

INBAR Construction Task Force – An Explorative Way for Development in the Bamboo Construction Sector

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ABSTRACT: The INBAR Construction Task Force (TFC), facilitated by INBAR since 2013 and officially established in 2014, helps to coordinate activities of international research institutes and commercial companies interested in structural uses of bamboo. Prior to the task force's initiation, there was little coordination or communication between individual research teams or commercial companies working on this subject. Currently, the TFC consists of a core group of 28 experts from 18 countries, aiming to serve as the world's premier information and knowledge repository on structural uses of bamboo. In the past four years, the TFC has contributed many achievements including: standardisation work for structural uses of bamboo; high quality peer-reviewed publications; international projects; consultancy services; international conferences; and capacity-building for the bamboo construction professional.

1 BACKGROUND

Since the early 2000s, INBAR has served as the liaison organization to the Timber Structures Technical Committee of the International Organization for Standardization (ISO/TC165) and successfully led an international expert group in the development of two international standards (ISO 22156 and ISO 22157-1) and one technical report ISO/TR 22157-2 in 2004. This work has had significant impact globally, with a number of INBAR member countries, such as India, Ecuador, Peru and Colombia, subsequently developing chapters on bamboo in their respective national building codes which reference these ISO standards.

Despite the impact of this initial work, and without funding for its continuation, INBAR was unable to sustain further development of international standards development in the years since then. The standards published in 2004 were in many respects "version zero" standards; they identified needs and served as placeholders upon which revisions could be based. The 2004 ISO standards, in particular, lacked guidance on crucial issues such as connection design and strength grading. Nonetheless, despite major advances taking place in the field of bamboo construction in the subsequent decade, no new or revised ISO standards for structural uses of bam-

boo were developed. Additionally, engineered structural bamboo products, which were relatively new in the early 2000s, have gained commercial importance but are, are not covered by existing international standards.

It is noted that since the first ISO bamboo standards were developed there has been some development and revision of national standards. Most significantly, in Colombia, the publication (and ongoing revision) of NSR-10 (AIS 2010) and the inclusion of composite bamboo “lumber” into ASTM D5456 in 2010.

Recognising the gap in standards development, in 2013, with new core funding from China, INBAR initiated new research on structural uses of bamboo through a strength grading project with Coventry University in the United Kingdom and partners in Colombia and Ecuador. The project was able to successfully obtain permission from ISO/TC165 to include a new Working Group 12 (WG12) on structural uses of bamboo. This working group has the mandate to amend existing ISO standards as well as to propose new ones. INBAR has served as the Convenor for this working group since its inception in 2014.

In addition to the project, INBAR had also successfully organised an informal network of about 15 research institutions and a few commercial companies that were researching structural uses of bamboo. This group met at the University of Cambridge in 2013 and at Coventry University in 2014. The process indicated that there was a growing international community of researchers (in Canada, China, Colombia, India, Indonesia, Malaysia, Mexico, USA and the UK) working on bamboo-based construction. Prior to the two meetings in the UK, however, there was little coordination or communication between individual research teams or commercial companies.

Despite the advances made by the China Government-funded project and INBAR’s efforts to build informal networks, it was clear that in order to avoid repeating the experiences of post-2004, INBAR needed to put in place structures that would leverage different stakeholders working in this area to work together and pool resources. Therefore, INBAR proposed to set up a new task force to enhance its network and global reach on structural applications of bamboo.

The initial INBAR Construction Task Force (TFC), consisting of 11 experts from Canada, China, Ethiopia, India, Nepal, Peru, the UK and USA, was formally established in 2014. Four years later, the core group of experts has increased to 28 individuals in 18 countries representing a truly global reach (Fig. 1).

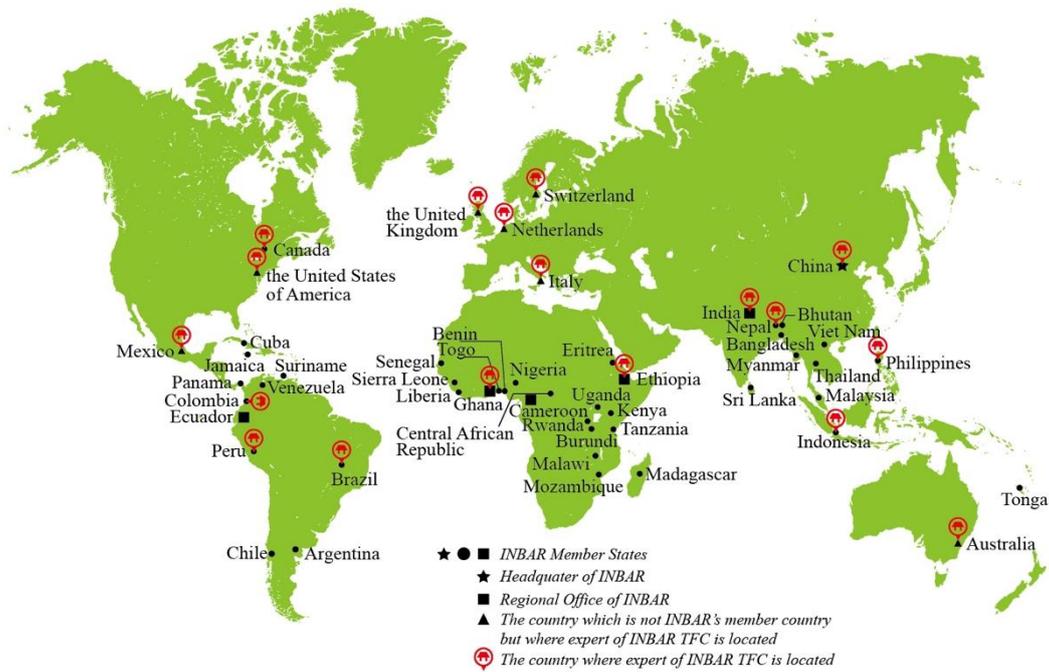


Fig. 1 Distribution of INBAR TFC Experts

2 INTRODUCTION

2.1 Objective of INBAR TFC

The primary objective of INBAR TFC is to act as the world's premier information and knowledge repository on structural uses of bamboo. The specific objectives are as follows: 1) help drive and refine development of new international standards on structural uses of bamboo, as well as help to review and update existing international standards in this area; 2) support global coordination and knowledge dissemination on sustainable bamboo construction; 3) facilitate the development of socio-economically appropriate methodologies for designing and constructing sustainable bamboo housing; 4) contribute towards capacity-building of construction sector stakeholders in sustainable bamboo housing; and, 5) raise awareness and advocate for bamboo construction being mainstreamed in national housing policies and regulations.

2.2 The structure of INBAR TFC

INBAR TFC has a management team consisting of a TFC Manager and a TFC Chair; the latter is a technical expert but not on INBAR staff. This management team is responsible for coordinating the task force. Both the Manager and the Chair are members of the ISO TC 165 WG12 and are responsible for ensuring that the actions of the TFC are integrated into ISO's international standard development. At present, Ms. Kewei Liu, the Global Bamboo Construction Programme Coordinator of INBAR is the Manager of INBAR TFC and David Trujillo, Assistant Professor at Coventry University in the UK is the Chair of the group. At present, the TFC experts are as follows:

Denamo Addissie: Addis Ababa University, Ethiopia

Nripal Adhikary: ABARI, Nepal

Yann Barnet: San Martin University, Peru

Ramesh Chaturvedi: Indian Institute of Technology (retired), India
Juan Francisco Correal Daza: University of the Andes, Colombia
Edwin Zea Escamilla: University of Zurich, Switzerland
Romildo D. Toledo Filho: Federal University of Rio de Janeiro, Brazil
Verónica María Correa Giraldo: KALTIA and BAMBUTERR, Mexico
Mateo Gutierrez Gonzalez: University of Queensland, Australia
Kent Harries: University of Pittsburgh, USA
Sebastian Kaminski: ARUP, UK
Sanjeev Kappe: Konkan Bamboo & Cane Development Center, India
Emmanuel Appiah Kubi: CSIR-Forestry Research Institute, Ghana
Mauricio Cardenas Laverde: Studio Cardenas Conscious Design, Italy
Andrew Lawrence: ARUP, UK
Haitao Li: Nanjing Forestry University, China
Luis Felipe Lopez: Base Bahay Foundation, Philippines
Rodolfo Lorenzo: University College London, UK
Michael Ramage: University of Cambridge, UK
Hector Archila Santos: Amphibia BASE Ltd, UK
Bhavna Sharma: University of Bath, UK
Greg Smith: University of British Columbia, Canada
Martin Tam: Able Mart Limited, Hong Kong, China
Caori Patricia Takeuchi Tam: National University, Colombia
Arjan Van Der Vegte: Moso International, The Netherlands
Andry Widyowijatnoko: Bandung Institute of Technology, Indonesia
Qingfeng Xu: Shanghai Research Institute of Building Sciences, China
Biographical information of all experts is provided on INBAR's website.

2.3 *Membership*

2.3.1 *The principles and the benefits of membership*

Membership in INBAR TFC is on a voluntary basis. Benefits of TFC membership are as follows:
1) experts are first option candidates to take on short consultancies for INBAR on bamboo construction related topics; 2) experts may leverage their membership when applying for grants; 3) experts publish their profile and links to their latest work through INBAR's network.

2.3.2 *How to become a member of INBAR TFC?*

INBAR TFC is open to new members, who can substantively add to the expertise of the group. To be admitted as a new expert to the INBAR TFC. Information on the application process is available from the TFC Manager - Ms. Liu Kewei - kwliu@inbar.int.

2.4 *Communications*

The TFC communicates primarily via email. Virtual meetings are organized for small groups of experts to discuss specific projects. The TFC meets once per year to discuss new standards and the amendment of existing ones, as well as to share research results and findings and agree on an annual action plan for the task force.

3 WHAT IS INBAR TFC DOING?

At present, INBAR TFC mainly focuses on the following works on bamboo construction related topics: 1) standardisation for structural uses of bamboo; 2) production of high quality publications; 3) international projects; 4) consultancy services; 5) international conferences; and, 6) capacity-building for bamboo construction professionals.

3.1 *Standardization work for structural uses of bamboo*

3.1.1 *International standardization work*

Since INBAR officially established TFC in 2014, ISO TC/165 WG12 consists of a group of bamboo construction experts mainly from INBAR TFC. Many TFC members have been nominated representatives of or “advisors” to their TC165 national standardisation bodies. As introduced in the background of this paper, INBAR has engaged in the international standardization work since the early 2000s. Through the end of January 2019, ISO published four international standards and one technical report related to bamboo construction as follows:

ISO22156:2004 Bamboo — Structural Design;

ISO22157-1:2004 Bamboo — Determination of Physical and Mechanical Properties — Part 1: Requirements; (Withdrawn)

ISO/TR 22157-2:2004 Bamboo — Determination of Physical and Mechanical Properties — Part 2: Laboratory Manual; (Withdrawn)

ISO19624:2018: Bamboo Structures — Grading of Bamboo Culm — Basic Principles and Properties;

ISO22157:2019: Bamboo Structures -- Determination of physical and mechanical properties of bamboo culms -- Test methods

ISO22156, ISO22157-1 and ISO/TR 22157-2 were published in 2004. In January 2019, ISO 22157:2019 was published while ISO22157-1 and ISO/TR22157-2 were withdrawn. Led by David Trujillo, the revised Standard ISO 22157 adds two additional test methods not included in 2004 and revises a number of other test methods with the intent of improving the utility – and therefore hopefully the adoption – of the methods and Standard. It is the intent of WG12 to withdraw

ISO 22157-2. This “Laboratory Manual” would provide better utility as a curated ‘living document’ maintained by INBAR to support the use of ISO 22157:2019.

In September 2018, ISO published another new standard ISO19624:2018 which deals with the structural grading of bamboo culms for construction. The new standard is the final output of an INBAR-funded project, “Strength grading of bamboo”, led by David Trujillo from 2013 to 2016. Trujillo then led the ISO 19624 standard development effort from 2014 to 2018. This was the first ISO Standard developed with the support of the INBAR TFC. The aim of this standard is to provide the framework for any national or locally adopted grading process adopted anywhere in the world. It identifies criteria that should be considered in a visual grading protocol, and outlines the basis on which declared capacity or strength values would be arrived at.

In addition to the published ISO 19624 and ISO 22157, WG12 is currently revising another existing ISO standard (ISO 22156) and developing two new standards (NWIP23478 and another standard about engineered bamboo products yet not formally proposed to ISO) as follows:

- Revision of ISO 22156:2004. Led by Kent Harries, a complete revision of ISO 22156 is underway. This revision will provide both capacity and stress-driven approaches to design and provide means of design or acceptance of details, particularly for connections. The revised document builds upon the considerable research and development conducted in the last 20 years and better integrates ISO 22157, ISO 19624 and other modern ISO standards. The work is presently underway at the Committee Document stage: CD22156: Bamboo Structures — Bamboo Structural Design

- NWIP23478: Bamboo Structures — Engineered Bamboo Products — Test Methods for Determination of Physical and Mechanical Properties. This new test methods Standard, led by Arjan van der Vegte and Bhavna Sharma, is a landmark for the development of international standardization work for engineered bamboo materials. Since the 1990s, industrially produced engineered bamboo products like bamboo flooring have been developed and introduced to the international market. Recently, engineered bamboo is being used increasingly for external features of buildings, as well as interior finishes. This has boosted the demand for engineered bamboo products (van der Vegte, 2017). This new project will develop test methods mainly for two types of engineered bamboo products: glue laminated bamboo and bamboo scrimber.

In order to make clear that the scope of standards what ISO TC165 is developing is different from ISO TC296 (Bamboo and Rattan Technical Committee, which was established in 2015 with its Secretariat in China), the title of the standards to be developed in TC165 will begin with “Bamboo Structures”.

3.1.2 *National standardization work*

In addition to the work on international standardization, INBAR also works very closely with national standardization authorities in different countries, like China, Ecuador, India, Ethiopia and Kenya. For example, INBAR has close collaboration with the China Southwest Architectural Design and Research Institute (CSCEC) which mirrors ISO/TC165 and the China Association for Engineering Construction Standardisation committees responsible for bamboo and timber standards. CSCEC helps to nominate Chinese experts to participate in the development of international standards of bamboo construction in ISO/TC165 and is the management organization supervising the development of association standards for bamboo construction. Since China revised its standards policy in 2015, the status of association standards has been elevated while

it is difficult to apply for any new national standards in the future. Currently, two Chinese members of INBAR TFC, Xu Qingfeng and Li Haitao, are leading the development of four association standards for engineered bamboo in China. As CSCEC is very familiar with the international standardization work in ISO as well as for the association standards in China, it is possible a new chapter on bamboo structures will be developed for future revisions of the Chinese national timber standard.

3.2 *International Projects*

Although the membership and all the work of INBAR TFC is on a voluntary basis, the relationship between members have been enhanced greatly since the group was established. In the past four years, several international projects were successfully implemented with the cooperation of the INBAR TFC.

3.2.1 *Bamboo in the Urban Environment*

Led by the University of Pittsburgh and Coventry University with INBAR as a partner and funded jointly by the US Department of State and UK Council, this project brought together leading experts in various streams of bamboo research to carry out extensive, cutting edge analysis and testing to further enable the safe use of bamboo in urban centers. The resulting collaborative research has significant technical and social relevance through its potential to reduce the cost and environmental impact of safe housing for a significant proportion of the world's population. This work addressed the global grand challenges of urbanization and resilience in the face of natural hazards and climate change through facilitating the use of a renewable 'green' material.

The project funded three international symposia (Winnipeg 2015, Pittsburgh 2016 and Bogor (Indonesia) 2017) reaching (and supporting) a total of 83 registered participants representing 18 countries, 25 universities, 14 companies, 5 inter/governmental agencies and 3 NGOs. The attendees ratified the Pittsburgh Declaration in 2016 and reconfirmed this in 2017. The project also supported three international graduate student research exchanges. At least 15 journal articles have been developed from the collaborations initiated as a result of this project. A number of research proposals, including successful US National Science Foundation funding also resulted.

3.2.2 *The BIM Bamboo project*

Led by University College London (UCL) and funded by the UK Engineering and Physical Sciences Research Council (EPSRC) this project is focused on developing new digital design and fabrication workflows for bamboo poles following the principles of Building Information Modelling. INBAR's support enabled a field trip to China to trial these processes and introduce stakeholders to the potential of these technologies to stimulate growth in the bamboo construction sector and reduce the negative environmental effects of intensive manufacturing. The close links developed following this field trip led to a successful application to the UK-China Joint Research and Innovation Partnership Fund (British Council/CSC) to further develop this research during a six-month PhD research placement in Nanjing Forestry University.

3.2.3 INBAR Garden Pavilion

For the upcoming 2019 Beijing Horticultural Expo, INBAR invited architect Mauricio Cardenas Laverde to work with a local engineering company in China to design and construct an innovative INBAR Garden-Pavilion having an area of 3600 square meters. This project will provide a great opportunity for INBAR to showcase contemporary uses of the traditional natural material “Bamboo”. The architectural concept, from which the project has been developed through all the following phases, is that of melting together architecture, engineering and landscape in order to express bamboo to its maximum. This idea presented by the Colombian architect based in Milan Italy in the architectural Design Concept and Design Development has generated a fruitful international cooperation between experts from different professional fields and backgrounds following the research and innovation approach of INBAR and its Task Force.

3.3 Production of High Quality publications

3.3.1 Technical report or working report

Since its establishment in 2014, INBAR TFC has published a series of technical or working reports about bamboo construction. Electronic versions are available on INBAR’s website and can be downloaded for free.

1. Bamboo Test-kit-in-a-Back Pack (Fig. 2)

This digital publication series illustrates the fabrication and use the “Test-kit-in-a-Back Pack” for rapid field assessment of bamboo mechanical and material properties using four ISO 22157 test methods (Glucksman and Harries 2015). It includes two parts: the Technical Report describes the fabrication of and provides reference for the use of the kit. the User’s Manual, presently available in six languages (English, Spanish, Portuguese, Chinese, Haitian Creole and French), is a simple illustrated guide to performing the tests.

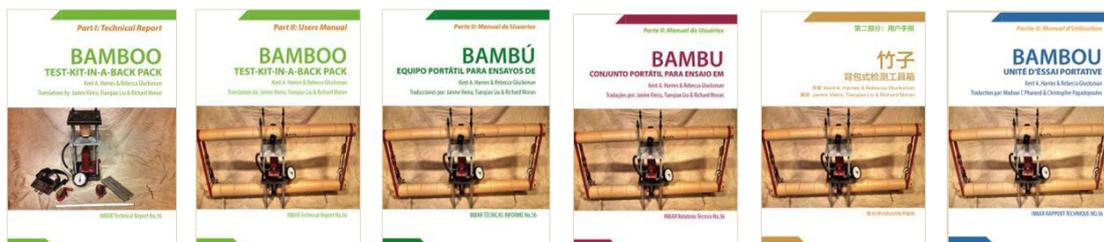


Fig. 2 Bamboo Test-kit-in-a-Back Pack (Harries et al. 2016)

2. Grading of Bamboo (Fig. 3a)

This INBAR Working Paper (INBAR WP) presents research into potential grading methodologies for one species of bamboo – *Guadua angustifolia* Kunth – and recommends criteria for both visual g and machine grading (Trujillo, 2016). The report also represents critical background material for the development of ISO 19624. For visual grading, the diameter of bamboo culms is deemed to be an important consideration when grading for flexural capacity. Wall thickness

is considered to be critical to shear and tension perpendicular capacities. For machine grading, three main properties were found to be significant: flexural stiffness is important for the design of beams; slender struts and portal frames; and linear mass is adopted to infer density. The INBAR WP suggests that additional properties that may be critical to design for other applications should be further researched including: shear strength or tensile strength perpendicular to fibers; both of which are important to the process of connection design. Implemented effectively, the grading methodologies presented in the report have the potential to enhance the supply of bamboo and deliver positive engineers, and consumers. The English e-version is available on INBAR's website.

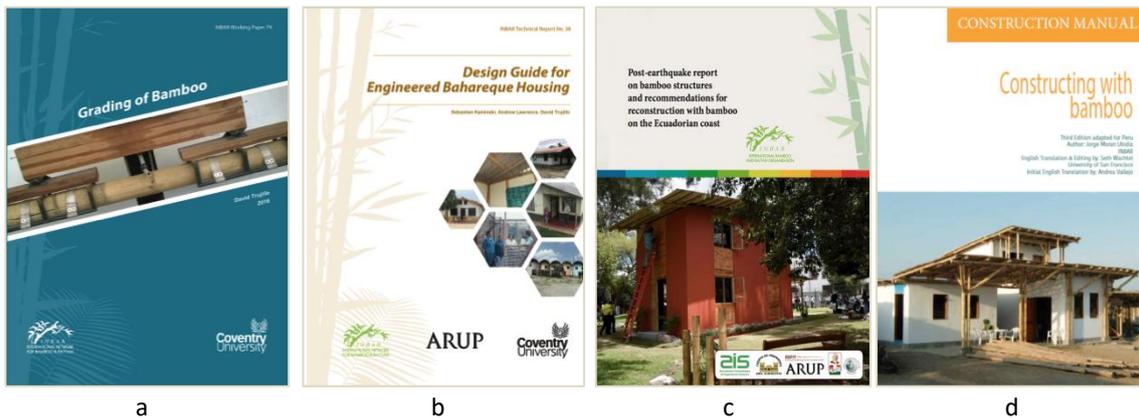


Fig. 3 Published INBAR TFC Publications

Photos are from INBAR: Grading of Bamboo (a); Design Guide for Engineered Bahareque Housing (b); Post-earthquake report on bamboo structures and recommendations for reconstruction with bamboo on the Ecuadorian coast (c); Constructing with Bamboo (d)

3. Design Guide for Engineered Bahareque Housing (Fig. 3b)

Engineered bahareque is a modified form of construction that takes traditional wattle-and-daub type housing and improves upon it, using modern materials, knowledge, and construction techniques (Kaminski et al. 2016). Engineered bahareque houses have successfully been constructed in various countries including: Costa Rica, Colombia, Nepal, Ecuador, El Salvador, and The Philippines. When properly designed and built, they have demonstrated their effectiveness as an affordable, hazard-resilient, safe and durable form of housing. This technical report is intended as a guide for both architects and engineers, addressing both conceptual and detailed design and construction of engineered bahareque housing in both developed and developing countries around the world. The report provides guidance on design for structural (wind and earthquake) loads. Typical construction details are also provided, along with guidance for quality control during construction. The English, Spanish and French e-versions are available on INBAR's website.

4. Post-earthquake report on bamboo structures and recommendations for reconstruction with bamboo on the Ecuadorian coast (Fig. 3c)

This INBAR TP describes the potential for bamboo to be used more widely in Ecuador (and in other countries) to build low-cost housing (Drune et al. 2016). Topics covered include the high tolerance of bamboo to earthquake loads, how homes can be built from bamboo to make

them earthquake-resistant, and how to ensure that homes built from bamboo have lasting durability. The report also covers the availability of bamboo supplies and how these might be improved. The English and Spanish e-versions are available on INBAR's website.

5. Constructing with bamboo (Fig. 5d)

The translated third edition of this construction manual (Ubidia, 2015), first published in 2005, provides a basic, hands-on guide to using bamboo for construction: from choosing and treating the raw material, to putting together durable and safe structures. It draws heavily on experiences from the Andean region of Latin America, where bamboo is a vernacular construction material. The publication includes photographs and diagrams to illustrate best practices. The English and Spanish e-versions are available on INBAR's website.

3.3.2 INBAR Construction Task Force Newsletters (Fig. 6)

INBAR also published a series of INBAR Construction Task Force Newsletters which aim to share the latest research, projects, events and publication information from all TFC members with INBAR's member states and all the stakeholders of bamboo construction.



Fig. 6 INBAR Construction Task Force Newsletters

3.4 Consultancy Services

With the resources of bamboo construction experts around the world, INBAR TFC began offering consultancy services for third parties in 2017. For example, CRS (Catholic Relief Services) in India commissioned INBAR to conduct a study on bamboo shelters in the State of Odisha where frequent flooding, cyclones and monsoon rains cause widespread damage to shelters. The aim of the project is to understand the feasibility of using locally available bamboo for shelter construction, and to recommend strategies and approaches to improve bamboo shelters in both post-disaster and long-term development context. Sebastian Kaminski, an expert of INBAR TFC from Arup accepted the task and carried out a field visit. The assessment found that bamboo clearly plays an essential role in the shelter and ancillary structures throughout rural communities in the State. Unfortunately, current levels of knowledge along with the adoption of techniques that support optimal utilization of bamboo for shelter are low.

As a unique intergovernmental organization working on bamboo and rattan, INBAR receives many inquiries; enquiries about construction are most frequent and include queries on methods of treatment, how to build houses using local species, and where to get training about bamboo construction, etc. Although the experts of the INBAR TFC do their best to provide the information requested, the most frequent inquiries should become the topics of the coming INBAR publications.

3.5 International conferences

Since 2015, INBAR TFC has been organizing many international conferences on bamboo construction around the world to promote the internal communication between TFC experts while disseminating the latest knowledge and information of bamboo construction to stakeholders as well as the public. The Bamboo in the Urban Environment project (see above) provided significant resources in this regard and helped to accelerate ISO Standards development efforts.

For disseminating the latest knowledge and information of bamboo construction, INBAR organized several international conferences around the world. For instance, in 2016, a side event, “Bamboo housing for sustainable, resilient urban development and post-disaster recovery” was organized by INBAR in Quito during Habitat III. Several TFC experts were invited to introduce their own experiences on building temporary bamboo shelters after natural disasters. During the World Bamboo and Rattan Congress 2018 (BARC2018) which was held in June, 2018 in Beijing, INBAR organized the Sustainable Bamboo Building Materials and Third International Conference on Modern Bamboo Structure (ICBS2018) with local partners in China. Almost half of TFC experts were present in Beijing to share the latest information of bamboo construction with more than 1000 participants from around the world.

An important effort in bamboo construction is to advocate and bring the material into mainstream construction. In April 2019, a number of TFC members will lead a special session at the American Society of Civil Engineers (ASCE) Structures Congress on bamboo materials and construction.

3.6 Capacity-building for bamboo construction professionals

Most of TFC experts are from global universities where they teach and train students from architecture, engineering and landscape departments every year. However, the majority of higher education and vocational training institutions across the world do not provide exposure to or training related to the use of bamboo materials for construction (Liu and Frith 2013). Therefore, professional and trades capacity-building for bamboo construction is an urgent need.

INBAR joined the effort with Prof. Xiao’s team in China and trained more than 100 students from around the world in the “Village Bamboo Summer Programme” from 2017 to 2018. However, the number of trainees is limited due to limited financial support. The issue of adequate support cannot be understated: while students from most developed countries can generate financial support for such activities, few students from developing areas have access to the same resources. Therefore, we need to look for other ways to involve more students from around the world to get chances to interact with bamboo.

INBAR is planning to organize the International Bamboo Construction Competition (IBCC) in 2019 with the aim of providing an opportunity for college students of architecture, civil engineering, landscape and other bamboo construction related majors to get access to bamboo.

The main theme of IBCC is to explore the potential use of existing bamboo construction materials in the market, for both round bamboo poles and various types of engineered bamboo. The competition topic(s) will be designed by TFC experts. Wherever participating students come from, they all will have chances to build bamboo houses once they participate in the competition when selected as finalists.

4 THE FUTURE WORK PLAN OF INBAR TFC

On the track of current development, the TFC will focus on the following aspects of the work about bamboo construction in the next few years:

- Promote the international standardization work step by step and promote the adoption of ISO standards by more countries;
- Strengthen cooperation with local standardization authorities in different countries to promote the development of national or regional standards;
- Carry out international projects of bamboo construction in Asia, Africa and South America.
- Publish more bamboo construction publications to meet the need of all stakeholders; and,
- Find sustained financial support to strengthen the capacity-building for bamboo construction professionals.

5 CONCLUSION

INBAR TFC is an explorative way to promote the development of a global bamboo construction industry. Although it is a new concept, a healthy group has grown up with many achievements on bamboo construction related topics in the past four years. Aiming to act as the world's premier information and knowledge repository on structural uses of bamboo, INBAR TFC sincerely invites bamboo construction experts from around the world to work with us.

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