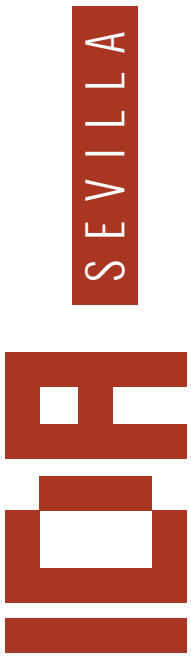
SEVILLA

IDA: ADVANCED DOCTORAL RESEARCH IN ARCHITECTURE



IDA: ADVANCED DOCTORAL RESEARCH IN ARCHITECTURE

Antonio Tejedor Cabrera, Marta Molina Huelva (comp.)

IDA: Advanced Doctoral Research in Architecture
Sevilla: Universidad de Sevilla, 2017.

1.408 pp. 21 x 29,7 cm

ISBN: 38765987928376375
Legal Dep.: 236235768336

EDITOR
Universidad de Sevilla

COMPILERS
Antonio Tejedor Cabrera
Marta Molina Huelva

DESIGN AND LAYOUT BY
Pablo Blázquez Jesús
María Carrascal Pérez
Daniel Longa García
Marina López Sánchez
Francisco Javier Navarro de Pablos
Gabriel Velasco Blanco

ADMINISTRATION AND SERVICES STAFF
Adoración Gavira Iglesias

Seville, november 2017

SEVILLA

IDR

ORGANIZED BY

INSTITUTO UNIVERSITARIO ARQUITECTURA Y CIENCIAS DE LA CONSTRUCCIÓN

Universidad de Sevilla eidus Escuela Internacional de Doctorado

arquitectura Escuela Técnica Superior Universidad de Sevilla

COLLABORATORS

Consejo Andaluz de Colegios Oficiales de Arquitectos

fundación arquia

All manuscripts have been submitted to blind peer review, all content in this publication has been strictly selected, the international scientific committee that participates in the selection of the works is of international character and of recognized prestige, an scrupulous method of content filtering has been followed in terms of its veracity, scientific definition and plot quality.

COMMITTEES

CONFERENCE CHAIRPERSONS

Antonio Tejedor Cabrera, *Coordinator of the PhD Program in Architecture and Director of the University Institute of Architecture and Construction Sciences, Professor Department of Architectural Design, University of Seville*

Marta Molina Huelva, *Secretary of the University Institute of Architecture and Construction Sciences, Professor of the Department of Building Structures and Geotechnical Engineering, University of Seville*

ORGANISING COMMITTEE

María Carrascal Pérez, *Department of History, Theory and Architectural Composition, University of Seville*

Mercedes Linares Gómez del Pulgar, *Department of Architectural Graphic Expression, University of Seville*

Ángel Martínez García-Posada, *Department of Architectural Design, University of Seville*

Pilar Mercader Moyano, *Department of Architectural Constructions I, University of Seville*

Domingo Sánchez Fuentes, *Department of Urban Planning and Spatial Planning, University of Seville*

Manuel Vázquez Boza, *Department of Building Structures and Land Engineering, University of Seville*

CONFERENCE SECRETARY

Pablo Blázquez Jesús, *Ph.D. student, Department of Architectural Design, University of Seville*

Marina López Sánchez, *Ph.D. student, Department of Architectural Design, University of Seville*

FORMATO

Mesas temáticas
Las mesas temáticas son lugares de presentación de las metodologías y las experiencias de jóvenes doctores y de estudiantes de doctorado procedentes de las diferentes universidades. Son gestionadas por los propios estudiantes de doctorado que generan unas conclusiones para ser debatidas y reelaboradas en la sesión plenaria final. Las sesiones se desarrollan de manera simultánea con la presentación de los *papers* seleccionados en la *call*, organizados en cuatro áreas o líneas temáticas:

1. Tecnologías de la Arquitectura
2. Vivienda, Ciudad y Territorio
3. Patrimonio y Rehabilitación
4. Análisis y Proyectos Avanzados

Taller
El workshop del Congreso se orienta hacia el análisis de los problemas y las necesidades de gestión de los Programas de Doctorado con el fin de extraer conclusiones que pueden ser útiles a las Universidades implicadas. En el workshop participan los coordinadores de los programas de Doctorado en Arquitectura y los representantes de los doctorandos. Son temas de debate: las líneas de investigación, las metodologías, las necesidades organizativas de los programas de doctorado, el Doctorado Internacional y el Doctorado Industrial, y el futuro de la investigación doctoral.

Sesiones Plenarias
Las sesiones plenarias se realizan al inicio y al final del Congreso. En la primera sesión de bienvenida e introducción al Congreso se invita a participar a expertos investigadores del panorama nacional e internacional y a los coordinadores de los programas de doctorado. En la segunda sesión plenaria se propone un debate abierto para la reelaboración de las propuestas extraídas del taller y de las mesas temáticas. Sirve también de clausura con la presentación de las conclusiones finales del Congreso IDA_Sevilla 2017.

SCIENTIFIC COMMITTEE

José Aguiar-Universidade de Lisboa
Benno Albrecht-Università IUAV di Venezia
Francisco Javier Alejandre Sánchez-Universidad de Sevilla
Darío Álvarez Álvarez-Universidad de Valladolid
Antonio Ampliato Briones-Universidad de Sevilla
Joaquín Antuña-Universidad Politécnica de Madrid
Ángela Barrios Padura-Universidad de Sevilla
José María Cabeza Laínez-Universidad de Sevilla
Pilar Chías Navarro-Universidad de Alcalá
Juan Calatrava Escobar-Universidad de Granada
María Carrascal Pérez-Universidad de Sevilla
Helena Coch Roura-Universitat Politècnica de Catalunya
Jorge Cruz Pinto-Universidad de Lisboa
Carmen Díez Medina-Universidad de Zaragoza
Fernando Espuelas Cid-Universidad Europea
Alberto Ferlenga-Università IUAV di Venezia
Luz Fernández-Valderrama-Universidad de Sevilla
Vicente Flores Alés-Universidad de Sevilla
María del Carmen Galán Marín-Universidad de Sevilla
Jorge Filipe Ganhão da Cruz Pinto-Universidade de Lisboa
Carlos García Vázquez-Universidad de Sevilla
Sara Girón Borrero-Universidad de Sevilla
Francisco Gómez Díaz-Universidad de Sevilla
Amparo Graciani-Universidad de Sevilla
Francisco Granero Martín-Universidad de Sevilla
Francisco Hernández Olivares-Universidad P. de Madrid
Miguel Ángel de la Iglesia-Universidad de Valladolid
Paulo J.S. Cruz-Universidade do Minho
Francesc Sepulcre-Universitat Politècnica de Catalunya
Ángel Luis León Rodríguez-Universidad de Sevilla
Mercedes Linares Gómez del Pulgar-Universidad de Sevilla
María del Mar Loren Méndez-Universidad de Sevilla

FOREWORD

The Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), in collaboration with the Escuela Técnica Superior de Arquitectura (ETSAS) and the Escuela Internacional de Doctorado (EIDUS) of the University of Seville are pleased to welcome the heads of research from both Spanish and overseas universities, consolidated researchers and young doctoral researchers to the First International Congress of Doctorates in Architecture IDA Sevilla, from 27th to 28th November 2017.

The **IDA_Sevilla 2017** Congress offers a general perspective of doctoral studies in the field of Architecture and its related disciplines: urban planning, heritage, landscape, construction technologies and sustainability. In the new context generated after the elimination of the doctoral programs prior to RD 99/2011, it is necessary to carry out an analysis of the complex panorama that the former programs and the new doctoral programs have drawn up, in order to know in detail both what has been achieved so far, as well as the challenges of the future of advanced doctoral research in Spain, in the European and international context.

The startling changes that are taking place in our society call for a vision of research that is not compartmentalised into traditional disciplines or areas of knowledge. Doctoral research in Architecture must adapt to changes in society and to the sustainable productive needs of territory.

The congress will take place at the Escuela Técnica Superior de Arquitectura de Sevilla, organised in four simultaneous thematic tables, a workshop on the administration of doctoral programs and two plenary sessions.

The **thematic tables** are aimed at young doctors and doctoral students of the different participating universities who will present their experiences and methods of their research - in development or recently concluded. The participation in the thematic tables is carried out through the selection procedure with blind peer review established in the call for papers and through express invitations to the debate. The almost 70 communications have been structured in four thematic areas representative of the PhD programs in Architecture.

The **open workshop** will be held in two sessions with the participation of the coordinators of each of the collaborating programs of the Congress, and professors with extensive doctoral experience. Its objectives are multiple: to discuss the experiences undertaken in the different universities, exchange ideas about the approaches and models applied, address the challenges of internationalization and management, launch the new Industrial Doctorate with companies and public agencies, and so on.

There are two **plenary sessions**: one, a plenary session of introduction to the congress, with the participation of coordinators of national and foreign doctoral programs; and a closing plenary session, with an open debate for the going-over of the conclusions drawn from the thematic tables and the workshop, and the presentation of final conclusions.

We thank the Escuela Internacional de Doctorado of the University of Seville, and the Escuela Técnica Superior de Arquitectura de Sevilla for the support they have provided for the holding of this meeting, which contributes so much to the clarification of the future of doctoral studies in Spanish universities in the face of the great challenge of internationalization and the continuous improvement of the quality of research in Architecture. We also thank those responsible for the participating Doctoral Programs, the Architecture library of the US and all the participants and attendees.

Antonio Tejedor Cabrera
Marta Molina Huelva

Conference Chairpersons IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

PRÓLOGO

El Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), con la colaboración de la Escuela Técnica Superior de Arquitectura (ETSAS) y la Escuela Internacional de Doctorado (EIDUS) de la Universidad de Sevilla, se complacen en recibir a los responsables de investigación de universidades españolas y extranjeras, a los investigadores consolidados y a los jóvenes investigadores de doctorado en el I CONGRESO INTERNACIONAL DE DOCTORADOS EN ARQUITECTURA IDA_Sevilla, del 27 al 28 de noviembre de 2017.

El congreso **IDA_Sevilla 2017** ofrece una perspectiva general de los estudios de doctorado en el campo de la Arquitectura y sus disciplinas afines: urbanística, patrimonio, paisaje, tecnologías de la construcción y sostenibilidad. En el nuevo contexto generado tras la extinción de los programas doctorales anteriores al RD 99/2011 es necesario realizar un análisis del complejo panorama que han construido los programas extintos y los nuevos programas de doctorado, con el objeto de conocer con detalle tanto lo conseguido hasta ahora como los retos que depara el futuro de la investigación doctoral avanzada en España, en el contexto europeo e internacional.

Los vertiginosos cambios que se están produciendo en nuestra sociedad reclaman una visión de la investigación no compartimentada en disciplinas o áreas de conocimiento tradicionales. La investigación doctoral en Arquitectura debe adaptarse a los cambios de la sociedad y a las necesidades productivas sostenibles en el territorio.

El congreso se celebra en la Escuela Técnica Superior de Arquitectura de Sevilla organizado en cuatro mesas temáticas simultáneas, un taller sobre la gestión de los programas de doctorado y dos sesiones plenarias.

Las **mesas temáticas** están dirigidas a los jóvenes doctores y a estudiantes de doctorado de las diferentes universidades participantes que exponen sus experiencias y métodos sobre las investigaciones en desarrollo o recientemente concluidas. La participación en las mesas temáticas se realiza por el procedimiento de selección con revisión por pares ciegos establecido en la *call for papers* y por medio de invitaciones expresas al debate. Las casi 70 comunicaciones se han estructurado en cuatro áreas temáticas representativas de los programas de doctorado en Arquitectura.

El **taller** de puesta en común se realiza en dos sesiones con la participación de los coordinadores de cada uno de los programas colaboradores del Congreso y de profesores con amplia experiencia doctoral. Sus objetivos son múltiples: debatir sobre las experiencias desarrolladas en las distintas universidades, intercambiar ideas sobre los enfoques y los modelos aplicados, abordar los retos de internacionalización y de gestión, poner en marcha el nuevo Doctorado Industrial con empresas y agencias públicas, etc.

Las **sesiones plenarias** son dos: una sesión plenaria de introducción al congreso, con la intervención de coordinadores de programas de doctorado nacionales y extranjeros; y una sesión plenaria de clausura, con un debate abierto para la reelaboración de las conclusiones extraídas de las mesas temáticas y del workshop y la presentación de las conclusiones finales.

Agradecemos a la Escuela Internacional de Doctorado de la Universidad de Sevilla y a la Escuela Técnica Superior de Arquitectura de Sevilla el apoyo que han proporcionado para la realización de este encuentro que tanto contribuye a clarificar el futuro de los estudios doctorales en las universidades españolas ante el gran reto de la internacionalización y la continua mejora de la calidad de la investigación en Arquitectura. Damos los gracias también a los responsables de los Programas de Doctorado participantes, a la Biblioteca de Arquitectura de la US y a todos los participantes y asistentes.

Antonio Tejedor Cabrera
Marta Molina Huelva

Directores Congreso IDA_Sevilla 2017
Instituto Universitario de Arquitectura y Ciencias de la Construcción IUACC

OBJECTIVES

1. Analyze the research lines of the various programs and build a map of doctoral research in Spain with the support of coordinators, tutors / thesis supervisors, doctoral students and young doctors in the disciplines related to Architecture and their related areas.

2. To know the status of doctoral theses in progress or defended in the last three years, selected by means of a call with blind peer evaluation of the doctoral programs participating in the congress.

3. Discuss the structure and university management of doctoral programs in relation to employment challenges, collaboration with the productive sector and national research programs.

4. Exchange experiences with other international doctoral research programs on international mobility management, theses with international mention, co-supervised theses, theses with industrial mentions, etc.

5. No less important, consolidate a national and international network of Doctoral Programs related to Architecture, Urban Planning, Heritage, Landscape, Technologies and related disciplines.

IDA ADVANCED DOCTORAL RESEARCH SEVILLA 2020

LT 1 ARCHITECTURE TECHNOLOGIES

LT 2 HOUSING, CITY AND TERRITORY

LT 3 HERITAGE AND REHABILITATION

LT 4 ANALYSIS AND ADVANCED PROJECTS

FORMAT

Thematic tables
The thematic tables are places to present the methodologies and experiences of young doctors and doctoral students from different universities. They are managed by the doctorate students themselves, who generate conclusions to be debated and reworked in the final plenary session. The sessions are developed simultaneously with the presentation of the papers selected in the call, organized in four areas or thematic lines:

1. Architectural technologies
2. Housing, city and territory
3. Heritage and Rehabilitation
4. Analysis and advanced projects

Workshop
The workshop of the Congress is oriented towards the analysis of the problems and management needs of the Doctorate Programs, with the objective of arriving at conclusions that may be useful to the Universities involved. The coordinators of the Doctorate in Architecture programs and the doctoral students' representatives will participate in the workshop. The following are topics for debate: lines of research, methodologies, organizational needs of the doctoral programs, the International Doctorate and the Industrial Doctorate, and the future of doctoral research.

Plenary Sessions
The plenary sessions are held at the beginning and end of the Congress. In the first session of welcome and introduction to the Congress, researchers from the national and international scene and the coordinators of the doctorate programs are invited to participate. In the second plenary session an open debate is proposed for the going over of the proposals drawn from the workshop and the thematic tables. It also serves as a closing ceremony with the presentation of the final conclusions of the 2017 IDA_Sevilla Congress.

Beams were tested in bending, according to UNE-EN 408 (2011) (Fig.6), and the effects of GFRP reinforcements in the MOE, ultimate strength (MOR) and improvement in the dispersion of results were measured and analyzed. The failure modes of each beam were also observed.

Fig. 6 Duo beams test according to UNE EN-408.

The results of these tests on reinforced Populus beams are shown in Figure 7, with a significant improvement with increments in the moduli of elasticity of 10% for GFRP reinforcements of 1200 gr / m2 and of around 15% for GFRP reinforcements of 2400 gr / m2.

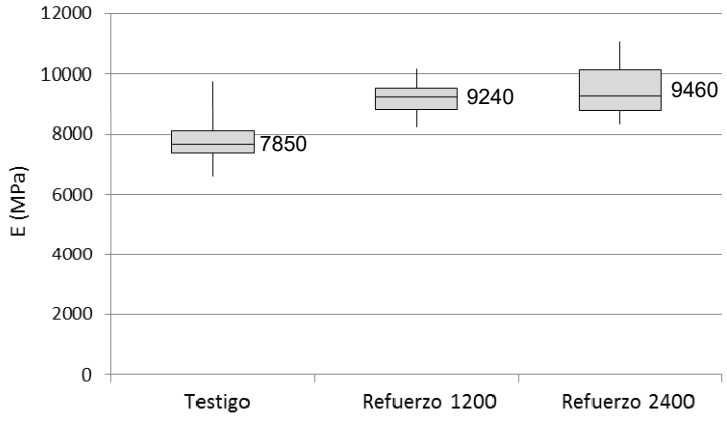


Fig. 7 Box and whiskers graph with the modulus of elasticity of poplar duo beams.

At the present time only the previous data analyzes of the poplar duo beams are available, and the bending test of the Pinaster beams is scheduled for close dates.

3.3. Creep tests

In order to study the long-term behavior of the reinforced duo beams, in relation to unreinforced ones, a long-term test has been set up, according to UNE-EN 380 (1998), with a total load of 10 kN, which represents approximately 50% of ultimate load of the beams. The ambient conditions of the laboratory remain nominally constant, 20 ± 2ºC; 65 ± 5% humidity in air, corresponding to a hygroscopic balance of 12% HR in the wood (Kollman 1959).

The load is applied by means of the filling and filling of individual tanks (Figure 8), single wall polyethylene (PE), with a useful capacity of 1000 liters and dimensions of approximately 1650x720x1260 mm, with upper filling nozzles and lower emptying device, with locking key. The support of the tanks on the beams is made with an intermediate resistant platform, which allows to apply the load on the beams on two points, following the support distances proposed by UNE-EN 408 (2011).

OBJETIVOS

1. Analizar las líneas de investigación de los diversos programas y construir el mapa de la investigación doctoral en España con el apoyo de los coordinadores, los tutores/directores de tesis, los doctorandos y los jóvenes doctores en las disciplinas relacionadas con la Arquitectura y sus áreas afines.

2. Conocer el estado de las tesis doctorales en marcha o defendidas en los últimos tres años, seleccionadas por medio de una *call* con evaluadores por pares ciegos de los programas de doctorado participantes en el congreso.

3. Debatir sobre la estructura y la gestión universitaria de los programas de doctorado en relación con los retos de empleo, colaboración con el sector productivo y los programas nacionales de investigación.

4. Intercambiar experiencias con otros programas de investigación doctoral a escala internacional sobre gestión de la movilidad internacional, tesis con mención internacional, tesis en cotutela, tesis con mención industrial, etc.

5. No menos importante, consolidar una red nacional e internacional de Programas de Doctorado relacionados con la Arquitectura, la Urbanística, el Patrimonio, el Paisaje, las Tecnologías y sus disciplinas afines.

IDA INVESTIGACIÓN DOCTORAL AVANZADA

LT 1 TECNOLOGÍAS DE LA ARQUITECTURA

LT 2 VIVIENDA, CIUDAD Y TERRITORIO

LT 3 PATRIMONIO Y REHABILITACIÓN

LT 4 ANÁLISIS Y PROYECTOS AVANZADOS


IDA
SEVILLA

LT 1

TECNOLOGÍAS DE LA ARQUITECTURA

ARCHITECTURE TECHNOLOGIES / TECNOLOGÍAS DE LA ARQUITECTURA

METHODOLOGY OF COMPLEMENTARY ASSESSMENT TO A LIFE CYCLE ANALYSIS OF THE SUSTAINABILITY OF USE GADUA BAMBOO IN CONSTRUCTIVE SOLUTIONS

Torres Rojas, José Eduardo [(1)(*)] Neila Gonzalez, Francisco Javier [(2)]

(1)(*) Evidally GBS. Research and consulting Oviedo University - jetorres@evidally.net.
(2) Universidad Politécnica de Madrid Professor - fjavier.neila@upm.es

Abstract: Initial breakthroughs in research work for the development of a methodology that allows comparative evaluation of the degree of contribution to the increment of the integral sustainability of a building or constructive solution achieved with the use of bamboo Guadua. Using as a basis the parameters that are most suitable among all those that can relate the material and sustainability, which will allow later to make such assessment and that are complementary to those of a life cycle analysis. Environmental impacts related to ecosystem services are clearly identified. In this order, there are the services provided by the soils with guadua forests, especially those that have to do with water sources, their contribution to water regulation and contribution to the conservation of biodiversity. The potential impact on the socio-cultural aspect is important, highlighting within the cultural variable the precarious knowledge of the Guadua resource and its possibilities, resulting in an insipid sense of identity with the material and very low stimulation and support to its use by the institutions state or private entities. In sum, these and other aspects are analyzed in the first instance, identifying possible sustainability indicators that can be assessed for the subsequent elaboration of a file, the basis of an eco-labeling. This evaluation will complement its physical and mechanical properties, allowing to define its efficient use as a utility for the designer at the time of its choice in the implementation of constructive solutions.

Keywords: Bamboo, Guadua, Methodology, Sustainability, Construction

1. Introduction

The environmental benefits of bamboo and its contribution to the mitigation of environmental problems are highlighted, its multiple applications for all types of solutions ranging from food products to structural elements, through textile, to paper production and energy source in shape of charcoal (Minke 2010). Its properties are mentioned as a CO2 sequestrator, a water basin regulator and a microclimate maintainer. It is not strange to refer to a natural, plant material that has about 1500 different species (Liese 2015), as well as multiple and numerous applications.
In this context, a material that contributes from the environmental, social and, of course, economic point of view deserves to be taken into account in order to delve more particularly into at least one of the species, and in particular that which is considered, as the most suitable for use in construction, because to refer to the bamboo used in construction, is to speak of the most important species according to their already demonstrated physical-mechanical characteristics, in a multitude of thesis of end of career, masters and doctoral theses , in this case it is the Guadua Angustifolia Kunth. But similarly could be done with other species such as Dendrocalamus, or Phyllostachys, Chusquea and bambusa (Minke 2010), used throughout the world according to their origin and possibilities, with which reference would be made to its use in construction in about a third of all homes on the planet.
The possibilities offered by the use of Guadua bamboo as a construction material merit the development and structuring of a project aimed at its valuation as a multipurpose and sustainable

resource, recognized by eco-labeling. This implies having a traceability and indicators of contribution to the regeneration and conservation of biodiversity, the social fabric and the improvement of the quality of life, as a complement to a life cycle analysis. In addition to having a technical file containing its characterization and physical and mechanical properties that allow to define its maximum use.
At present, most of the relevant studies related to bamboo species, in their use as construction material, focus their attention on physical and mechanical properties. As material in its natural form (round cane), in the different types of structural joints. Studies focusing in particular on the

determination of their life cycle analysis and environmental costs are more scarce and focused on specific processes involving the material. Within the Design for Sustainable DFS program of the Faculty of Industrial Design Engineering of the Technical University of Delft, the engineer Pablo van der Lugt has carried out a study titled "Bamboo, a sustainable solution for Europe Occidental "as one of its interventions to stimulate the commercialization of bamboo. The work was supervised by Prof. Dr. Han Brezet while the environmental assessments were carried out in close collaboration with Dr. Joost Vogtländer.2002. In part this study focuses on questioning perceived environmental sustainability of industrialized bamboo products and the main research objective of this report is to assess the environmental sustainability of various bamboo based products based on their use in Western Europe, compared to the alternatives of materials in common use, and in particular of wood. Although many bamboo products are currently marketed, generally perceived as environmentally friendly, there are few quantitative assessments of the environmental impact of the material through the Life Cycle Analysis methodology, and none existent involving the sociocultural environment. The only studies available at the moment are a study by Dr. Richard Murphy (Murphy et al., 2004) and another study by the first author for his master's thesis (van der Lugt 2003) published in several journals (van der Lugt et al., 2003, van der Lugt et al., 2006). And the most recent published by himself, Engineered Bamboo Products - A Sustainable Choice?: Industrialized Natural Resources for Architecture and Construction (van der Lugt, 2017).
This paper intends to help in this sense and more precisely to contribute to the development of a methodology that, in addition to reaffirming the value of Guadua bamboo as a construction material, has information that values its contribution to sustainability in solutions constructive in which their use is proposed.

1.1. The Guadua *angustifolia Kunth*

The species Guadua angustifolia as a species and natural material stands out for its culms, which reach up to 30 meters in height and 15 centimeters in diameter (Londoño 2002). In addition, among all the bamboos of america stands out as one of the 20 best in the world (Londoño 2011) thanks to its excellent physical-mechanical properties, applied in the construction sector and possibilities of industrialization, which makes it a natural resource, agro-forestry, with many possibilities and multiple benefits.
In Guadua angustifolia as a species, most research and studies have focused on such areas as: its taxonomy, molecular genetics, phenology, and physiology, as well as its anatomy, associated flora and fauna, biotechnology, biomass, quantification of environmental services, CO2 sequestration, forest inventories, propagation methods, site qualities and physical planting, forms and inputs for fertilization, management and use, preservation and drying, physical and mechanical properties, structural behavior, unions, and market studies (Londoño 2011).
The Guadua Angustifolia is found in a natural state in Colombia, Ecuador and Venezuela, where it forms dominant colonies known as "Guaduales", mainly concentrated in the Andean region, between 0 and 2000 masl. (Londoño 2002). Since the mid-1980s, Guadua angustifolia has been introduced for adaptation in Central America, with the most prominent countries for their interest in and use of the material: Mexico and Costa Rica, and now Panama, and Honduras.
In Colombia, Guadua angustifolia has had a historical, cultural, economic and environmental conservation tradition and the generation of knowledge about this native bamboo, becoming a pioneer country in its structural use and in the development of appropriate constructive technologies for this material in its natural form as a round cane, besides being the only country in America that has developed a series of technical regulations for the quality in its cultivation, preservation and drying, elaboration of furniture and crafts, joints in structures and use in construction, as well as pre-industrialization, as well as a specific chapter for design and construction with Guadua incorporated into the 2010 Earthquake Resistant Regulation (NSR10). Currently, countries such as Peru and Ecuador have already adopted their own Guadua use and construction regulations based on Colombian regulations and adapted to the characteristics of their bamboos.
The guadua is used in construction in its natural, round shape, sections of between 6 and 16 cm in diameter and lengths of 6 to 12 meters, generally used as structural element in roof slabs and columns, in combination with elements of reinforced concrete in buildings gives up to two heights (Fig.1), agricultural structures and pedestrian bridges of up to 25 meters between supports.

Fig. 1 Casa Santoyo by Zuarq architects. La Calera- Bogotá Colombia. Source: Photo by José E. Torres R

In the form of mats, which are the product of a process of unrolling the rod, deriving in elements between 30 and 40 centimeters wide by 3 to 4 meters in length (Fig. 2), ideal for formwork, partitions, enclosures etc. And then there are the cans (Fig. 2), which are the product of longitudinal cuts of the cane with which elements are obtained between 3 and 4 centimeters by 3 to meters long, which are used inter alia as soil support and stairs. Also industrialized structural elements of cans of guadua as is the case of beams and laminated boards.

Fig. 2 Mats (left) and cans (right) of guadua. Source: Photo by José E. Torres R.

1.2. The Guadua as construction material

The Guadua angustifolia stands out within the genus for its structural properties, because it has strong longitudinal fibers, 40% fiber tissue, is large, with a height of up to 30 meters and diameters up to 22 cm, has a high resistance ratio / weight, with average values of compressive strength ranging from 350 kg cm^{-2} to 500 kg cm^{-2}, and of great flexibility, qualities that make it an ideal material in the construction industry (Takeuchi, 2004).

Table 1. Permissible efforts Fi (MPa), CH = 12% (NSR-10 Table G.12.7-1)

Fb Flexión	Ft Traction	Fc Compressión ∥	Fp* Compressión ⊥	Fv Cut
15	18	14	1.4	1.2

∥ = compression parallel to the longitudinal axis.
⊥ = compression perpendicular to the longitudinal axis.
* Perpendicular compression strength is calculated for internodes filled with cement mortar.

Table 2. Modulus of elasticity, Ei (MPa), CH = 12% (NSR-10 Table G.12.7-1)

Average Module E0.5	Percentile Module 5 E0.05	Minimun Module Emin
9.500	7.500	4.000

Eligible efforts according to chapter G12 of Code NSR-10 (Colombian Norm of Design and Construction Resistant Earthquake 2010)

With the Guadua have erected monumental constructions like the pavilion of Colombia in the exposition of Hannover of the 2000, initiating its approval like material of construction in Germany. But the truth is that with the Guadua were mostly building low-cost housing, however, its use has now been extended to luxury housing (Londoño 2002).
Construction costs with the use of Guadua can be reduced by up to 45% compared to other materials (Londoño 2002). Especially for the cost savings of labor, due to its easy manipulation and consequent saving in auxiliary means like cranes, contributing to the minimization of the energy consumption in the assembly of structural elements, especially in prefabricated systems; which makes it an alternative resource in helping to solve the housing deficit in Latin America and with the possibility of being an alternative to the use of structural timbers in the rehabilitation of slabs and the use of terraces in favor of the densification of urban space.
The basic elements of Guadua used in construction are the reeds in their natural, round shape, sections between 6 and 16 cm in diameter and lengths of 6 to 12 meters. There are also the mats, which are the product of a process of unrolling the cane, deriving in elements between 30 and 40 cm wide by 3 to 4 meters long, ideal for forms, partitions, enclosures etc. And then there are the cans and latillas that are the product of longitudinal cuts of the cane with which elements are obtained between 3 and 4 cm by 3 to 4 meters in length.
There are industrialized elements based on bamboo Guadua, such as panels and laminated beams that are commercialized as structural elements, becoming an alternative to those made from wood.

2. Objectives

2.1. General Objective

- To present the advances in the development of an adequate methodology that, by means of indicators, allows to evaluate comparatively with other materials, the contribution to the sustainability of the Guadua bamboo in a building or constructive solution, complementing the data provided by a life cycle analysis

2.2. Objetivos parciales

- To present the variables that can impact social, cultural, environmental and economic factors, which serve as a basis for the establishment of indicators of the degree of contribution to sustainability provided by the Guadua bamboo as a material component in a construction project.
- To establish some preliminary indicators of the degree of contribution to sustainability provided by the Guadua bamboo as a material component in a construction project.

3. Results

3.1. Identified Variables

In the particular case of the evaluation of Guadua bamboo, its environment is evaluated as a natural material used in construction, which in itself contributes to sustainability, but its degree of contribution in this sense must be known. Clarifying, Who is the recipient of the evaluation, is another very important thing to take into account, since the approach given to evaluation work should be based on their expectations and applications. Based on the data collected in a field work carried out in Colombia, Costa Rica and Ecuador, we obtained useful information for the identification of variables that may impact social, cultural, environmental and economic factors, and serve as the basis for the conceptual framework of the evaluation of the degree of contribution to sustainability provided by the Guadua bamboo as a material component in a construction project. Starting from a clear concept of sustainable construction and the requirements that are considered must fulfill this construction; especially the materials used, which are responsible for a large part of the impact of the construction,

so that their proper selection can improve the environmental performance of buildings, and an appropriate measurement of the loads produced by these materials is necessary.
According to the data obtained, it has been possible to determine relevant impacts from the environmental point of view, directly related to the variables that affect ecosystem services, understood as the ecological functions that result in some benefit for humans and therefore to satisfy their needs (Fisher, Turner and Morling 2009), services derived from processes such as: regulation of hydrological cycles, climate regulation, air quality, biological control, erosion control, pollination and habitat diversity
Variables such as: percentage, location and density of natural forest of Guadua, number of deforested areas of these forests, areas of expansion of agricultural frontiers or affected by the expansion of the urban area; significantly affect the ecosystem processes mentioned above and are relevant in analyzing and assessing the impact of the natural forests of guadua and their contribution to these processes, thus being of vital importance in the determination of sustainability indicators closely related to the environmental aspect.
On the other hand, it has also been possible to determine important impacts that have to do with variables such as: the degree of knowledge and sense of belonging to the bamboo species Guadua and environmental policies, both governmental and institutional, involving this renewable natural resource and its contribute to the solution of environmental problems, and which in turn affect the cultural aspect, such as those related to cultural services derived from the quantity and diversity of landscapes that, as a result of the forests of guadua are generated for the benefit of recreational, ecotourism and sports activities, just as they are a source of artistic inspiration and the generation of spaces to carry out studies of a scientific and educational nature, at the same time places that can constitute cultural heritage.
Support and provision services are similarly impacted directly in ecosystem functions such as: the provision of timber and non-timber forest products, water sources, material and genetic resources as well as ornamental and aesthetic resources.
As relates to the social aspect and based on the relationship between the state of ecosystems and human welfare have been identified variables keeping close relationship with the cultural aspect, impact and deal with components of the welfare, such as: security, related to guarantees of integrity derived from the quality of their homes, good living conditions, clean air and water, psychological well-being, social cohesion and cooperation.
It is evident that the variables found can affect more than one of the aspects under consideration and according to their impact derived, directly or indirectly from the Guadua bamboo forests and the natural resource as such, the following are identified:

- Conservation of the natural forests of Guadua
- Percentage of natural forests of Guadua
- Density of the natural forests of Guadua
- Areas for the extension of agricultural frontiers
- Impact on the forests of Guadua due to expansion of urban áreas
- Degree of knowledge for the bamboo species Guadua
- Sense of belonging to the bamboo species Guadua
- Governmental and institutional environmental policies involving the resource
- Use of the Guadua resource
- Generación de bienestar económico y social derivado del recurso

3.2. Establishment of indicators

The development of an evaluation methodology, which allows an objective quantification and analysis of sustainability, is a necessity to advance in the achievement of the same (Sarandón and Flores 2009).
In order to assess sustainability, it is necessary to use indicators, and the first thing is to understand what an indicator is; this is a selected and quantified variable that allows us to see a trend that otherwise is not easily determinable (Sarandón SJ 1997). Hence the importance of identifying variables that serve as a conceptual framework for the evaluation of sustainability, understood as a system of values or ideas that defines what is good or bad for sustainability, and from which positive or negative relation to it (Imbach et al. 1997).
The objective of the indicators is to provide an empirical and numerical basis to know the problems, calculate the impact of our activities on the environment and to evaluate the performance of public policies (Rodríguez 2002).
Aware that there are no universal indicators, we should particularize them based on the clarification of the following questions: What to evaluate?, Why evaluate it? and what is evaluated?, so that we can define indicators, based on the most relevant variables as appropriate.

Once clarified the concepts. Based on the variables identified previously, and taking into account their impact spectrum, some indicators have been preliminarily determined in this first phase of the work, and a corresponding evaluation and quantification of these impacts will be carried out in a next stage.

3.2.1. Land use

This indicator refers to the forest inventories of Guadua, both natural and cultivated, their distribution, percentage and density, in relation to the territory where the resource is used.
The distribution in a given region and the location of forests provides information related to the ecosystem services that such forests can provide and their relevance to use as hedges as enhancers or mitigating potential environmental impacts.

3.2.2. Types of ecosystem service

The types of ecosystem service are another indicator that within the analysis coverage provides information on the quality and relevance of each of the different services in which the resource intervenes as a unit and is also associated with other species within its own ecosystem. Being able to identify the category or type of service (provision, regulation, support or culture) according to their processes, understood as the ecosystemic functions provided or resources provided, such as: water supply, habitat, recreation, soil formation, etc.

3.2.3. Contribution to the improvement of ecosystem services

The contribution indicator has to do with the capacity of the Guadua bamboo forests or their units as a resource, to contribute significantly to the improvement, that is to say, to the increase of the quality of the ecosystem services or the amount of resources provided, depending on their quantity, location and density. To the extent that the service is improved, it can contribute to the restoration and / or guarantee the maintenance of other services.

3.2.4. Contribution to the restoration of ecosystem services

It is the indicator of the contribution to the restoration of ecosystem services, that is to say, the restoration of a previous backstopping service that provides the associated resource to other species within its own ecosystem, such as the restoration of services degraded by loss of density, as a result of deforestation or expansion of agricultural frontiers.

3.2.5. Contribution to the maintenance of ecosystem services

This indicator is related to the capacity of the Guadua bamboo resource or forest as guarantor of the maintenance or stability of the different types of ecosystem services associated with it and that contribute decisively to avoid or minimize any type of environmental impact related to possible effects due to potentially polluting activities within its area of influence.

3.2.6. Governance of the resource

It is the indicator that refers to the correct orientation, as well as the effectiveness and quality of the intervention of the corresponding government departments; related to maintenance, standardization of exploitation and legislation for efficient use of the resource, thus guaranteeing the contribution of this to social welfare in aspects such as: air quality, potability of water sources, support for conservation cooperation of the resources. At the same time they contribute to the enhancement of the cultural services provided by the ecosystems that contain these resources.

3.2.7. Identity of the resource

The identity of the resource as an indicator refers to the knowledge of the resource by the population that is within the circle of influence of the latter, as well as the sense of belonging to it and the different utilities that it makes and that helps both to their environmental contributions and to the improvement of the quality of life.

3.2.8. Local resource utilization

This indicator is directly related to aspects such as: the use of the resource by the local population and the possible existence of a chain of production and consumption of the same, the forms of exploitation and exploitation, and their possibility of production with projection to external markets.

3.3. Direct relationship between indicators

The relationship between indicators is analyzed as a whole, according to their incidence and type of impact according to the dimensions to be assessed: cultural, social, environmental and economic. Starting from a strong sustainability approach, which is the one that considers natural capital as provider of some functions that can not be replaced by man-made capital (Constanza and Daly 1992), so that we identify the vivifiable; as the relationship that links the social dimension with the environmental, through the knowledge of the environment and a sense of belonging to it. Equitable; as the relationship that links the economic with the social, contributing to the improvement of the quality of life. And the viable as the relationship that links the economic dimension with the environment making possible the conservation of ecosystem resources and services with the practice of closing cycles, ie the practice of recycling, reuse and use of waste as raw material of other processes.
Once the indicators are defined, and for their evaluation and preliminary assessment, the existing relationships (Table 3) are identified among them according to the impact variables that are common, taking into account their mutual impact and their relevance.
In a next phase we will work on a standardization, where due to the multiple dimensions of sustainability, the indicators are expressed in different units, depending on the variable to be quantified (ecological, economic, sociocultural). There will be indicators expressed in units of weight, length, area, number (insects, plants), attitudes of producers, economic gain, etc. This, of course, greatly hinders the interpretation of results (Sarandón and Flores 2009). To arrive at a weighting will be one of the objectives of the base thesis of this article, for which the relative importance of the different indicators, according to the variables that compose them, will be decided at the time.
We are currently working on the identification of sub-indicators to help determine the qualitative assessment, its standardization and subsequent weighting of the indicators, based on, among others, the quality of previously identified ecosystem services. From an analysis of geographic unit with a level of detail corresponding to the species Guadua within a productive system associated to the forest that contains it. The weighting of the indicators will depend on the weight of the ecosystem service according to the geographical unit of analysis and will follow the model of situation indicators, that is to say, those that provide information on the current situation of the evaluated system.

Table 3. Matrix of direct relation of indicators

#	**INDICADOR**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	Uso de la tierra		X	X	X	X			X
2	servicio ecosistémico	X						X	X
3	Aportación al mejoramiento	X			X	X		X	X
4	Aportación a la restauración	X		X		X		X	X
5	Aportación al mantenimiento	X		X	X			X	X
6	Gobernanza del recurso	X	X	X	X	X		X	X
7	Identidad del recurso	X		X	X	X	X		X
8	Aprovechamiento local del recurso	X	X	X	X	X	X	X	

The indicators are analyzed as a whole, according to their incidence and type of impact

Work is currently under way on the quantitative and qualitative assessment of the indicators, based on, among others, the quality of previously identified ecosystem services. Owing to an analysis of geographical unit with a level of detail corresponding to the species Guadua within a productive system associated with the forest that contains it. The weight of the indicators will depend on the weight of the ecosystem service according to the geographic unit of analysis.

4. Conclusions

After identifying the preliminary indicators to be evaluated, it is evident the importance of having information on the traceability of the resource, contribution to sustainability in terms of contribution to conservation, improvement and restoration of ecosystem services, and quality of life of the actors in the production chain, especially the producers and all those involved in the primary transformation and marketing phases.

A quantitative and qualitative assessment of the identified indicators constitutes complementary information to the material data sheet and equivalent CO2 emissions, forming an important argument for the use of the resource as a natural material or constructive solutions based on the Guadua bamboo.

The structuring of institutional or governmental programs of the Guadua bamboo production chain would decisively contribute to the correct management and use of the material, while contributing to applied research and training, enabling training for innovation, being one of the avenues for that

science and technology contribute in this sense to the solution of many of the social and environmental problems facing the regions producing bamboo Guadua.

The methodology resulting from this work could be applied to other types of materials, contributing decisively to complement the ecocostos, helping to know its true contribution to sustainability in construction.

5. References

Londoño, Ximena (2011) El bambú en Colombia. Biotecnología vegetal Vol. 11, No. 3: 143 - 154

Betacourt, Riquelmel (2009) El cultivo del Bambú y sus beneficios al medio ambiente. Agricultura orgánica

Rodríguez, N. Dill, W. O. Bidegaray, P. Botero, R. (2006) Utilización del bambú (Guadua angustifolia Kunth) como una alternativa sostenible de construcción de viviendas en la zona Atlántica de Costa Rica.

Carmiol Umaña, Virginia. (2009) Bambú Guadua: un recurso ecológico. Tecnología en marcha Vol 22 P 3 -9

Imbach, A et al (1997) Mapeo analítico, reflexivo y participativo de la sostenibilidad, MARPS. Unión Internacional para el Cuidado de la Naturaleza (UICN), Costa Rica. 56 p.

Costanza R, Daly HE. (1992) Natural capital and sustainable development. Conservation Biology 6:37-46.

Sarandón S, Flores C (2009) Evaluación de la sustentabilidad en agroecosistemas: una propuesta metodológica Agroecología 4: 19-28

F. Hendriks, Ch, Vogtländer, Joost, M. T. Janssen, G (2006) The Eco-Costs/Value Ratio: A Tool to Determine the Long-Term Strategy for Delinking Economyand Environmental Ecology. International Journal of Ecodynamics Vol 1 136-148

doi:10.2495/ECO-V1-N2-136-148

Vogtländer, Joost, Brezet, Han, F. Hendriks, Charles (2001) The virtual eco-costs ‘99 A single LCA-based indicator for sustainability and the eco-costs-value ratio (EVR) model for economic allocation. The International Journal of Life Cycle Assessment Vol 6 157-166

doi: 10.1007/BF02978734

Vogtländer, Joost, Lugt, Pablo, Brezet, Han (2010) The sustainability of bamboo products for local and Western European applications. LCAs and land-use. Journal of Cleaner Production - J CLEAN PROD Vol 18 1260-1269

doi:10.1016/j.jclepro.2010.04.015

Fisher, B et al (2009) Defining and classifying ecosystem services for decision making Ecological Economics Vol 68 643-653

doi:10.1016/j.ecolecon.2008.09.014

Londoño, Ximena (2002) Recurso de incalculable valor. En: Villegas, M (ed), Gudua.Arquitectura y diseño. 1st edn, Bogotá, p 22-39

Minke, Gernot (2010) Manual de construcción con Bambú, Cali

Liese, Walter (2015) Bamboo. The plant and its uses. Switzerland

Van der Lugt, Pablo, Vogtlander, Joost, Brezet, Hanz (2009) Bamboo a Solution Sustainable Solution for Western Europe Desing Cases, LCAs and Land-use. Netherlands

Takeuchi, C (2004) Comportamiento estructural de la guadua. En: Universidad Tecnológica de Pereira. Memorias Simposio Internacional Guadua, Septiembre 27-Octubre 2, 2004. pág. 214-227 Pereira, Colombia

Van der Lugt, Pablo (2017) Engineered Bamboo Products – A Sustainable Choice?: Industrialized Natural Resources for Architecture and Construction. En: Cultivated Building Materials

Sarandon SJ (1997) Evaluación de la sustentabilidad de agroecosistemas mediante el uso de indicadores. En: III jornadas científicas sobre medio ambiente. Asociación de universidades Del grupo Montevideo.diciembre 10 de 2006

Walter. V. et. Al. (2014) Evaluación de los Ecosistemas del Milenio 2 Informe de Síntesis. Disponible en https://www.cbd.int/doc/meetings/ecr/cbwecr-2014-09/other/cbwecr-2014-09-presentation-17-es.pdf

Rodríguez C (2002) Diseño de indicadores de sustentabilidad por cuencas hidrográficas Instituto nacional de ecología https:// www.inecc.gob.mx/descargas/cuencas/ind_sust.pdf
AIS (2010) Asociación Colombina de ingeniería sísmica Código Colombiano de construcción sismo resistente (2010) Título G-12 NSR-10 Bogotá

6. Acknowledgments

This paper is part of the fieldwork of the doctoral thesis research project entitled "Methodology for assessing the sustainability of the use of Guadua bamboo in construction projects based on an integrated Life Cycle Assessment (LCA)". We would like to thank the Ximena Londoño de la Pava Engineer for the information provided, such as Taxónoma and coordinator of the forest center of Guadua La Esmeralda and the farm El Paraíso del Bambú y la Guadua in Montenegro, department of Quindío, Colombia. We also thank the engineer Eugenia González as coordinator of the Guadua research group of the National University of Colombia, Medellin. Also to the architect Eugenia Solís of the University of Costa Rica and the architect Jorge Morán of Ecuador.