Extended Abstract


The International Red Cross listed the three relief priorities in Environmental Disasters: food, medicine and shelter. Providing shelter allows quickly returning to normal life, and keeps families connected. Furthermore establishing the routine stimulates the reconstruction of affected areas. This work presents a quick solution aligned to concepts of sustainability, green building and waste recycling, to catch up affected families needs on environmental disasters events. In order to provide shelter in a very short time, a sandwich panel composed of a bamboo honeycomb core was developed, in a new approach of bamboo utilization, and recycled material panels glued with castor oil resin. The material used are natural and non pollutant, recycled, low-carbon, low-cost housing and low energy consumption. A sandwich panel was developed and its mechanical behavior analyzed for building applications. The main objective of this work was developing a resistant material, ecologic, sustainable, using residues, and local, ingenious and natural materials, that must be strong enough to substitute conventional materials and, at the same time economically feasible, to address emergency sheltering. As a result, a modular shelter is proposed, in which the minimum module is like a core house nevertheless it can be expanded turn in a permanent home. The shelter is also portable as it can be collected and transferred to other places, wherever needed.

Introduction

In recent times the world have been witnessing overwhelming natural disasters caused by floods, inundations, earthquakes, tsunamis, typhoons, hurricanes, landslides, volcanic eruptions, cyclones, as the runoff that occurred in
2011, at Rio de Janeiro mountain range. This tragedy left a trail of destruction, human and material losses, and was considered our greatest natural disaster since 1967, with about 918 people killed, over 300 people missing and about 30 thousand homelessness. (Rio de Janeiro Civil Defense, 2011). All over the world, thousands of people become homeless overnight. Governments and Humanitarian Entities are used to providing shelters that become definitive at the end. The reconstruction process is frequently slow, especially in poor countries, where often makeshift tents become housing for long periods of time. In Pisco, Peru, five years after the 2007 earthquake there were 180,000 homeless living precariously. (Direito.org, 2012) In Port-Au-Prince, Haiti, two and a half years after the tragedy of 2010, there were 78,175 homeless people living in makeshift shacks on former landfill. (Oxfam GB, 2012). And, even in rich countries, like Japan, the earthquake and tsunami in Fukushima, March 2011, two years later it still accounts for 21 000 people with relatives or shelters. (UN (OCHA), 2013 apud Exame Magazine). Besides, in Brazil happened the same way, two years after the flood of 2011 that hit the mountainous region of Rio de Janeiro, none of the six thousand houses promised by the government was built and 8311 families are still receiving rent assistance (State Department of Social Services, 2013).

"Developing countries suffer the worst impacts, for example, among 262 million people affected by climate disasters annually from 2000 to 2004, over 98 percent live in developing countries"(United Nations Development Programme, 2008:8). Poverty Reduction Strategy Papers (PRSPs) - United Nations Program for Environment (UNEP).

While governments provide the infrastructure works and negotiate land for the construction of new houses, it is essential that construction researchers create solutions that meet these needs to provide decent housing during this long standby time. Even though natural disasters have been happening frequently since ancient times, modern society way of life with its industries, carbon dioxide emissions and waste production have been contributing to increase these events. In the other hand, as the accelerated growth of world population and the number of people living in urban areas is expected to increase, more people will lost their lives, damages will be more devastating, and more houses will be destroyed, especially those built over unstable areas, most of them occupied by poor people. Furthermore, the materials frequently used for city buildings and infrastructure are
pollutant in most cases, either at the manufacturing process and in the construction itself, besides, urban areas absorbing and releasing heat during the night contribute to increase the temperature and cause a negative effect, mostly known as Urban Heat Islands.

**State-of-art**

Government Institutions, NGOs and Humanitarian Entities coordinate the provision of shelters worldwide after environmental disasters. At the beginning, people rescued are housed in public buildings, gymnasiums, schools, religious temples and houses of relatives and friends. After the first day people are relocated and accommodated in temporary tents until they get teams to organize and assist in the reconstruction of the affected areas (UNDRO - United Nations Disaster Relief Organization). Tents are practical, easy to store, easy to carry and easy to assemble. In the other hand, are also, inadequate in winter, small, can not be expanded, deteriorate rapidly, have high cost when added to shipping costs. Many times sub-occupation takes place, because they are far from the family estate. Imported Units are suitable for extreme climates, like severe winters, sometimes are better than the previous housing and are ready to inhabit. However, needs plenty of room to carry, costs are high, needs specialized know-how to assemble, there are not availability of material, do not connect in increments. They can overcome the pattern of the previous life, creating a risk of setting people at shelter, configuring new permanent settlement and new slums. Using local materials and the technique of construction-site brings minimal intervention, but creates external independence, at the same time encourages collaboration and socialization. The problems faced with the use of this technique are the long time of construction, only a small portion benefited, sketchy technology, precarious buildings, high cost on transferring technology. Quite often the cost of qualified personnel to provide technical assistance and transferring knowledge is very high and may exceed the cost of ready-made solutions. Temporary housing provides shelter for only a few months, replaces permanent housing, and gives dignity while waiting reconstruction, can also provide mass production and low cost. They can become permanent, only a small portion benefited, use rudimentary technology, produce substandard buildings, and can not be reused.
"On occasions where the reconstruction of housing exceeds six months, the temporary shelter housing becomes more permanent than temporary." (Barbosa, 2011)

The distribution of materials uses homelessness manpower, encourages consumption, leverages the local market and is low cost, besides promoting socialization. But can become permanent and emphasizes the demand for materials triggering run out of materials and leavings to skyrocketing price. Has also rudimentary technology resulting in precarious building, unhealthy housing. Materials distribution without technical support results in unsanitary dwellings and affects residents’ health. Core Housing is a minimal cell to be increased or be disassembled and be taken to another place, can also become permanent, as it can be located in own land. Alternatively has the necessity to remove debris and immediate cost is greater than tents. The shelter proposed in this work fits into this category.

**Technical guidelines**


The recommended size shelter ideal is based on 3.5 m² per person. According to Sphere 2004 - Shelter and Settlement, Standard 3, a covered area of 3.5 m² per person may be appropriate to save lives and to provide adequate shelter for short term, immediately after a disaster, especially in extreme weather conditions. In such cases, where shelter materials are not readily available, the longer it takes to arrive the well-being and health of those affected can be compromised. Some shelters have already been implemented with various sizes, ranging from 9 m² to 74 m², resulting in different needs, continuity, logistics budgets, restrictions, reception standards and official policies. Materials such as wood and bamboo composite panels made of wood or bamboo, are frequently used in projects of shelters, due to the ease of using local construction techniques, availability, lightweight transportation, easy construction, suitability for use in modular structures, and to be reused, resold or recycled later on.
**Portability and mobility**

The temporary shelter should be designed in order to be relocated whenever necessary. So it should be easy to dismantle and move to the beneficiary’s land once they return. The project should include a durable solution that can be extended later. Improvements can also be incorporated by occupants after transferring to a definitive place and turn it into permanent housing. (Shelter Transitional Guidelines, p.12). According to Kronenburg (2003), Schools of Architecture has always taught that the buildings should be static, stationary and without movement, stopped in time and space, but portability has been an appropriate solution to solve emergency problems immediately. "Portable Architecture" means disassembling parts or structural units, carrying and reassembling elsewhere. Historically dismantled architecture is an appropriate solution for emergency housing. For thousands of years, man has brought with him his nomadic dwelling, made of animal skins, mats or fabrics, which was built quickly and easy to disassemble. Recently, were found in Africa, Asia and the Americas, reminiscent huts of ancient people, their log structure spans could win up to ten meters, weighting approximately 5 kgf/m², i.e. much lighter than the minimum of 8 kgf/m² metal structures existing nowadays. (Khan, 1993)

**Sustainable development - bamboo sandwich panel**

The Brundtland Commission's report defined sustainable development as "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs" (Our Common Future, UN, 1987). These days, for an activity to be considered sustainable should include three sectors: environmental, economic and social, referred to as Triple Bottom Line (TBL). Conventional construction materials such as cement, sand, stone and clay, besides not being renewable and contributing to the run out of planet's natural resources, they are also responsible for converting cities into urban heat islands in fact. It is estimated that construction consumes between 20% and 50% of the total resources used by society currently (Sjostrom, 1992). Romans had discovered the pozzolana for over 2000 years, concrete was developed from this technique, and till these days it has been adopted as the best way to build. In
Brazil, particularly, the use of materials such as clay bricks and reinforced concrete is widespread, and it is a construction default. The shelter proposed in this work consists of sandwich panels composed of natural renewable materials, like bamboo and castor oil, and industrial waste as recycled plates. Therefore, fits into the reported Agenda 21, items 3 and 4, “Sustainable consumption and goods production” and “Conservation and management of natural resources” and is in accordance to the economic, environmental and social guidelines for sustainable development.

**Materials selected**

Bamboo was chosen due to its great advantages. There are more than 1500 botanical species, needs three to six years for harvesting and grows well in equatorial forests. Using internally, without contact with moisture it can last 230-250 years, as the bamboo walls found in La Unión and Cartago, Valle del Cauca, Colombia. Beyond the main disadvantages are the incipient supply chain (Brazil), its cylindrical shape, nonlinearity culms, dimensional variations, difficulties with sockets and connections, in general uses handmade construction, needs rain and moisture protection. The species, *Phyllostachys aurea* was selected because its weight and diameter are appropriate to the panel dimensions, besides having a great resistance to woodworm. It is rarely attacked by insects and can be easily found in Brazil- Southeast and South regions which have the highest supply of treated sticks plantations.

Recycled Plates are flexible when used individually and are therefore underutilized in secondary applications such as: sidings, linings, pallets, for protecting floors, and wall coverings. Among its main advantages are: the resistance to moisture, resistance to sunlight, 100% recycled and recyclable, resistance to chemicals in general, self-extinguishing, does not propagate flames, easy attachment, do not crack under the penetration of nails and bolts, thermo-acoustic insulation, compatibility with plaster, mortar and texture, acceptability of acrylic paint, latex, synthetic varnish, among others, accepts contact glues and adhesives in general. Recycling milk packages is a process that reintegrates composed materials to the production chain. A long-life packaging comprises six
layers of three materials: paper (75%), low density polyethylene (20%) and aluminum (5%).

The adhesive chosen, was a vegetal polyurethane based resin, from castor oil source. Adhesive systems have replaced mechanical fixation systems, including applications of industrial interest, due to the advantages related to the performance of adhesive joints associated with factors of productivity and low cost (Silva, Shana. A, et al, 2007). Castor oil based adhesive offers no health hazard and is therefore also used in the medical field as a biomaterial to repair bone loss shortcomings and the production of implants for reconstruction on jaws and skulls. (Ferneda, 2006) Some previous studies have produced positive results in tests even when compared with other commercial adhesives (Buaszczyk et. al., 2006).

**Bamboo sandwich panel**

Sandwich structures have been widely used in aerospace, automotive, civil and military industries. Alveolar design combines high strength resistance and lightweight, resulting in a very efficient structure. According to (Gagliardo&Mascia, 2010), sandwich structures projects have been designed and adopted due to its resistance, durability and lightweight. Natural and recycled materials were selected to build the panel in order to avoid carbon emissions and have low energy consumption. The panels can be used as a slab, wall, and ceiling among other applications. It provides high resistance to distributed loads, ability to support large spans, humidity and weather resistance, thermal and acoustic insulation, high impact resistance and excellent fire resistance. This work is part of emergency housing solution development for post disaster homeless using low energy materials. Acknowledged researchers worldwide prescribe the use of the sustainability principles in construction to mitigate the impacts of this large industry, by reducing residues, using renewable energy and materials. The modular construction process made up with prefabricated panels is in accordance with these principles and, besides speeding up the runtime of building construction, generates almost no residues, losses and debris, there is no use of water or non-renewable resources such as stone, sand and clay. This research takes into consideration the advantages of alveolar panels and modular panels’
production. Several initiatives on using bamboo panels have been studied, however it has always been used in its longitudinal direction, with entire culms or laminated. Highlighting that bamboo is an organic material, and therefore, the lack of diameter standardization and irregularity in nodes region makes it difficult to apply as a core in a multi-layer sandwich panel. Using bamboo in the longitudinal shape makes it impossible to standardize the thickness of the panel and to bond the outer layers due to lack of uniformity of bamboo surface (nodes). Looking for overcoming this limitation and getting a uniform thickness, either thicker or thinner, according to the purpose of the panel, bamboo culms were used in cross section, cut into slices with identical thickness, previously defined, to be used as the sandwich panel core. The system is basically a sandwich panel structure with multiple layers, and the core composed of bamboo, forming an alveolar configuration, as a honeycomb, bonded between two recycled plates. The sandwich structure is rectangular, with irregular surface, which has specific characteristics, such as acoustic, vibration, thermal, and mechanical strength. It is a panel of multilayer structure, called sandwich panel, with two layers of recycled material plates (tetrapak, basically composed of milk packages, among others), linked by a core of bamboo slices with the same thickness. These two plates are linked to the core by an adhesive. The core is composed by a disordered bamboo network, in which bamboo slices are bonded by contact with plates surface impregnated with adhesive. This structure connected to the two plates when the entire block is glued. The panel consists of a double wall and a sliced bamboo core that provides a vibration damping, reduction of noise pollution, and also a thermal screen function.

**Experimental procedures**

Results about industrial materials properties were obtained from the manufacturers, whilst, to know the behavior of bamboo sandwich panel created, some tests were performed. ASTM Standard C393-00: standard test method for flexural properties of sandwich constructions (recommended for sandwich panels and similar materials) was applied standard for flexural tests. Other tests (compression and shear) were performed but the results were inconclusive. The panels were tested by applying the load in the mid-span along the specimen width,
with 0,40m distance between supports. An excessive deformation on the bamboo sandwich panel was observed and cracking characterized by small failures between the adhesive contact and the plate surface. The test was discontinued due to deformation and adhesive crack. The average flexural strength was 2.38 MPa among the specimens tested.

The shelter project

The emergency shelter design was based on guidelines and manuals published by International Entities: UN-Habitat, Shelter Projects, Humanitarian Charter and Minimum Standards in Disaster Response, Sphere Project, and International Council for Research and Innovation in Building and Construction, among others. The emergency shelter was designed for a family of up to five people, with an area equal to 24,20 m². United Nations guidelines calculate 3,50 m² per person, and 18,00 m² the minimum acceptable for five people. The module consists of bathroom and kitchen in the central module, living room and bedroom on the sides, which can be connected to other modules for expansion. The assembly of shelter parts is made by a method known as kits-of-parts. The floor structure is set, then the pillars, panels, ceiling and then the roof to finish. The shelter was designed to be completely dismantled. It was divided packages for easy transport according to the containers and trucks dimensions.

Conclusion

Throughout this work, a new construction material was developed using bamboo cut cross wide, in slices, as the honeycomb core in a sandwich panel. There were no references to studies similar to this, as it is, therefore, a pioneer study in Brazil and abroad. The development of this research is intended to replace conventional walls by bamboo sandwich panels made from recycled and sustainable materials. Important aspects for emergency shelters development were considered, so as kit-of-parts technique, low-cost material, dry construction, renewable resources, quick-assembly and reduced amount of energy for materials and panels production, in addition speeding up construction time. As happened in the past, by 1920’s and 1930’s, when new materials and techniques brought
enormous changes in construction methods (Kronenburg, 1995), this research aims to design a portable and small shelter by assembling prefabricated panels and units, similar to an automobile assembly line. The portable emergency shelter and the bamboo sandwich panel presented have achieved this work proposal. The proposal of developing a core shelter prefabricated which is a prototype, quickly assembled with easy skills, collapsible, lightweight, using sustainable materials, low energy consumption, taking advantage of local materials, modular designed to facilitate expansion with the possibility of being increased and become permanent with the addition of new modules, or instead, being removed to be used elsewhere, is possible with the design shown and the bamboo sandwich panel developed. Given the environmental performance required by the project and the requirements of sustainability, were used recycled materials, renewable, low energy content, non-toxic, and also easily found in the market and produced in Brazil. The Emergency Shelter presented in this study met the guidelines for sustainable construction issued by CIB (1999) International Council for Research and Innovation in Building and Construction, The Netherlands (1999) in all issues, both the material used as the design and constructive method: uses renewable materials, recyclable/reusable, is easy assemble/disassemble, has patterned dimensions, low energy content, uses non-toxic materials. The Agenda 21 requirements for Sustainable Consumption and Production, and Natural Resources Conservation and Management have been completely attended in the following items: water economy in construction, high availability of natural resources, high ability of renovation in used resources, low power embedded in the life cycle, low energy consumption/m2 built and components production, low emission of pollutants in indoor air, no emission of CO2 and other greenhouse gases in the production, non-use of toxic and heavy metals, no use of toxic substances, water economy in production (partially achieved, due to the water use in the material production), distance traveled (depends on each case), transport emissions (depends on each case). The emergency shelter developed covers the requirements for temporary shelters, according to the Definition of Temporary Shelter (Transitional Shelter Guidelines, p.12), the temporary shelter should be able to: be relocated to another place, easily dismantled, easy to transport to beneficiary household land be durable to be expanded incorporate improvements, become permanent housing. At the end of this study, it is found that the main
objective of this research was achieved, with prefabricated shelters for emergency situations in environmental disasters, composed by bamboo sandwich panels, designed to enable the rapid assembly and disassembly of shelters. The emergency shelter developed can be used to meet the immediate needs of displaced people or homeless, which may affect between 25 million to a billion people in environmental disasters, according to the report released in May, 2012, by the High Commissioner United Nations for Refugees (UNHCR), a UN specialized agency, as a result of climate change expected for the next 40 years. The emergency shelter developed in this study is also completely suitable for any need of housing, whether permanent or transitory.

**Keywords**

Emergency shelter; sandwich panel; bamboo; castor oil; tetrapak; natural disasters; sustainability.