Author/s:
Henriques, Pedro Gameiro, PGH;Vaz-Serra, PVS

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EXPLORE A COMBINATION OF MATERIALS IN BUILDING SUSTAINABLE CONSTRUCTION PRACTICES

Pedro G. Henriques[1], Paulo Vaz-Serra[2]
[1] Department of Civil Engineering and Architecture, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal, pedro.henriques@ist.utl.pt
2 Faculty of Architecture, Building and Planning, University of Melbourne, Parkville, Victoria, 3010, Australia. p.vazserra@unimelb.edu.au

Abstract: The construction sector is associated with significant environmental impacts, being a major consumer of raw materials and energy, and generating a lot of pollution. Therefore, it is essential for the industry to move towards more sustainable construction practices. The selection of building materials is a relevant factor in sustainability, nevertheless, it seems that the industry is more focused on other aspects, such as speed of construction and cost reduction, rather than careful choice of materials. Research through the life cycle assessment methodology has identified that all stages of construction introduce environmental, social and economic impacts. Within the theme of sustainability, there are some important concepts that can also be applied to construction, such as recycling, which is converting waste materials into raw materials to produce new products, and reusing, which uses materials or products again without going through industrial processes and transformations. Sustainable materials must have all the benefits of a conventional product and still have a sustainable performance. Two of these natural materials, bamboo and cork, are alternative construction materials, and when used together, produce new elements for building construction that can be used on sustainable constructive systems. This research proposal introduces the concept of using those materials during the construction phase.

Keywords: bamboo, cork, construction, modular, sustainability.

1. Introduction

The theme of this article focuses on sustainability, specifically, focusing on natural materials which may be recycled and reused. Given that the construction sector is one that consumes natural resources and is also a major generator of solid waste, this issue becomes crucial for the future of humanity. The concept of "sustainable construction" (Peris-Mora, 2007; Ding, 2008; Li and Du, 2015) is now accepted globally and represents the main issue in sustainability.

In recent years, there has been an increasingly concerning risk regarding the depletion of natural resources, with a growing need to identify new materials and construction techniques (Hebel *et al.*, 2014). This industry, despite its contribution to improving the quality of life, has a great share of responsibility for polluting the planet. Thus, we seek to build with more responsibility, thinking ahead or, in other words, seeking sustainable construction. Some new methodologies for refurbishment and renovation have been developed for a Life Cycle Assessment (LCA) (Vilches *et al.*, 2017) of the construction industry to avoid this situation continuing without control.

The construction industry has been one of the main industries responsible for environmental degradation, from which derive other problems that harm humans and their surroundings. These problems are not only environmental pollution through the emission of carbon dioxide (CO2) into the atmosphere (Heinonen *et al.*, 2016), but also waste production associated with the construction and demolition of buildings (water and soil pollution), and the excessive and reckless consumption of natural resources (dos Reis Pereira and Ferreira Barata, 2014; Alwan *et al.*, 2017).

From this perspective, there is a growing need to develop processes, methodologies and construction operations in order to significantly reduce these environmental and energy issues associated with the construction industry. The concept of Green Building (GB) has taken a leading position with practitioners and researchers (Darko and Chan, 2016) as well as lean and more sustainable construction practices.

2. Options for building materials

Given that construction is a high-waste industry, the choice of sustainable building materials has become and essential one. The concerns in the complete whole life cycle of raw material extraction, production, installation and dismantling need to be carefully understood to reduce negative impact on sustainability.

In fact, in the construction field lies a significant opportunity for a building material choice that considers sustainability. Even though there is no universally accepted definition of what sustainable building materials are, the ones with the following characteristics should be privileged: non-toxic, provided from renewable sources, promote a close-loop cycle and life cycle thinking, and associated with low embodied energy.

2.1. Life cycle impact

To establish the environmental impact of a building, focusing on minimising impact, it is critical to analyse all aspects of the materials, elements and processes involved, based on an integrated life cycle thinking (Figure 1).

The life cycle is a term used to refer to all stages and processes of a system to generate products or services. Specifically, in the case of a building, the phases are design, construction, operation and demolition. Increasing the lifespan ensures the reduction of material consumption and the reduction of environmental impacts and several measures in all stages of the cycle should be taken to ensure this increase. Therefore, designers must implement a durability project and prescribe the maximum number of sustainable materials.

Within the building sector tools exist for assessing the environmental impacts of a given material or product. The standardised and most internationally recognised tool is the Life Cycle Analysis (LCA), also known as Life Cycle Assessment and cradle-to-grave analysis. It consists of a technique to assess environmental impacts associated with all the stages of a material's life. The LCA looks at material supply chains to reveal the energy-related and ecological effect of materials, creating the basis for selecting building materials more responsibly, avoiding the overlook of the environmental priorities. However, there still are flaws and limits to this complex and time-consuming evaluation process. One of these limits is that the method relies heavily on the available data on building materials and processes, and such data are not always complete or reliable.

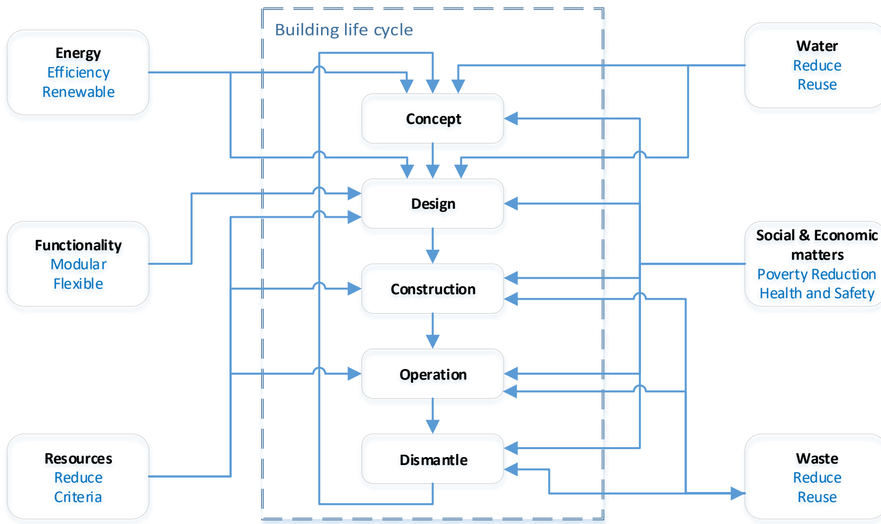

Figure 1: Integrated and sustainable approach to the phases of a building life cycle (Source: Bragança 2006).

3. Materials for sustainable construction

Nowadays, basic construction materials are still composed of wood, stone, steel, concrete, glass and bricks, which has been the case since the industrial age. However, the processes to producing and transformation of some of these materials cause harmful emissions, making them non-environmentally friendly. Moreover, the abuse of certain materials has significant impacts on our planet, impossible to continue to ignore. Being aware of this, the choice of alternative construction materials should consider the availability of the material, and its application in specific contextual settings. In addition, the concept of materials for sustainable construction must be present throughout the life cycle of the building: concept, design, construction, operation/maintenance and demolition/dismantle (Figure 1). This paper presents a case study using cork and bamboo.

3.1. Cork as a material of construction

Cork is a 100% vegetable tissue from the bark of the cork oak trees (named *Quercus suber*). This tree grows in Mediterranean regions, such as Portugal, Spain, Italy, France, Morocco, and Algeria (Figure 2).

Cork oak trees are endowed with a great longevity and capacity of regeneration, live on average 150 to 200 years, and can be discarded every nine years without being cut. Cork has been known since antiquity as a floating and sealing device, and its market increased from the beginning of the 20th century when it began to be used in the creation of various agglomerates.

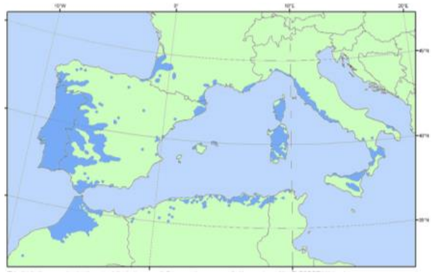

Figure 2: Cork oak (Quercus suber) distribution map (Source: Gil and Varela, 2008).

Currently, cork is used in exterior and interior coatings, thermal and acoustic insulation and several other applications in different industries. It consists of alveolar-like cell layers, which are filled with an air like gas and mostly coated by suberin and lignin that give it special characteristics for different uses.

Cork as a material part of construction elements, makes a great contribution to the sustainable construction during the building life cycle. Chiebao (2011) identified a number of key sustainability attributes for cork (see Table 1).

Table 1: Key sustainability attributes of cork construction (Source: Chiebao, 2011).

Building life cycle attribute	Environmental advantage
Design	
Material	Since the selection of materials is a critical factor in designing a sustainable building, raw cork, as a building material, has undeniable environmental advantages and can contribute significantly to increase sustainability in construction
Construction	
Material efficiency	Cork is an environmentally-friendly material because it does not use scarce resources, it is not a pollutant, and it does not require transformation processes of the raw material which make use of expensive energy resources.
Energy efficiency and emissions	The use of cork products is ecologically very important because a renewable product is used in long life products, promoting the sequestration of CO2. According to Amorim's sustainable report of 2008 (Corticeira Amorim, 2008), 0.379 kg of CO2/kg of cork is emitted by each kg of final product is responsible for fixing 1.833 kg of CO2.
Waste	Cork elements produce virtually no waste, except for those that result from the combination with other materials to produce construction elements. At the building dismantle phase, the cork should not cause environmental problems, and reusing/recycling should be possible (Gil, 2011).
Operation	
	Cork elements use a natural material which are non-toxic, so it is not generally associated with the harmful effects of indoor air pollution with Volatile Organic Compounds (VOCs), presenting no pernicious effect on the health of building occupants.

Building life cycle attribute	Environmental advantage
Health	Insulation corkboard agglomerates have three principal applications: thermal insulation, acoustical absorption and vibration damping (Silva *et al.*, 2005) Cork agglomerates are suitable for diverse construction applications, interior or exterior walls, buildings and ceilings, to provide thermal and acoustic insulation and sub-paving insulation to minimise transmission of repercussion noises. This allows significant energy savings during the operation phase as earth buildings use less energy for heating and cooling.
Thermal comfort Acoustic insulation	Under fire conditions, cork does not release toxic substances as may occur with alternative materials, such as polyurethane foams or extruded and expanded polystyrene
Fire resistance	Cork flooring is naturally resistant to damage from scratching and denting due to impact and friction. A very dense material, it has an excellent recovering ability from high shoe-heel damage, heavyweight objects, and abrasion. Also, its elastic nature helps it maintain its stability during times of expansion and contraction due to climate conditions.
Durability	
End-of-life	Usually, the expanded corkboard pieces are removed entirely, and their insulation properties are unchanged. If necessary, its grinding is promoted, obtaining a re-granulated material destined to be used as an inert material or for thermal insulation applications (Gil, 2011).
Reusability	

With this we can say that cork is a 100% natural and ecological material due to its low embodied energy, that is, the energy spent during the extraction, production and transport is reduced in relation to other insulating materials.

3.2. Bamboo for an Innovative Building Technology

Bamboo belongs to the botanical family of grasses, like rice, corn and sugar cane. Bamboos, in their wild form, grow on all continents except Europe, especially common within the equator belt areas around the globe (Figure 3). Some of the largest species can grow up to 30 meters high with a culm (botanical term for the stem of grass) diameter of up to 15 centimetres (Minke, 2012). Bamboo is one of nature's most versatile products, and there are great benefits that results from using it as a construction material.

Bamboo is a material extremely resistant to tensile stress, adapting to natural forces, such as the wind. It is also a plant that assimilates CO2 for photosynthesis, storing it during its growth time. Because of its rapid growth, bamboo can take in more CO2 than a typical tree. As a self-regenerating plant, with adequate management and harvest, bamboo can permanently absorb CO2, unlike any other species.

Although it has many advantages as a building material, it also has some weaknesses that prevented it being used as a durable construction element. Water absorption, swelling and shrinking behaviour, limited durability and vulnerability to fungal attacks and insect infestations have limited most of the bamboo applications in the past.

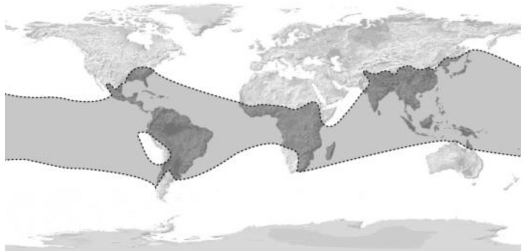

Figure 3: Bamboo grows in a ring from 46N to 47S latitude (Source: Laroque, 2007).

3.2.1. Bamboo in Construction – the present

Bamboo has been used as a construction material around the globe for centuries. However, untreated bamboo has its limitations. In recent years, through the development of new treating, bonding and laminating techniques, bamboo has even migrated to European countries, where there is no tradition of using bamboo for the construction of buildings. The construction of the bamboo pavilions for the 2010 Shanghai World Exposition and the Nomadic Museum in Mexico City, came to demonstrate that bamboo is now recognised around the world as a high-performance building material.

Another reference for bamboo applied as a structural system is the recently-developed project designed by Penda for the Beijing Design Week (BJDW) 2015, called "Rising Canes". Here the potential of bamboo as a modular construction system, made entirely of bamboo canes and joints tied with rope, was demonstrated. There exist different solutions to fix the joints: Traditionally one uses "lianas" or binding of natural fibres, another option is hard wooden or palm tree (or metal screws) or even bamboo pins, and finally the structural connections are today often reinforced by steel joints (Minke, 2012). From small structures to skyscrapers or even entire modular cities – developed proposals made from this ancient material are being released and built with ever more frequency. Nowadays, bamboo is seen as a sustainable and eco-friendly building material but is still not as widely recognised as perhaps it should be as an exceptional construction material (Minke, 2012).

3.2.2. Bamboo in Construction – the future

International researchers have spent decades investigating ways to profit on bamboo's tensile strength and material properties, and the possibility of extracting bamboo fibre from the natural raw material, transforming into a manageable industrial product and a viable building material that could be an alternative to steel or timber (Javadian *et al.*, 2015).

The idea of bamboo as a reinforcing component in established building materials such as concrete is not entirely new. However, early attempts to use it as an untreated, non-composite reinforcement material in concrete were not successful. Researchers are working with the newly-developed technologies to explore new types of composite bamboo material. The principle is based on the extraction of the fibre from the natural bamboo, transforming it into a manageable industrial product, and introducing it as a viable building material, an alternative to steel and timber (Fairs, 2015).

Preliminary results of research conducted by Javadian *et al.* (2015) demonstrate that the bamboo composite can exceeded steel, in tensile capacity and weight.

4. Case study of sustainable unit

A case study project was prepared based on the latest research for sustainable urban units, and the design of the units needs to incorporate the basic human needs and functionality but also needs to be designed with solutions to preserve the longevity of material and low maintenance costs. Therefore, the designed layout needs to be simple and efficient. This aim of this research is also to join the design proposed by Rodrigues and Henriques (2016) with the technical solutions proposed by Xiao and Paudel (2008) (Figure 4).

Figure 4: Single module proposed by Rodrigues and Henriques (2016) and design solutions proposed by Xiao and Paudel (2008).

The central core can be either built from bamboo poles, or thick laminated panels, to form the necessary thickness, load-bearing and structural properties. All materials applied as 50mm thick wall panels are self-supporting and rigid enough, damage-resistant and easily replaceable/available. The floor can be made of either laminated bamboo panels or simple cut bamboo canes, properly arranged (Figure 5). E.g. Some examples of bamboo structures used for different purposes include temporary scaffolding (Yu and Chan, 2005), small bridges (Laroque, 2007), and internal walls (Varela et al., 2013). Recently recycled bamboo was used to build a temporary theatre for cultural activities such as the Cantonese opera pop up in Hong Kong (http://www.bbc.com/travel/story/20130129-cantonese-opera-pop-up-whets-hong-kongs-appetite-for-art).

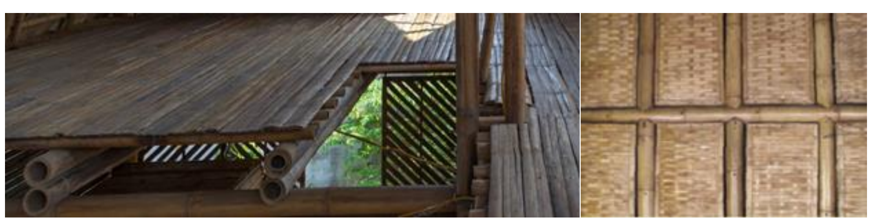

Figure 5: Example of flooring and a wall structure using cut bamboo poles (Sources: H&P Architects and Minke, 2012).

The use of non-renewable materials was minimised as much as possible, with only the use of polycarbonate panels for the windows/openings. The materials used are from an available natural source, contributing for low embodied energy materials.

4.1. Building solutions

One of the main concerns when using some raw materials is the stability of their characteristics over time, that is, how they perform when exposed to natural conditions such as, rain, wind or quick change of temperatures. Using the materials focus in this project and applying some of the knowledge collected by experience of the authors and latest literature review it was possible to propose a new situation and possible future application for the envelope, roof and walls.

The proposed solution (Figure 6) was built from the following materials: (1) structure and flooring: bamboo (2) exterior layers and insulation consisting of expanded cork agglomerate - ICB (Insulation Cork Board), already tested, and laminated plasterboard; (3) waterproofing and roofing: Ceramic roof tiles and underlayment sub-tile and ICB.

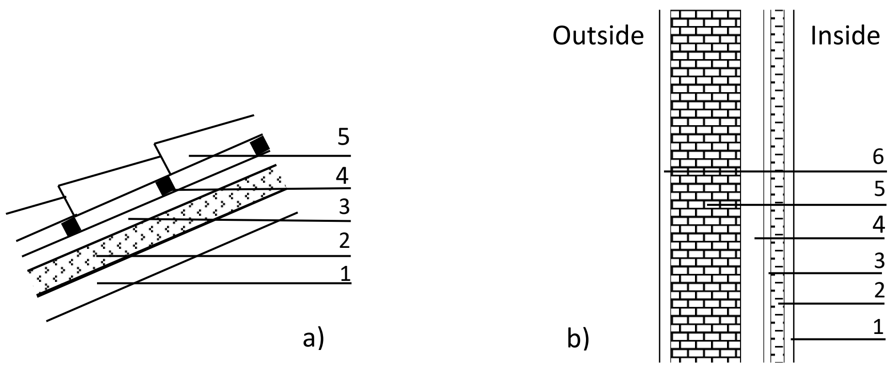

Figure 6: Constructive sections for walls and inclined roof with bamboo and cork (a – 1. Bamboo Structure, 2. Cork, 3. Underlayment, 4. Batten, 5. Clay roof tiles) (b – 1. Gyptec, 2 – ICB, 3 – Traditional plasterboard, 4 – Airbox with Bamboo, 5 – Brick 15, 6 – Traditional plasterboard).

The solution for construction sites will use modern prefabrication and modular panels techniques, to facilitate transportation and assembly at the location of the construction site. This part of the research proposal will be based on the modular experience for timber and steel modular structures for containers and temporary facilities (Smith, 2010). The first modular prototype will be prepared with six panels: a floor panel, the four walls and a roof panel. The dimensions of the prototype will be for a typical office container for a construction site. To reduce the labour on site and transportation costs, the roof tiles will be replaced by bamboo tiles (Figure 7). The prototype will be developed in Portugal and Australia and tested at two construction sites in both countries.

Figure 7: Tiles in bamboo to replace clay roof tiles. (Source: Mathews, 2013)

5. Conclusions

The aim of this research proposal emphasises the need for thinking globally in building sustainable construction practices. The future project is to develop new agile constructive methodologies to achieve an increased commitment to wellbeing for the future of humanity in how to build. This will be achieved using and combining different materials that exist in abundance in certain regions of the planet, such as South America, Africa and Asia, and are environmentally friendly. The combination of more sustainable materials and the responsibility of thinking in the whole life cycle of building materials are revealed as a matter of priority. Although new materials are being used in some construction sectors, due to digitalisation and automation practices, there is now, more than ever, a need to rethink the management of the natural resources of our planet properly. The lessons learned from the past can be used in non-developing countries helping to increase use of natural resources more efficiently.

Although some of the concepts are not completely new, and bamboo as a structural element for temporary buildings and facilities has been used for centuries, this research proposal focuses on adapting some of those techniques in a more efficient way. Cork has been underestimated and its characteristics misunderstood. As one of the most important materials for sustainability cork was wrongly be accused to kill trees, however, it does exactly the opposite. Recently, a comparison between shearing a sheep and removing the bark of the cork oak tree made the situation clearer. Trees are not cut down to harvest cork (bark), and the bark grows back again and is harvested by hand every nine years, much like a sheep's wool with more time between each harvest.

The research proposes a project to develop the use of bamboo and cork with the current requirements in safety, habitability, and sustainability, but also as a business with flexible modular construction process and to help prefabrication and easy assembly methodologies. The present research project is also a solution for testing in a prototype to address rapid needs in urbanisation in developing countries using their natural and local resources. The project will primarily take into consideration the utilisation of such combination of materials for temporary works in construction sites, offices, warehouses, sheds and other short-term facilities and structures. The prototype will be developed using modular approaches, solutions based on panels for pre-fabrication and easy transportation and assembly. This will help developing countries with new business opportunities, reduce poverty and give them a role in the global sustainability of the world. Future research proposals will consist of a combination of other local materials, such as wool, coconut fibre, straw, corn silk and other local raw materials.

References

Alwan, Z., Jones, P. and Holgate, P. (2017) Strategic sustainable development in the UK construction industry, through the framework for strategic sustainable development, using Building Information Modelling, Journal of Cleaner Production, 140, Part 1, 349-358.

Bragança, L. Mateus, R. (2006). *Tecnologias construtivas para a sustentabilidade da construção*. Edições Ecopy: Porto.

Chiebao, F., 2011. Cortiça e Arquitetura. Euronatura, ed., Espaço Gráfico, Portugal.

Corticeira Amorim, (2008). Relatório de Sustentabilidade da Corticeira Amorim SGPS S.A. Ed. Corticeira Amorim, Mozelos. Available at: http://www.sustentabilidade.amorim.com/xms/files/RELATORIOS/Relatorio_Sustentabilidade_Amorim_2008_Bookmarks.pdf. [Accessed Jul. 2017]

Darko, A. and Chan, A. P. C. (2016) Critical analysis of green building research trend in construction journals, Habitat International, 57, 53-63.

Ding, G. K. C. (2008) Sustainable construction—The role of environmental assessment tools, Journal of Environmental Management, 86(3), 451-464.

dos Reis Pereira, M. A. and Ferreira Barata, T. Q. (2014) Bamboo as sustainable material used in design and civil construction: species, management, characterization and applications, Key Engineering Materials, 634, 339-350.

Fairs, M. (2015). Bamboo fibre is stronger and cheaper than steel, says Dirk Hebel. Dezeen Magazine. [online] Available at: <http://www.dezeen.com/2015/11/04/bamboo-fibre-stronger-than-steel-dirk-hebel-world-architecture-festival-2015/ > [Accessed Jun. 2017].

Gil, L. (2011). Environmental, sustainability and ecological aspects of cork products for building. Ciência & Tecnologia de Materiais, 87-90.

Gil, L., & Varela, M. C. (2008). Technical Guidelines for genetic conservation of Cork oak (Quercus suber). Bioversity International.

Hebel, D. E., Wisniewska, M. H. and Heisel, F. (2014) Building from waste: recovered materials in architecture and construction, ed., Birkhäuser.

Hebel, D.; Heisel, F.; Javadian, A.; Wielopolski, M.; Schlesier, K. (2015). Constructing Bamboo - Introducing an alternative for the construction industry. Constructing Alternatives - Research Projects 2012-2015, (Special Issue), FCL. pp.10 - 21.

Heinonen, J., Säynäjoki, A., Junnonen, J.-M., Pöyry, A. and Junnila, S. (2016) Pre-use phase LCA of a multi-story residential building: Can greenhouse gas emissions be used as a more general environmental performance indicator? Building and Environment, 95, 116-125.

Javadian, A., Heisel, F., Schlesier, K., Wielopolski, M. and Hebel, D. (2015) Green Steel.

Laroque, P. P. V. M. (2007). Design of a low cost bamboo footbridge (Doctoral dissertation, Massachusetts Institute of Technology).

Laroque, P. P. V. M. (2007). Design of a low-cost bamboo footbridge (Doctoral dissertation, Massachusetts Institute of Technology).

Li, R. Y. M. and Du, H. (2015) Sustainable construction waste management in Australia: a motivation perspective, in, Construction Safety and Waste Management, Springer, 1-30.

Mathews, D (2013) Traditional bamboo floating homes updated. EarthTechling. Available from: Open Source Repository http://earthtechling.com/2013/04/traditional-bamboo-floating-homes-updated/ (accessed 20 September 2017).

Met-Office (2012). Helping you understand: Weather and climate. Devon. Available from: Open Source Repository https://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/4/d/weather_and_climate_guide.pdf (Accessed 20 September 2017)

Minke, G. (2012) Building with Bamboo: Design and Technology of a Sustainable Architecture, ed., Walter de Gruyter.

Peris-Mora, E. (2007) Life cycle, sustainability and the transcendent quality of building materials, Building and Environment, 42(3), 1329-1334.

Rodrigues, B.V., Henriques, P.G. (2016). Reduce reuse recycle recover need to rethink materials in construction. International Scientific Conference PBE2016, Luhacovice, Czech Republic, www.fce.vutbr.cz/ekr/PBE

Silva, S. P., Sabino, M. A., Fernandes, E. M., Correlo, V. M., Boesel, L. F., & Reis, R. L. (2005). Cork: properties, capabilities and applications. International Materials Reviews, 50(6), 345-365.

Smith, R. E. (2010). Prefab Architecture. [electronic resource]: A Guide to Modular Design and Construction. Hoboken: Wiley, 2010.

Varela, S., Correal, J., Yamin, L., & Ramirez, F. (2013). Cyclic Performance of Glued Laminated Guadua Bamboo-Sheathed Shear Walls. Journal Of Structural Engineering, 139(11), 2028-2037.

Vilches, A., Garcia-Martinez, A. and Sanchez-Montañes, B. (2017) Life cycle assessment (LCA) of building refurbishment: A literature review, Energy and Buildings, 135, 286-301.

Xiao, Y., Inoue, M., & Paudel, S. K. (Eds.). (2008). Modern Bamboo Structures: Proceedings of the First International Conference. CRC Press.

Yu, W., Chung, K., & Chan, S. (2005). Axial buckling of bamboo columns in bamboo scaffolds. Engineering Structures, 2761-73. doi:10.1016/j.engstruct.2004.08.011