Re-start from straw

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Abstract

This paper describes the ideation and realization of an earthquake-proof prototype to verify the appropriateness of an orphanage to be built in Haiti. The construction system utilizes mainly natural and local materials like rice straw bales and bamboo.

This work is the result of a master thesis in Architecture at the Politecnico di Torino. It originates from the collaboration with Architetti senza frontiere Piemonte, an Italian NGO.

The wider scope of the project is to contribute to returning to rice farming and to recognizing rice straw as an appropriate building material for Haiti. Both goals would constitute a step towards establishing a virtuous social, economical, environmental, agricultural, and architectural process.

1. Introduction

Haiti is a special place where to build, not only because of the difficult economic and social conditions that have been prevailing in the country for decades, but also because of its geographical and climatic features that have generated a series of natural disasters, which one must consider before starting a project.

Haiti is annually affected by tropical storms that sometimes may develop into hurricanes. Wind can have a serious impact on the structure of buildings. The average wind speed is around 15-20 km/h but tropical depressions often occur where speed reaches 63 km/h. These depressions may increase, reaching 120 km/h and more. [1]

History shows how this country is prone to hydro-geological threats and earthquakes. The latter are due to the fact that the country – and particularly the areas where unfortunately lives the majority of Haitian population – sits on the fault between the North American and the Caribbean tectonic plates. These two plates move at an average speed of 2 cm per year [2].

After the tragic earthquake of December 2010, an intensive program of reconstruction has been activated. This has highlighted that construction industry is one of the main problems in Haiti. In fact, Haiti is a country with few raw materials. Most building materials on the market come from abroad, especially from the United States, Canada, and Brazil.

The most used construction system is reinforced concrete. However, this costs too much and the lack of specialized labor produces poor quality structures, which is the reason why more than 80% of the buildings collapsed during the earthquake.

When we visited Haiti in March 2012, our primary objective was immediately to look for a “native”

material and find a constructive system combined to it, that was economically viable and could be earthquake-resistant.
Most data in this paper are the result that one month journey across the country, that two of us – Matteo Restagno and Gianni Ricci – made to begin our research: analyzing the Haitian building market and visiting 12 building sites was really useful to get acquainted of the dynamics of the reconstruction process, in order to evaluate what kind of results were being obtained, and look for a possible alternative which could be more socially, economically, and environmentally sustainable.
Reconstruction programs are often managed by international NGOs, especially from the US. Most projects focus on new house construction. After 1½ years, housing was (and we're told is) still a big problem; displaced persons were concentrated in temporary camps. On the contrary, many schools were being reconstructed.
The majority of new buildings are made using reinforced concrete, and the use of steel has raised in order to increase the earthquake-resistance of buildings. In addition to the poor construction quality that characterizes the majority of the buildings, there is also a lack of design quality. Often in the designing process there is no consideration for climate appropriateness. Overheating is the main problem; the indoors are not properly ventilated.
Some NGOs have proposed new building systems that use an alternative materials instead of concrete. For example, CRAterre has built earthquake-resistant timber-frame buildings, with debris as infill. This new construction system is taught to workers on building sites. However, buildings making without concrete are mostly experimental (Fig. 1).

1. Usual renforced concrete system and CRAterre system

2. Construction materials in Haiti

The construction market in Haiti is focused mainly in the capital, Port-au-Prince.
Reinforced concrete was introduced in Haiti at the beginning of the 20th century and has been used for the realization of important buildings such as the cathedral of Notre-Dame (1912) and the National Palace (1918). The introduction of this material has been favored by a law which banned the use of wood in construction, because of some fires that struck the city. [3]
Since the 1940s, hollow concrete blocks came into use as infill or (reinforced) as load-bearing structure. Blocks are produced locally by small enterprises and sold by street vendors at the price of $ 1 each. Standard dimensions are 15x35x20 cm. Cement is produced from Haitian quarries while iron comes from the neighboring Dominican Republic. The cost of cement is very close to Western prices, ranging from $ 1.5 to $ 2 per 10 kg.
Using wood is not possible in Haiti. Felling of trees both to obtain export-grade lumber and to produce charcoal for cooking resulted in the disappearance of forests at the end of the 19th century (Fig. 2). Up to that time, the species most commonly used in construction were Caribbean pine and fir. Currently though, wood must be imported. The biggest exporters are the United States and Canada, which provide poor quality timber. Nevertheless, timber is very expensive because of

transport.
Other local materials such as limestone and clay can be found in abundance, but their use was lost and has been replaced by cement mortars. Moreover, the gradual deforestation has generated serious problems of soil erosion that has made the majority of lime sediments collapse. Haiti is mostly mountainous so local stone is largely available. But this stone is geologically very young and therefore brittle.

2. The boundary between Haiti and the Dominican Republic shows the high deforestation. On the right the production of cement blocks

3. Opportunities offered in Artibonite Valley
Haiti is a poor country, whose economy is mainly based on agriculture. Looking for a potential building material from this sector has been almost spontaneous to us.
During our journey, rice straw was identified as one of the best building materials widely available in the nation. Rice cultivation is developed in inland valleys, like Artibonite. Straw, besides being much more economical than bricks and cement, it is excellent to build with, especially in rural areas where this material is largely available. Furthermore, straw is biodegradable, renewable on an annual basis, easy to handle, and its embodied energy (due to the harvesting, the baling and the transport to the building site) is far lower than virtually any other material employed in the building trade. [4]
Specifically, we decided to study the feasibility of using rice straw, pressed in bales, for the construction of a living module.
Data about rice cultivation in Haiti were kindly provided by the agronomists of RACPABA, a local organization that helps farmers to increase yield through technical support.
Along with corn, cassava and fruit, rice is a basic element of Haitian diet.
Rice crops grow on the mountains and in swamps. Mountain fields are small, subsistence cultivations close to Cap Haitien and between Léogâne and Jacmel. Swamp rice is more common and is mainly cultivated in Artibonite valley, where 80% of national rice is produced (Fig. 3).
28,000 hectares are cultivated in the valley, of which 24,000 are rice fields – a number that could increase, because 32,000 hectares are irrigable land.
The most cultivated varieties are TCS-10, Sheilav, Schelde, La Crete and Prosequisa-4. Because of favorable climatic conditions, many farmers obtain two production cycles throughout the year, one from December to March and the other from April to December.
The minimum land parcels cultivated by a single farmer is 0.25 hectares. The process of separation of grains from stalks is made by hand and leaves on the ground huge amounts of straw which are burned directly on the field. In Artibonite an average of 4,000 kg rice/hectare are produced, and an equivalent amount of straw.
For our project, we specified standard-size straw bales (that is, 45x35x90cm). This choice is due to ease of transportation, assembling and handling.

In Northern countries, the bales are realized through a mechanized process that can lead to a density of 120 kg/m3 or higher. In Haiti, where agriculture is not mechanized, we have considered the use of a manual press for baling, to reach a density of about 96 kg/m3. This value still allows load bearing construction [5].
We have estimated that to build a 40 m2 house (corresponding to the Haitian living standard) we needed 240 bales, i.e. 4,800 kg of straw, which might be produced in three rice fields (0.75 hectare).
The use of straw in the construction trade, instead of burning it as waste, would trigger a development process from local resources. It would also give an opportunity to increase rice production, which has been declining since 1970, substituted in local alimentation by imported rice. [6]
Farmers could self-build their own houses – but this could happen only through cooperation with local associations which, like Racpaba, work closely with the farmers themselves.
Once confirmed its availability, we started to study the characteristics of straw, in order to realize a prototype that used rice straw as the main structural material.

3.1 Rice straw

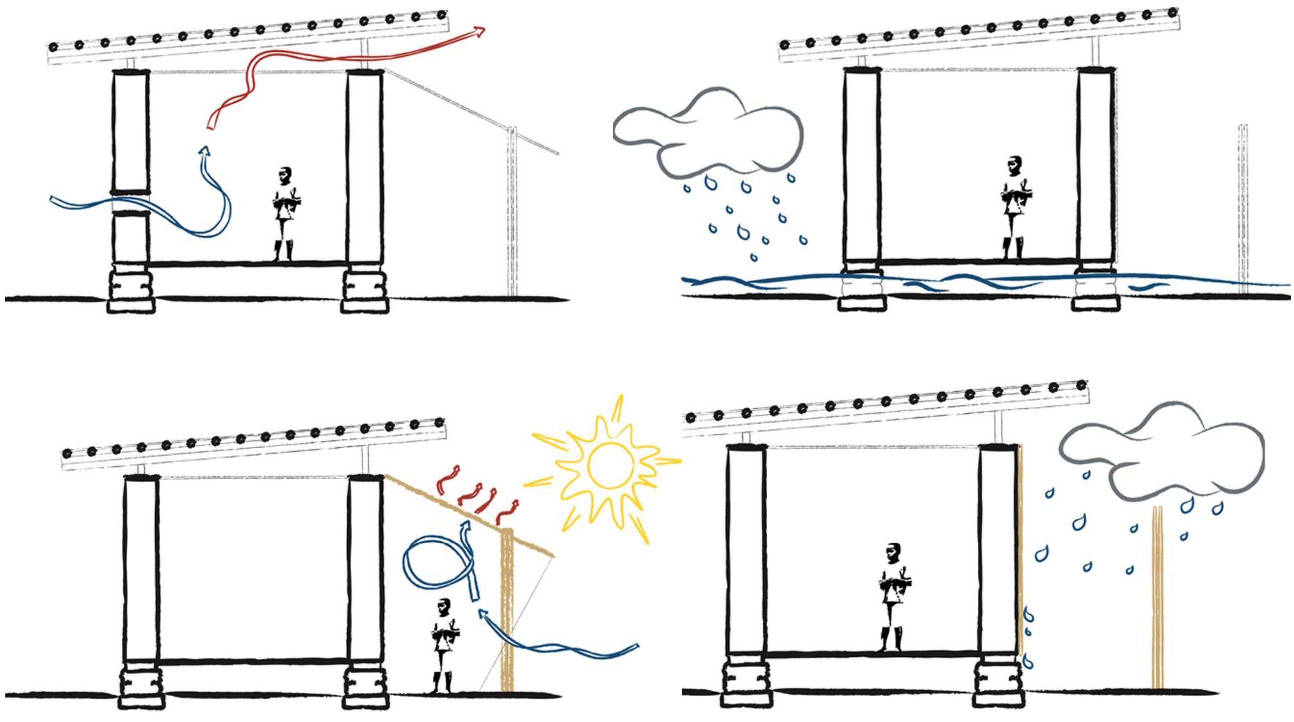
Straw, like wood, consists of several components whose proportions and chemical characteristics vary according to climate and solar exposure of the plant.
Specifically, with respect to rice straw, the components are:
cellulose (about 40% by volume): long fibers of microcellulose ensure the tensile strength and the "structure" of the plant
hemicellulose (about 25% by volume) is the glue connecting the cellulose microfibers
silicon (about 20% by volume)
lignine (about 15% by volume) is the glue that unites all elements, like concrete in reinforced concrete. [7]
Like all fibrous materials as wood, paper, and cotton fabric, straw tends to decompose if moist. In fact, straw is a potential food source for some microorganisms such as mushrooms or bacteria, which are already inside the bale at the time of harvesting. Under certain conditions of humidity and temperature, a process similar to composting could start. Rice straw seems to resist better to decomposition than other types of straw, thanks to its high silicon content.
Anyhow, to build safely with straw bales, moisture inside them should be less than 15%. [8]

3. Artibonite valley

4. The Haitian project

Once back from our journey we started to develop a technology to build there. The design process was developed in cooperation with the Italian NGO Architettura Senza Frontiere Piemonte which had recently built a school in Léogâne. With the help of FEBS, a Haitian aid organization, we

started to design an orphanage for St.-Marc – a city close to Artibonite Valley, where FEBS owns a suitable plot.
The choice of materials was the most important aspect of the design process, because it can affect costs and dimensions. We decided to specify local materials like bamboo and rice straw bales, thereby reducing imports. Where this was not possible, we opted for imported materials that are widely available in Haiti, such as reinforced concrete, metal sheet, and wood.
The orphanage was designed for 32 children and 5 staff. There are two wings for the children's rooms, while other two accommodate a the kitchen-dining room and the director's office. To make the constructive process easier, the small complex is composed of one-storey buildings with the same width – 3 m. This would allow to fit in the dimension of straw bales, and to keep the costs associated with timber elements as small as possible.
In addition, most of the design choices resulted from the need to manage local climatic conditions. Haiti is particularly vulnerable to strong winds and heavy rains, moreover the temperature is high throughout the year.
To avoid flooding risks, we decided to raise the building about 40 cm above grade, using tyre piers.
In order to enhance natural ventilation, the roof is detached from the walls, so that fresh air would flow in from an inlet in the lower part of wall, which is less exposed to direct sunlight. Air would go up and ventilate the space under the roof.
To protect the occupants from direct sunlight, a movable shade system defines a 2-m-deep outside space where it is possible to sit during the day (Fig. 4).



4. Climatic considerations

5. The prototype

Once the project of the orphanage was completed we started to build a prototype in 1:1 scale that represents a section of a wing of the orphanage. This experimental building was erected in Poirino, a town close to Torino (Italy).
Technological and structural design choices are based on European standards requirements and on data from tests performed on straw-bale buildings at international universities [9]. In other cases, we tried to develop logical solutions, but future experiments will be needed to demonstrate their validity.
Structural issues explained in this paragraph were detailedly discussed with professor Walter

Ceretto, Politecnico di Torino.
The reinforced concrete curb thickness depends on the characteristics of the soil on which the building stands. In Poirino, we dug into the ground to a depth related to the type of soil in St.-Marc. The width, however, was determined by the diameter of the salvaged tyres which rest on it. These are stacked in pairs, joined with iron wire, and filled with pressed earth and gravel. On top of such piers lays a system of timber beams which support the wooden floor. The latter is made integral with the previous two through a threaded metal rod, which – after having been embedded in cast concrete – is fixed with a nut.
This basement has a double function: not only it protects the building from water falling on the ground during heavy rains, but it aims to insulate the building from ground motion during earthquakes. In such an event, in fact, the concrete curb would move with the ground, whereas the elasticity of tyres would disconnect the displacement of the ground from that of the building. In this way the construction would oscillate at a period longer than that of the structure, thus reducing the seismic acceleration, which depends on the building mass. Knowing the mass of the construction it is possible to determine the stiffness of the isolator to be used for a specific building – but here, as opposed to current building products, the exact stiffness of tyres is not known. In order to verify the appropriateness of this earthquake-resistant system one should carry out tests beyond the prospects of this work. However, it is possible to conceptually compare the behavior of a seismic isolator made in this way with a elastomeric isolators commonly used in industrialized countries. Rammed earth in salvaged tyres and the rubber of the tyres themselves create a highly elastic structure able to dissipate the energy of the earthquake in the same manner as the elastomeric material used for more conventional insulators.
With regard to the vertical load that each tyre should support, we referred to the test performed by the engineering department of Swartmore College, whose results show a linear behavior in displacement of tyres [10]. In the St.-Marc *foyer* the maximum load is higher than that of the American experiment, but the tension of the ground pressed inside the tyres, which is 0.11 MPa, lets us assume that there would be no problems. Obviously a load test that equaled, or better exceeded the load considered in the design of the orphanage, would allow to assess whether the behavior of tyres continues to develop elastically.
The structure, made of wooden planks and joists, which rest on tyres, has been dimensioned to support the load of roof and walls. Beams supporting the floor planks have been verified so that their flexion is two hundred times lower than their length (Fig. 5).

5. Foundations

After the completion of the base, we started to erect the walls with rice straw bales. We used bales as the only load bearing element of 35-cm-thick walls. Bales were arranged in staggered courses. A series of wooden stakes, with a diameter ranging between 3 and 5 cm, were used to join courses,

thus increasing the robustness of the system. This technique was inspired from Barbara Jones's book (Building with straw bales).
A timber window frame has been inserted in the wall, so to be 8 cm deeper than the walls. In such a way the frame can support the plaster on the two sides. Haiti tropical climate allows to avoid glass windows – only shutters to protect from ill-intentioned people have been installed. This choice, which also implies a significant load reduction, has led to a more slender wooden frame.
A top wooden beam, consisting of two beams enclosed between two planks, rests on the seventh and last row of straw bales such as it is showed in Barbara Jones' book. [11] (Fig. 6).
This distributes all over the wall the pressure exerted by 8 polyethylene straps that connect the bottom with the top beams. A ratchet allows to tension the belts which pre-compress the walls. In this way, the solidity of the structure is greatly increased. The height of the straw bale walls was reduced by almost 10 cm. After the construction of the walls we started to assemble the roof-supporting system. This structure was built entirely with struts and beams made of bamboo with mechanical joints. First, four pillars were constructed: each element consisted of three bamboo poles.

6. Wooden structure at the top of straw bales walls

Such pillars were sunk into the walls through circular holes in the wooden top beam described above. The bayonet joints at the top end of each pillar allows to insert the joists. These are two; each one is composed of two 6,2 m long bamboos joined by rope connections and two threaded rods which hold them together with two metal nuts. The secondary framework is composed of 15 bamboo poles, 3.85 m long and fixed to the two joists with rope connections.
Metal sheets are used for roof covering. They are fixed to the bamboo structure with metal rods, bent manually in a U shape. During the assembly of this connection some small rubber rings were pinched between locking nuts and metal sheets to prevent rain water to seep in through the holes.
The analysis of roof beams has been developed according to ISO / DIS 22156 and 22157 and ISO/wg9. Data provided by ISO standards were used to dimension main and secondary beams, verifying that both could resist the action of Haitian wind. Wind speed has been assumed 118 km/h which is a very high value compared with the average on the island. Assuming a form factor (Cp) of 2.1, a 1.41 kN/m2 wind pressure was obtained, which corresponds exactly to the snow load to be considered (with the sign changed) for the prototype built in Italy.
The secondary frame has to be composed of 8-cm-diameter bamboos, and joists have to be put at 40 cm. Joists are made of two 10-cm-diameter bamboos. It was also verified that the weight of the entire construction, including foundations, was heavier than the lifting force originated by the wind, so there was no risk wind tearing off the roof (Fig. 7).
Walls were plastered with different materials. The exterior plaster is made of lime, while the inner one of earth. Both were daubed on the wall alternating two 2-cm layers with a hexagonal wire mesh. This coat, in addition to protecting the straw wall from the threat of water, increases

considerably the resistance to fire. A structure made of any material and daubed with 1.25 cm plaster can resist fire for 30 minutes, which is the requirement to satisfy for traditional houses [12]. The wire mesh fixed to wooden frame, helps increasing the stability of the structure.
As a final step, a movable shade system was built on one of the two short facades. This is made of a bamboo frame which supports a vegetal mat. This element rotates along the upper part of the wall and hooks in two bamboo poles plunged in front of the façade. The movement allows to open the veranda to shade the adjacent portion of the wall, therefore creating a protected outdoor space where to sit. The same system allows to lay the shade against the wall during a storm or strong wind, in order not to damage it (Fig. 8).

7. Structures

8. Final Prototype, movable shade

6. Conclusions

Our research has shown that the building system designed is easy to realize and the structural studies were correct. Tyre foundations, rice straw-bale walls and bamboo roof structures were built without any constructive problems demonstrating that this building method can highly reduce the use of concrete.
The next step of this research would be the development of a series of tests to obtain data about the experimental solutions we used in the prototype. Unfortunately, lack of funding prevents this at present.
Constructing rice straw-bale buildings in Haiti would be very complicated for a number of reasons: for instance, it would be hard to get materials, because even if all of them are available there, it is

essential to have the right contacts to find the best suppliers and workers. But the major problems seem to be cultural and systemic: The chaotic situation of the country and the wide use of concrete currently prevent a building system that uses natural materials. A step in the right direction might be to train a group of workers to use straw-bales in construction. This might happen in the occasion of the *foyer* at St.-Marc, in case this project is transformed into reality.

9. Rendering of the orphanage

7. Acknowledgments

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