdoor landscape projects, even involving urban infrastructure construction. The Guadua bamboo pavilion constructed for the 2000 EXPO in Hannover, Germany, opened the eyes of many in the Western world. In 2004, the use of fire-resistant bamboo material for the 230,000 m<sup>2</sup> ceiling of the Madrid-Barajas Airport in Spain was the starting point of a new chapter in the application of bamboo as an interior decorative material. Meanwhile, in Bali, Indonesia, the “Green School” perfectly combined this environmentally friendly material with education for young generations. There is now a Green Village of majestic bamboo buildings nearby. Bamboo is now used throughout Europe for interior design, including the completed City Life shopping complex in Milan, which was designed by the late Zahad Hadid.

Under the background of global bamboo construction development, China, which possesses the largest bamboo forest area in the world, has made significant contributions to promote the development of bamboo construction materials and bamboo constructions. China produces a large amount of bamboo construction materials every year and exports them to many countries. For example, the annual export volume of China’s bamboo flooring, for which statistics are available, accounts for more than 90% of the total global export trade. In the past 10 years, China has begun to use bamboo in large quantities in many public buildings and urban environments. For instance, the indoor and outdoor decorative materials in art galleries, theaters, hotels

and high-end office buildings, as well as some small public transport facilities, and even all the outdoor flooring of the Civic Service Center, newly built in Xiong'an New Area, Hebei Province, all adopt high-durability bamboo materials. In addition, bamboo, as a structural material, has begun to develop in some small-sized buildings, such as 1–3-story bamboo-structured villas and public spaces, more than 90% of which are made of bamboo materials.

China has also adopted bamboo construction in sustainable rural construction. The First International Bamboo Construction Biennale was launched in 2016, at which 18 characteristic bamboo constructions were built, making a small remote village with rich bamboo resources a cultural tourism destination featuring bamboo constructions, thus greatly improving the income level of locals. Moreover, more and more young people are willing to return from the big cities to their hometowns for employment and entrepreneurship which provides vitality and a sustainable exploration path for the future development of the countryside.

*Contemporary Bamboo Architecture in China* was published in Chinese in May 2019 with a free full-text e-book issued simultaneously on INBAR's official Web site. Through the INBAR platform, these successful stories of bamboo architecture in China have been spread to more than 50 countries around the world. Through a large number of exquisite pictures, non-Chinese-language readers can understand stories of classic bamboo architecture. INBAR received many positive comments from our partners that encouraged us to publish an updated English version for our international audience of those interested in bamboo architecture, including researchers, designers, policy and standard makers and developers.

In the process of updating and translating the Chinese-language version, on behalf of INBAR, I would like to express my gratitude to Shanghai Research Institute of Building Sciences Co., Ltd., International Centre for Bamboo and Rattan, Tsinghua University, the University of Pittsburgh, Tsinghua University Press and Springer Nature for their support.

Last but not least, I hope that everyone can get useful information from this book and be inspired to continue exploring the potential of bamboo construction development around the world.



Dar es Salaam, Tanzania  
March, 2021

Ali Mchumo  
Director-General of International  
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## Foreword by Simón Veléz

Since the creation of INBAR in 1997, 24 years has passed. It has been very impressive to see the evolution and acceptance of these materials. Rattan only exists in Asia, and it has been believed that bamboo was also limited. However, in Central and South America, starting from Mexico and all the way to Argentina, with an epicenter in Colombia and Ecuador, native bamboo has had enormous importance not only in the landscape, but also in popular culture. Unfortunately, it also has a stigma attached to it that it is the “wood of the poor people” and the poor are the ones who most reject bamboo. For someone in Asia, one does not understand life without bamboo: It is in the food, textiles, in the fibers used for basket weaving, in the artisanal crafts, mat making and as temporary supports and scaffolding in the construction industry.

Environmental concerns and global warming are now integral parts of any political, economic and social agenda. The construction industry is one of the biggest contributors to pollution of the earth—through the transport, mining and transformation of construction materials.

Bamboo in construction and rattan in furniture are clean and natural alternatives so that the construction industry no longer abuses minerals in a disproportionate manner. We are exaggerating in the use of concrete, steel, brick, glass, and what I consider even worse, whatever construction materials are derived from petroleum. We must become more vegetarian.

This book shows us a very complex evolution of how a humble vegetal material with vernacular use and an association with poverty has already been converted into an alternative for construction that competes equally with, and in some cases supersedes, wood, steel and concrete. The fibers of bamboo are much stronger than steel and are equivalent to other high-tech materials. When institutions such as INBAR,

the academic world, the technology industry and the finance industry become interested in materials such as bamboo and rattan, revolutions are produced such as those that are shown in this book and tell us that the future is green.



Bogotá, Colombia  
March 2021

Simón Veléz  
Chief Architect of Simón Veléz  
Architects

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## Foreword by Prof. Ying Hei Chui

The world is facing a serious challenge in terms of continued greenhouse gas (GHG) emission through various human actions. It is known that globally the construction sector is the third largest emitter of GHG into the atmosphere, accounting for 12% of the total emission. Increased use of low carbon footprint and renewable materials in construction will be an effective way to significantly reduce GHG emission. It is for this reason that wood has attracted worldwide attention in construction over the last decade because it is the only renewable material among the common construction materials. Wood also requires significantly less energy and emits substantially less pollutants during the manufacturing process, compared with steel, concrete and masonry.

Recently, bamboo is also attracting the attention of designers and architects as a viable construction material. This is not surprising because from a material property standpoint, bamboo has many of the same characteristics as wood. Bamboo offers even more environmental benefits than wood, in that it can produce more oxygen and biomass than conventional tree species. Obviously, bamboo has a long way to go before it reaches the same status as wood in terms of its acceptance as a common construction material. The wood products industry is more mature with well-established manufacturing processes and a regulatory framework that ensures the quality of end products and that the performance of structures built with wood products meet the requirements of building regulations and design standards. By comparison, use of bamboo in construction is still in its infancy.

An important step in the process of gaining acceptance and recognition of bamboo as a new construction material is the need to demonstrate to designers, developers, consumers and code authorities that bamboo can be used to construct safe, economical and aesthetically pleasing structures. A good example for bamboo to follow is the rapid development of cross laminated timber (CLT) as a product for constructing large and tall buildings. The interest in CLT increased by leaps and bounds about a decade ago after a few CLT buildings were designed and constructed by early adopters who believed in the product and persisted with their construction projects despite limited design guidelines for the product.

This book, *Contemporary Bamboo Architecture in China*, is an excellent resource for anyone interested in bamboo products and structures. The bamboo structures presented in Chap. 6 of this book, enhanced through the use of professionally taken color photographs, is a testimony to the creative ingenuity of their designers. These bamboo structures demonstrate the range of possibilities in architectural and structural designs with bamboo products. As a structural engineer myself, it is obvious that some of these impressive bamboo structures presented serious challenges to structural engineers in terms of performing rational structural analysis. One of the main features of the book is that the information presented is recent and up-to-date. The structures shown in Chap. 6 were constructed over the last 8 years.

I believe this book will have an impact on promoting the use of bamboo beyond the use of low-cost housing construction, not only in China but also internationally. Despite what the title implies, the scope of the book extends beyond China with structures from around the world illustrated in Chap. 6, and the discussion in various chapters provides an international context, most importantly for codes and standards in Chap. 4. In addition to showcasing various structures, this book also presents a wide range of technical topics. These topics include an introduction to bamboo properties, bamboo resource distribution around the world, the range of bamboo construction products commercially produced, the major types of bamboo structural systems, codes and standards development and organizations involved in bamboo promotion and research from around the world. The final chapter of the book discusses results from a strength–weakness–opportunity–threat (SWOT) analysis conducted to evaluate the potential of using bamboo in construction of residential, commercial and institutional structures.

The authors have done an excellent job in formatting and packaging the information in the book. Without a doubt, this book is the most comprehensive publication to date that addresses the use of bamboo in modern construction. Given the wide range of topics it covers, it is suitable as a textbook for university programs and can serve as an excellent reference for researchers, consultant structural engineers, practicing architects and government departments responsible for infrastructures.

I congratulate INBAR and its collaborating partners in not only taking the initiative to producing the first edition of the book in Chinese, but also the vision to translate the book into English, so that a wider audience interested in bamboo structures can benefit from this excellent publication.



Edmonton, Canada  
March 2021

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## Preface

With the largest population in the world, China needs a large number of buildings to provide necessary support for people's work and life. However, large-scale urban construction, dominated by concrete and steel, results in increased carbon emissions and places a burden on energy resources and the environment. Sustainable urban development faces enormous challenges. In recent years, people have begun to explore more environmentally friendly building materials and methods, and the use of natural building materials is popular among urban planners and builders. However, due to the lack of forest resources in China and the need to import large amounts of wood from other countries, bamboo has garnered attention as a natural native alternative to wood.

China not only has the richest bamboo resources in the world, but also has a deep-rooted bamboo cultural tradition. How to make rational use of this natural material so that bamboo architecture can play its unique role in sustainable urban and rural construction has become a new direction of exploration.

Against the background of global bamboo architecture development, this book describes the distribution of bamboo forest and bamboo species for construction, the types and characteristics of bamboo materials for construction, the development history and research status of different forms of bamboo architecture. We go on to describe standards, relevant international organizations, research institutions and production and processing enterprises and typical cases. Starting from six aspects, this book systematically describes bamboo building development in China, analyzes the opportunities and challenges faced by the bamboo construction industry in China and provides guidance for the development of the bamboo construction industry in China.

In the first chapter, the main species of bamboo used for construction and the distribution of resources are presented. Chapter 2 focuses on the introduction of two types of bamboo materials which are widely used in the construction sector: full-culm bamboo and engineered bamboo. The chapter introduces each type from the perspective of three potential uses: structural load-bearing materials, enclosure and decorative materials and other functional materials. Chapter 2 also introduces the physical and mechanical properties of these bamboo materials with relevant test

methods, as well as the research status of long-term performance, durability and fire resistance. At the same time, the application and research status of bamboo in other construction realms are briefly introduced, including bamboo scaffolding, bamboo-reinforced concrete and masonry, bamboo soil reinforcement, bamboo reinforcement for existing structures, etc. Chapter 3 introduces the development history and research status of full-culm and engineered bamboo structures. Chapter 4 systematically analyzes international standards related to bamboo structures, as well as the development of China's current national and provincial standards and industry and association standards. Chapter 5 briefly introduces the international organizations, research institutions and production and processing enterprises which are engaged in research, application and promotion of bamboo architecture in China. In Chap. 6, more than 70 exemplary (commercial) cases constructed mostly since 2014 are selected to provide a detailed overview of the use of bamboo as decorative and structural materials. In order to fully explore the potential of bamboo in engineering applications, the authors introduce the use of bamboo construction for transportation facilities (bridges, highway landscape fences and bus stations), landscape, water pipelines and urban municipal tunnels. The authors hope readers are inspired by these most vivid cases and experience the charm of modern Chinese bamboo architecture. In Chap. 7, the authors apply strength–weakness–opportunity–threat (SWOT) analysis to enumerate opportunities and challenges faced by China's modern bamboo construction industry. Approaches to leveraging opportunities and overcoming challenges are presented.

This book seeks to objectively describe commercial cases to showcase the status of the bamboo construction sector in China. No commercial endorsement is intended or should be implied in any instance. Please enjoy this book as it was intended: as a unique source of reference.

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We also want to thank the following individuals and their universities, research institutes, design institutes, as well as other institutions for their support in helping to collect information (presented in no particular order): Dr. Fu Jinhe, Director of East Africa Region of INBAR; Chen Zhaoyuan, Professor of Tsinghua University and Fellow of Chinese Academy of Engineering; Li Zhiyong, Chief Expert of Green Economy of ICBR and Vice President of China Bamboo Industry Association; Liu Xianmiao, Associate Professor of ICBR; Hu Tao, Associate Director of Institute of Ornamental Plants and Landscape of ICBR; Huang Biao, Planning Designer of Institute of Ornamental Plants and Landscape of ICBR; Wang Zheng, Professor of Chinese Academy of Forestry (CAF); Yu Wenji, Professor of CAF; Yu Yanglun, Associate Professor of CAF; Gao Li, Associate Professor of CAF; Wang Fusheng, Professor of Nanjing Forestry University; Tan Tianfang, Chairman of the Bamboo Industry Committee of Federation of Hong Kong Industries; Dong Jianning, Head of the Architecture Division of Tongji Architectural Design (Group) Co., Ltd; Xiang Linfei, Director of the Collection and Editing Center of World Architecture; Zhang Yun, Director of PR Department of Urbanus Architecture & Design Inc; Chen Wenyun and Deng Wei, Officer of PR Department of Urbanus Architecture & Design Inc; Xie Xiaozhang, PR Manager of MAD Architects; Shang Jingjing, Public Relations of Vector Architects; Fu Xiaoming, Architect and Media Director of Land-based Rationalism D.R.C of China Architecture Design & Research Group; Lai Linli, General Manager of Shanghai Office of PES-Architects Ltd; Xu Minmin, Marketing

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The authors acknowledge the contributions of Professor Chen Zhaoyuan and Professor Li Zhiyong to this work. Sadly, Professor Chen and Professor Li have since passed away; this work honors their memory.

## Authors' Note for the Second Edition

This book was originally published in Chinese by INBAR, SRIBS and ICBR in early 2019. This edition is a translation and substantial revision of the original. Some new information has been added, especially in Chap. 2. Chapter 5 has been rewritten. Twenty-one new case studies have been added to Chap. 6. The book's entire content has been rewritten, and in some cases reorganized, with an international readership in mind. This book is necessarily a snapshot in time of a very rapidly developing industry and practice. Revisions were made in from late 2020 to mid-2021.

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## About the Authors' Organizations



**INBAR:** Established in 1997, the International Bamboo and Rattan Organisation (INBAR) is an intergovernmental development organization that promotes environmentally sustainable development using bamboo and rattan. It is currently made up of 48 member states. In addition to its Secretariat Headquarters in China, INBAR has five regional offices in Cameroon, Ecuador, Ethiopia, Ghana and India. Bamboo, the fast-growing grass plant, and rattan, the spiky climbing palm, can be important nature-based solutions to a number of pressing global challenges, for poverty alleviation, green trade, climate change mitigation and adaptation, resilient construction and environmental protection. INBAR's mission is to improve the well-being of producers and users of bamboo and rattan within the context of a sustainable bamboo and rattan resource base, by consolidating, coordinating and supporting strategic and adaptive research and development.



**SRIBS:** Established in 1958, Shanghai Research Institute of Building Sciences Group Co., Ltd (SRIBS) is a state-owned science and technology service company, providing services of engineering consulting, testing and design in building, transportation and environment. Developed from a research and development institute, SRIBS has been regarded as a China top 10 green building consultants, China Prefabrication Building Industrial Basement, is among the biggest construction Testing, Inspection and Certification, and environment assessment institutes in Shanghai, and the biggest engineering supervision providers in China. In China, SRIBS ensures the safety, quality and performance of a great number of projects, including Shanghai Center, Shanghai Pudong Airport, Yangshan Port, Shanghai Metro, Hangzhou Bay Bridge, etc.



**ICBR:** Established in 2000, the International Centre for Bamboo and Rattan (ICBR) is a non-profit research institution affiliated to the National Forestry and Grassland Administration (NFGA) in China. The mission of ICBR is to build direct supports to and cooperate with INBAR, the first intergovernmental international organization headquartered in China, for helping INBAR's better fulfilling its Host Country Agreement, as well as promoting the sustainability of bamboo and rattan industry development both in China and across the world. ICBR mainly carries out six key research fields of bio-resources in preservation, cultivation, improvement, processing and utilization. Since its establishment, ICBR has made a series of achievements on biomass materials, genetic science, bio-resources chemistry, resource cultivation and physiological/ecological studies, green economy, garden flowers and landscape.



**Tsinghua University:** Tsinghua University is one of the most prestigious and influential universities in China. Since its establishment in 1911, Tsinghua University has developed into a comprehensive, research-intensive university, covering sciences, engineering, humanities, law, medicine, economics, management and art. Through the pursuit of education and research at the highest level of excellence, Tsinghua is developing innovative solutions that will help solve pressing problems in China and the world. Several faculties, such as architecture, civil engineering and environment, focus on frontier issues of future human habitats and support smarter and more sustainable urban–rural development.



**University of Pittsburgh:** The University of Pittsburgh is a state-related research university, founded as the Pittsburgh Academy in 1787. Pitt is a member of the Association of American Universities (AAU), which comprises 63 preeminent doctorate-granting research institutions in North America. Since 1846, the University of Pittsburgh's Swanson School of Engineering has developed innovative processes and designs that have shaped our state, our country and our world. Swanson School faculty and students are on the forefront of developing solutions to create a better future and continue its founding commitment. The Swanson School focuses on our health, our planet and the ingenuity that keeps us competitive with recognized programs in bioengineering, sustainability and energy. Nanotechnology, manufacturing and product innovation are also critical strategic initiatives.

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## About the Authors



**Mrs. K. W. Liu** is Coordinator of Global Bamboo Construction Programme at the International Bamboo and Rattan Organization (INBAR). She was born in 1981 in Sichuan, China. She graduated from Beijing Jiaotong University with master degree in Structural Engineering and is now a Ph.D. candidate of the School of Civil Engineering at Tsinghua University. Since 2008, she has been working on promoting bamboo construction around the world. She managed around 20 international bamboo construction projects in Asia, America, Africa and Europe. She is managing the INBAR Bamboo Construction Task Force, comprising more than 30 bamboo construction experts from around 20 countries. As Convener of Working Group 12 on Structural Use of Bamboo within the Timber Structures Technical Committee of International Organization for Standardization (ISO TC165 WG12), she is working on the development and revision of five international standards of bamboo construction currently. She is also actively participating in the development of six technical standards for bamboo construction in China. Her academic achievements include more than 20 peer-reviewed papers, the book *Contemporary Bamboo Architecture in China* in Chinese as the first author, the academic conference proceedings *Modern Engineered Bamboo Structures* in English as one editor-in-chief, and the Chinese-language version of the English book *Sustainable Building in Practice: What the Users Think* as the first translator. She is one of the experts in three committees “Timber and Composite Structures Committee” of China Association

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**Dr. Q. F. Xu** is Chief Engineer of Shanghai Research Institute of Building Sciences Co., Ltd (SRIBS) and Academic Leader of Shanghai Key Laboratory of Engineering Structure Safety. He is Professor of Engineering, Shanghai Subject Chief Scientist, National First-Class Registered Structural Engineer and Registered Consulting Engineer. He was born in 1973 in Jiangsu, China. In 2001, he graduated from Southeast University with a doctoral degree in structural engineering. He has been engaged in the research and technical service of wood and bamboo structure design and construction, performance improvement, maintenance and reinforcement for over 20 years. He is Member of INBAR Construction Task Force and ISO TC 165. His academic achievements include more than 150 academic papers including more than 50 SCI/EI cited papers; six editor-in-chief technical standards and 12 participated technical standards; 14 authorized national invention patents; five Second-Class Prize and two Third-Class Prize of Shanghai Scientific and Technological Progress Award and two First-Class Prize, one Second-Class Prize and one Third-Class Prize of Huaxia Architectural Science and Technology Award.



**Dr. G. Wang** is Professor and Head of Research Group of Bamboo Fiber Composite Materials of New Biomass Materials Institute at International Center for Bamboo and Rattan (ICBR). He is a provincial and ministerial candidate for “Millions of Talents Project in the New Century,” and project leader of the 13th Five-Year Plan in China. Born in 1965, Harbin, Heilongjiang Province, he graduated from Northeast Forestry University in 1988 with a bachelor degree and from the Department of Wood Science and Technology at the Chinese Academy of Forestry in 2003 with a doctorate degree in engineering. He has been engaged in processing technology research and product development of bamboo and wood composite materials for a long time. He presided over the completion of more than 30 national

projects related to bamboo and wood structural materials and bamboo fiber-based composites. His academic achievements include more than 140 academic papers including more than 50 SCI/EI cited papers; ten editor-in-chief national or industrial standards; one editor-in-chief monograph and three participated monographs, nine provincial and ministerial scientific and technological appraisal and recognition achievements and 20 authorized national patents; one First Prize of National Scientific and Technological Progress Award, two First Prize and two Second Prize of Liang Xi Forestry Science and Technology Award and two Second Prize of Society of Wood Science & Technology.



**Dr. F. M. Chen** is Associate Professor of ICBR, Visiting Scholar at the Swiss Federal Institute of Technology in Zurich and Secretary of National Key Research Projects. He was born in 1985, Anhui, China. He graduated in 2014 from the Department of Science and Engineering of Bamboo-Based Composite Material at the Chinese Academy of Forestry with a doctorate and his tutor is Professor Jiang Zehui. He is engaged in the research and development of new bamboo fiber composite materials and their application in prefabricated buildings. He presided over and participated in six national and provincial-level projects. His academic achievements include more than 30 peer-reviewed papers, including 20 SCI/EI cited papers; co-authored two English and one Chinese monographs; ten authorized national patents for inventions and practical new models; one Scientific and Technological Achievement recognized by the State Forestry and Grassland Administration of China, one Scientific and Technological Achievement of China Society of Forestry, one First Prize of Liang Xi Forestry Science and Technology Award and one Third Prize of Liang Xi Excellent Youth Paper Award.

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