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Review on the Traditional Uses and Potential of Totora (*Schoenoplectus Californicus*) as Construction Material

Juan Fernando Hidalgo-Cordero[1], Justo García-Navarro[1]

[1] UPM. ETSIAAB. Av. Puerta Hierro, 2-4. 28040 Madrid. SENESCYT, Spain

juanfernando.hidalgo.cordero@alumnos.upm.es

Abstract. The recent advances in the wood construction field have demonstrated the feasibility and advantages of using wood-based materials in tall buildings structures and other constructive uses, which could lead to a net reduction in CO_2eq emissions of the construction sector by replacing high-energy consuming materials like concrete or steel, with wood and biomass-based materials. Among these biomass-based materials are the Non-Timber Forest Products (NTFP)which are plantsthat canprovide important contributionsto the construction sector and help to reduce the net CO_2eq emissions of the building industry. One of these plants is the totora (*Schoenoplectus Californicus*) that has been long used by several communities for making handicrafts and as construction material. Recent studies on this plant have analyzed its properties and its feasibility to be used for producing materials of interest to the contemporary building industry. The totora is a bulrush that grows in lakes and marshes in America from California to Chile and some of the Pacific islands. It grows from the sea level to 4500maasl, it can grow in fresh water and estuaries, and it is resistant to water level changes and drought. This bulrush has been used by many cultures as medicine, food, forage, material for building houses, boats and different handicrafts. The most important examples of the use of totora in the world are the floating islands of the Uros in Lake Titicaca. The Uros people have developed traditional techniques for building their homes, boats, and even the artificial islands where they live on with methods based almost exclusively on the totora. This way of living and production system has been maintained for more than 500 years. This review is about the main constructive techniques that have been used for traditional construction in totora and some of therecent researches that have been made on this subject.Experiments in architecture and industrial design objects made with totora have shown its versatility, durability and high aesthetic value which is exploited in object design and architectural finishes. Additionally, recent studies on the insulating capacity of totora samples have determined an average conductivity of 0,06W/mK, which is comparable to some of the common insulating materials in the current market. The review of the historical uses and recent studies on this material indicate its potential in the contemporary construction field along with other environmental benefits.One of the key features is the totora productivity that can be as much as 56 tons of dry matter per hectare per year, which is near 5 times the average production of a conifer plantation. Therefore, to foster the research about its feasible applications in the contemporary construction field could lead to the reduction of the pressure on wood forests and plantations by developing a new material source for the construction industry.

1. Introduction
Considering that wood is the only major construction material that is naturally grown, it is the only material that we can use within a balanced cycle. However, deeper considerations are needed to assess

this whole subject accurately. The increase of tall wood-structure buildings projects has raised the discussion on how environmentally friendly, is to replace materials like concrete or steel with engineered wood or wood-based materials for tall buildings. Studies have shown that some engineered wood elements can perform as good as concrete or steel for tall buildings structures, although some considerations should be made when assessing tall wood structures, the experience has shown that its usage is possible and environmentally favourable. The maximum height limit of wood structures has grown fast in the last decade due to the technology advances and researches that have developed specific treatments and industrial processes to improve soft woods properties in order to use them in many different ways achieving high performance. Although the wood construction have demonstrated to be environmentally beneficial in comparison with concrete or steel, the demand for forests products is expected to grow very fast, which will increase the pressure on land and water resources. Therefore, we need to think about more efficient ways of producing our materials with the least impact possible. [1].

One of the forests products that can represent a solution to this issue are the Non Timber Forest Products (NTFP), which according to the FAO classification, includes herbaceous plants like rattan, bulrushes and reeds[2]. One of the interesting NTFP in is the totora (*Schoenoplectus Californicus*) which is a bulrush from the Cyperaceae family that grows in America from California to Chile and some of the Pacific Islands like the Cook Islands, the Eastern Island, New Zealand and Hawaii. It grows in lakes and marshes and achieves its best development between 30cm to 70cm water depth. It produces from 20 to 56 t/ha/yr of dry matter[3], [4], which is 5 times the average production of a conifer plantation. Its fast growing makes it possible to yield two harvests a year in some cases, which guarantees a constant source of material supply from a relatively small plantation area[3], [5]. The totora once dried is not prone to biological-agents attacks and needs no special treatments to protect it as we can see from traditional objects like esteras made with totora that can last for many years[6]. These features stimulated several ancient cultures to use it for making a wide range of things from rugs to huts. However, the most important example of the totora use in the word is the Uros islands in Lake Titicaca. The Uros constructive practices depends almost exclusively on the totora canes that are bundled, weaved or braided for making their houses, boats and the artificial floating islands where they live on[4].

Totora internal structure is made of the aerenchyma (Figure 1), which is a spongy tissue formed by air chambers and diaphragms. The external rind has a higher concentration of lignin and waxy tissue, which forms a hard crust that protects the internal tissue[7]. The combination of the two structures makes this material very light and resistant at the same time. The average density of a dried totora cane is 0.08g/cm3, which could be harnessed to produce low weight construction materials. Although being very light, the vertical compression resistance oftotora canes is about 30 $kg/cm^{2,}$ and this resistance can be improved by bounding the totora tightly [6].

In this research the main traditional techniques and some recent experiments will be described in order to provide a baseline for evaluating the material and its potential to the industry.

Figure 1. Totora cane section cut. (Hidalgo, 2007)

2. Constructive applications of totora

Quesana. The quesana is a traditional rug which is made by twining totora canes with a rope at intervals of approximately 30 cm. The quesana's thickness is about 5cm, its width is normally about 2 meters depending on the length of the totora canes, and its length depends on the size of the framework for waving it and its final use, but it is usually between 3 to 10 meters long. Herein, a description of the making of a quesana 2,4 meters wide and 9 meters long is described (Figure 3). The quesana was made in the Uros islands in 2006. A plastic layer is laid on the totora ground to avoid mixing the totora of the ground with the one of the quesana. Two 5cm diameter round logs of eucalyptus are placed at 9m from each other on the island ground and secured with planks. Nylon thread of about 3mm is tied to the eucalyptus logs at intervals of 30cm and tightened. These threads work as guides for the twinning process. Then, bundles of dry totora of approximately 5cm of diameter are placed perpendicularly over the thread guides and with another nylon thread the bundles are being twined together and tightened. Once the quesana is ready, the ends of the thread are cut and knotted. The final product is a 5cm thick textile that can be used as walls, roofs or rugs. Houses structure is made of thin eucalyptus joists of about 4cm x 5cm, to which the quesanas are nailed to form the walls and roofs (Figure 2).

Figure 2. Hut in the Uros Islands (Hidalgo, 2007) Figure 3. Quesana making process (Hidalgo, 2007)

[8]conducted a study to analyse the quesana insulation capacity and its suitability for using it as insulating material in the highlands of Peru. The tests were made using the ASTM C1155-95 standards and the conductivity obtained was 0,083 W/mK. It was stated that 5cm of quesana has the same

conductivity value of 30cm of adobe walls. Therefore, to use totora quesanas, which is an object made locally in Puno was a suitable solution for improving the thermal conditions in that case.

Another works have been made also on the use of quesanas in construction for example the research made by [9] is about panels made of quesanas covered with gypsum and cement mortar to be applied in Puno-Peru. Some tests were made on these panels mainly regarding their impact resistance, fire resistance, acoustic insulation and thermal insulation. Other author, [10]also made an analysis on the use of quesanas as thermal insulating layer incorporated to a mud and reed panel called quincha which is used in traditional architecture in Ecuador.

Single totora sheet. The single totora sheet is mainly used for roofing. These single cane sheets were observed in the Uros islands in 2006. They are normally 2 meters wide and can be from 2 to 10 meters long. They are made by perforating the totora canes with nail and thread and joining them together to form a single layer (Figure 4). It has one thread every 30cm and the ends of the totora canes are weaved with nylon or totora ropes to keep the canes joined.The reason why these sheets are used in roofs is because the flat external surface of this sheet allows the water to flow freely and avoid leakages. In the Uros huts at least three layers of these mats are used to make one roof (Figure 5). The external layer should be replaced every 6 months and the internal ones can last longer.

Figure 4. Single cane sheet (Hidalgo, 2007).

Figure 5. Roof layers (Hidalgo, 2007).

Esteras. Also known as petates are made by weaving totora canes. Esteras can be in various sizes, although normally not exceeding the canes useful length which is around 2,4m, it is possible to find bigger esteras made with interlaced canes[4], [5]. The following description of esteras making process was observed in the traditional handicrafts market called Plaza Rotary in Cuenca Ecuador (Figure 6). The making process of esteras starts by moistening the totora canes with some water and leave them in the shade for about one hour to absorb it in order to make them more flexible and suitable for weaving. Once the totora canes have been softened, a stone is used to blow the canes to flatten them, decrease volume and increase density, which gives the fibre more resistance and flexibility for weaving. Also this process helps to achieve a stiffer tissue because the canes would recover some of their volume by swelling adding rigidity to the final product. Esteras have been the most widespread object among totora-working communities, its use traces to thousands of years ago and it is still uses in many parts of the world as rugs, mats and wall or ceiling coverings. One interesting example of the use of petates is “La Petatera”, in Colima-México, where a bullring for approximately 5000 people is constructed every year using wood structure and petates are used as the building envelope[11].

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Figure 6. Esteras rolled (Hidalgo, 2007).

Figure 7. Estera weaving Imbabura(Hidalgo, 2007).

Totora Bound Bundles. Totora bound bundles is the construction technique used for building the traditional rafts and boats used by several totora working people for fishing and harvesting the totora. Although totora canes are relatively weak, when tightly bound together to form compact bundles, they gain considerable resistance. The process of making these totora bundles consist of wrapping the totora with a rope and bind them as strongly as possible to achieve a compact body. This technique has been used by several cultures of America for making totora balsas, and many other reed balsas reported to be made in similar way around the world since thousands of years ago. This same technique has been used for building nearly 14 seagoing totora boats up to now, that have crossed the seas in order to demonstrate the theories about the true possibility of ancient intercontinental contacts between cultures of the world. Most of these experimental journeys have been more than 2 months long, which is an important evidence of the resistance that totora bound bundles can reach considering the great stress at which the material is put trough to during this kind of journeys.

Figure 8. Balsa Making process (Hidalgo, 2007)

Figure 9. Titicaca Balsa (Hidalgo, 2007)

The “Totora Project”, was developed by the PUCP-Peru, the SAdBK-Germany, and the Uros community in the year 2010. The totora bound bundles technique was also used to build a series of experimental structures made as part ofthe Totora Project studied the possibilities of using totora for building contemporary structures that could house some cultural and communitarian activities of the Uros people. The structures built as part of the experiment (Figure 10) demonstrated that totora bound bundles can achieve considerable resistances[12]. Although there is not information on the structural resistance these structures achieved, they demonstrate thatit is possible to buildcomplicated structural shapes that support themselves and eventually extra loads using this technique. This suggests that a deeper research on this subject could widen the possibilities for the totora regarding the structural resistance field.

Figure 10. Totora Project, Community house structure. (PUCP & SAdBK, 2010).

Innovative techniques for processing the material were proposed by Hidalgo [6], who studied several possibilities of the use of totora in architecture as contemporary architectural finishes, where the main purpose is to harness the social and environmental benefits of its usage and aim to widen the possibilities of this traditional material in the contemporary architecture and industrial design field. Hidalgo´s totora design line obtained the UNESCO recognition for excellence in handicrafts in 2014, which recognizes the social and environmental values of the proposal. Among the innovative productive processes presented in this work is the "totora textile", which is a sheet made of short totora stems placed vertically and glued to a natural rubber back (Figure 11). The spongy tissue of the aerenchyma plays an important role in this case because it makes possible to achieve an almost perfect interlacing of the totora shapes minimizing the air space between the canes and improving the textile resistance. Other experimental processes were developed in his work harnessing the natural features of the material, its versatility and its aesthetic value for example: agglomerated totora blocks, malleable totora surface, pressed totora partitions, roof modules, etc. This work was focused on generating architectural coverings and partitions that could be suitable for contemporary architectural spaces and interior design.

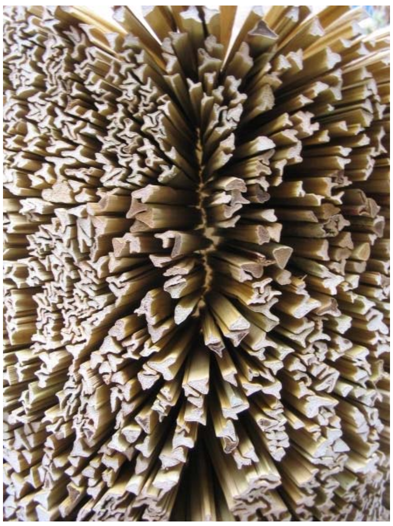

Figure 11. Totora cut canes texture (Hidalgo, 2007)

Aza [13], in her research about the thermal insulating capacity of totora studied several samples made of totora, using ground and whole canes agglomerated with natural glues. The thermal conductivity was analyzed using the thermal analyser Quickline TM-30.Although the samples that were made with ground totora canes showed the best thermal conductivity values with an average of 0.055W/mK compared to the ones made with whole canes with an average of 0.066W/mK, the flexural resistance of the latter was higher than the ones made with ground canes. The samples were also tested to their fire resistance according to the UNE 23-723-90 Standard. This test showed that totora samples had in general a good response to fire, with short ignitions and extinction cycles. However, the samples that received a basic fireproofing treatment based on alum were able withstand the tests with better results. The hygrothermal performance of the samples was also tested according to the standard UNE EN ISO 12572. This test showed that the samples made with ground totora had a vapor resistance similar to other insulating materials like wool or wood fiber. In conclusion this study is of interest because it demonstrates that totora boards could achieve a good balance between thermal conductivity and mechanical resistance in one layer, which is a very interesting feature for materials in the contemporary construction sector.

The Totora Cube-Archqid developed by Lerner F., Fuentes A., Jara O, Jones V., in Imbabura-Ecuador during the 2016 was an experimental project that used the traditional weaving techniques of the local community of San Rafael de la Laguna for making a series of mats that were used as the envelope of a cubic structure. This cubic structure was made of wood panels that were hinged and can be opened in order to open the space and use it in different ways. As the authors have stated, this is an experimental project that its main objective is to be a catalogue of the traditional weaving techniques of the community and an incentive for creating new ways of thinking about this material and the possibilities it can offer.

The versatility of this plant, it’s fast growing, the low environmental cost the harvesting, and other intrinsic environmental benefits of this fiber can be seized by the building industry to widen the current offer of construction materials and reduce environmental impacts.

3. Conclusions

The current demand of forest products from the building sector is increasing and it is expected to continue this trend, which had led to a spur in research and developments that had made possible to use a wider range of materials by improving their properties using different treatments and techniques. The research on non-wood fibers like totora could generate an interesting contribution to the contemporary construction field with several environmental benefits.

The historical uses of totora have demonstrated its suitability to be used as construction material although the traditional uses have been very specific and at a very low scale, new treatments and techniques can be applied in order to seize its full potential. Since totora can grow in many climate zones, it would be possible to generate local material sources in parts of the world where there are not wood forests.

The recent studies on totora have demonstrated its potential as insulating material, which is a sector where natural materials can make an important contribution. Considering that totora has a naturally configured insulating structure, it could have an interesting potential in this field.

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