

PREFABRICATED MODULAR STRAW WALLS AND PANELS FOR HOUSES BUILDING AND BUILDING RENOVATION

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ABSTRACT

Straw is compressed with low technology tools into bales, with a density of more than 90 kg/m³ and acquires special properties as a building material by its compactness and insulating capacity. In the last 4 years have tripled buildings made with straw bale in Europe, from over 2000 in 2010 to over 6000 today (FASBA 2013). In countries as Austria and Germany, the use of this material is regulated in technical building codes. Contemporary buildings with straw comply effectively energy efficiency standards such as passivhaus.

Cereal straw as an agro-fiber has been discovered in recent years either by the industry of biopolymers as by the building industry. Until now it had given prominence to biofibres from flax, jute, hemp or cotton, however for the use of these materials are necessary plantations and specific controls, while cereal straw is resulted from the agricultural residues sector.

Cereal cultivation worldwide covers 697,678.673 hectares (World Bank Group, 2013), the most of them are rice and wheat, each ton of grain produces 1.5 t of straw, because the high silicates content, straw cannot be used for animal feed, therefore must be destroyed each year, causing environmental disasters for instance through incineration.

With the research and development of building with straw, there are several proposals for serial production of prefabricated elements; ecococon.lt, eco-fab.co.uk, modcell.com, pailletech.be, strawbalehouse.co.uk, systemhausbau.at, strohTec (baubiologie.at), etc.

A team of students from the School of Building Engineering of the Valencia Technological University and the natural building company okambuva.coop have developed modules made from straw bales and wooden structures, which are being applied successfully in building of houses. An important aspect, along the performance of this material is the possible activation of the local economy through social and ecological solutions, thanks the use of local resources with low investment technologies.

Keywords: straw bales building, natural building, prefabrication, biofiber, passive house

1.- Introduction

1.1.- Building with straw bales

Straw is one of the oldest building materials known to mankind since old times was present as fiber in bricks and clay walls.

The straw bale appears mid-nineteenth century with the invention of mechanization needed to create compact blocks to better store and crop residues for cereals for many uses. With the creation of the first packers in Nebraska, they were the first buildings with these blocks.[Fig.1]



Fig.1 "Image of straw house of the Family Simonton, Purdum, Nebraska (1908)".
Source: www.prairiefirenewspaper.com



Fig.2 "US Patent 225 065 A, in March 1880, Straw Bale Building" Source:
<https://encrypted.google.com/patents/US225065>

From the late nineteenth century date the first patent for straw bale building, which shows the technical interest aroused this material since its inception.[Fig.2]

In the mid-twentieth century Europe get the first straw bale buildings, a proposal of architect Feuillette, in France, as a solution to build low-cost housing for the victims of the First World War. This house built in 1921, is now the head quarter of the French National Center for Straw Building and kept in perfect condition.[Fig.3]



Fig.3 "Photos from the Maison Feuillet comparing an image from 1920 and one from 2011" Source: Fondation du patrimoine.

But it was not until the 90s of XX century does not begin an intense stage in the discovery and development of the possibilities of the straw bale as a building material.

1.2.- Building Material Straw Bale

A straw bale suitable for building is a compressed block of cereal straw, mainly wheat, rye or rice, pressed with a density higher than 80kg / m³ and a relative humidity less than 18%.

Staw packing machines currently available by the agricultural industry produce pieces of about 50 cm wide, 35 cm high and 80 to 110 cm in length, with a density of up to 120-130kg / m³.

Worldwide more than 600 million hectares of cereals [1] are grown, most of them rice and wheat, each ton of grain produced 1.5 t straw due their low nutritional content cannot be used just for feed therefore has to be destroyed each year, resulting in part major environmental disasters with incineration, for instance.

Straw has a very similar chemical structure and physical properties like wood. Bales, allow us to create walls that can be bearing and provided with mortar coatings (clay, lime, gypsum), comply with all expectations applicable to an wall in conventional building and contribute significantly to the thermal insulation.

The German architect and engineer Gernot Minke, who has directed many of the tests performed on straw walls in Germany, pointing from his experience that straw bale walls may hold above 500kg / m as a load bearing wall, which would be 1000kg / m². [2]

The plastered walls of straw bales have passed all kinds of tests for resistance to fire, demonstrating its optimal resistance (Germany RF90, USA RF120) Thermal conductivity of straw bales the is between **0,0337 y 0,086 W/mk.**

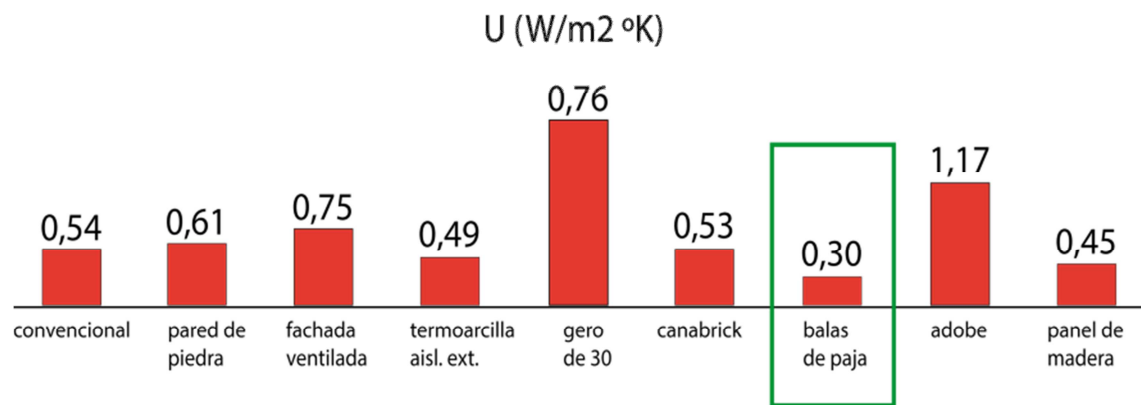


Fig.4 "Graph of thermal transmittance of different materials expressed in W / m²K." Source: Journal Ecohabitar.

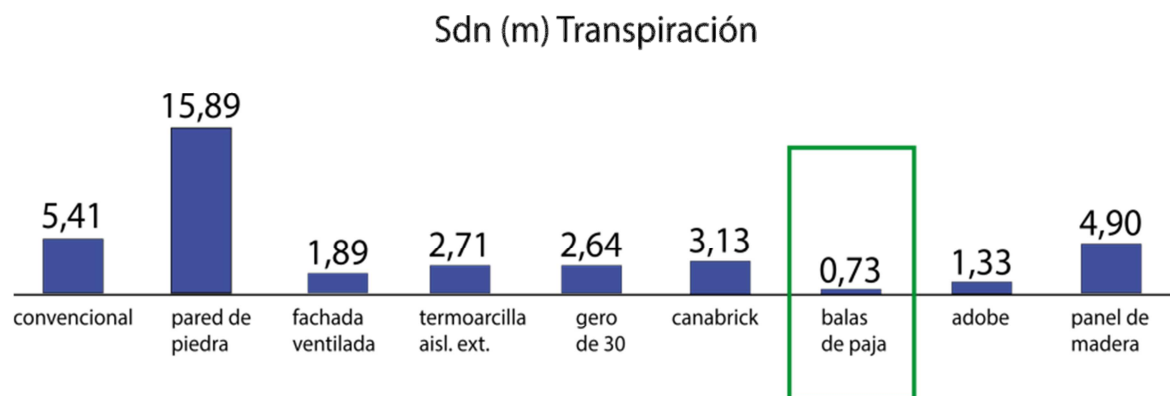


Fig.5 "Even so breathability". Source: Journal Ecohabitar.

Along with its structural capacity, the most important contribution of the straw bale is its insulating power.

These properties together with the big availability and low technological investment necessary for handling have been key to the development of building with straw bales over the past 20 years.

1.3.- Straw Bale Building in Contemporary Europe

Straw bale building has been institutionalized in Europe. In Germany and Austria there is an official certification for the straw bale as a building material, France [Fig.6], a leading European country with nearly 3,000 buildings, is working with professional Rules for straw building. [3]

In Spain there Straw Building Network since 2005 and some project done in this field. [4]

Currently, European countries are working together through the Leonardo Da Vinci Lifelong Learning program on the development of recommendations for rules and for professional training in this area for the member countries. [5]



Fig.6 "Residence Jules Ferry, France built with straw bales, passivhaus, 7 stories."
Source: <http://www.toit-vosgien.com/fr/performances-energetiques/immeuble-bois-grande-hauteur.html>

The building typologies with straw bales are diverse. The bale is used as load bearing wall (Nebraska style), but also in different structures, as a filler or insulation with varying structural contribution.

1.4.- Difficulties in the use of straw bales for conventional building.

Using Straw Bale has some difficulties for integration in conventional building.

At first, subjective, straw bales coming from agricultural and rural environment, do not inspire confidence, the field of construction is regulated and conditioned by complex regulatory structures and a straw bale, known as animal feed, is difficult to imagine in the context of contemporary engineering projects building.

It is true, because this material is produced in this format for logistical purposes within the agricultural sector and not for building, there is no convention, agreement or standard for proper quality control to use it in building.

Austria and Germany have already established a regularization and a certified check for building bales, based on density, moisture and purity, but, for example, within the Professional Rules of Building with Straw, developed and existing in France [3], it is noted with emphasis on the need for intense manipulation of a straw bale before being integrated into a wall. [Fig.7]



Fig.7 “Handling of Straw Bales for a load bearing Building” Source: okambuva.coop

Due to the different origin of the material we can not know exactly in advance their hygrothermal properties, nor structural, nor the final dimensions, once in the presence of the material, we can proceed to check and perform the necessary quality control, which generally difficult design, calculation and planning.

Building with Straw Bales requires space and conditions at the building site for storage and handling, wastes generated are biodegradable but are bulky and cumbersome, in form of dust and loose straw in the environment, undoubtedly a problem for urban building. A load of straw bales is not protected palletized and ready to use, it comes from animal feed stores or directly from the field, in large trucks.

2.- Objectives and scope of research

The premises and European experiences led us to find a solution in this sense for our environment and apply to our reality. It is proposed as main objective the design, development and manufacture of prototype called alfaWALL. The alfaWALL building system is a modular system for walls, based on slatted wooden structures containing straw bales. The wooden structure and its dimensions allow easy mounting, with conventional manual tool and special construction screws. In addition there are not necessary additional supporting structures for the building.

The scope of research is undergoing a more overall set, which not only should propose technical solutions specifically prefabrication construction system, but must also take into account aspects such as:

- Regularisation and standardization of building elements made up of straw bales. How to set specific dimensions and practices for project development. How to have clear and reliable parameters relating to their specific physical properties.
- Logistics and handling. How to have the means and conventional systems for transportation, storage and assembly, familiar to the conventional building practices.
- Image and confidence. Designing constructive elements whose properties and characteristics approaching this material, highly efficient, practices and possibilities within the trades and professions of conventional building.

3.- Prefabricated Straw Bale Walls

3.1.-Background

Very interesting is the response of various countries to develop solutions prefabricated walls, modules and panels. [10]

The prefabricated straw and wood panels enable fast, simple and clean implementation in areas that require it, as in urban areas. On the other hand, we must emphasize the strength and monolithic that is available in the entire product, making straw and wood work as a single entity.

Each of the products that have appeared in the market has nuances that differentiate between them, such as the amount of raw material, manufacturing or formal characteristics.

The method of manufacture of these modules is also a branch point between the alternatives on the market. There are manufacturers who decide to form modules with straw bales, others wear loose straw pressing it through a continuous matrices getting some modules that facilitate the production of elements of any height. We also have the option not only to have prefabricated in our workshop but also pre plastered. This alternative has pros and cons, as long as we can save the rendering at work, can they invest in repairing cracks or damage caused by transportation, plus the added complication of weight, which involve greater difficulty in handling and resorting to auxiliary machinery for placing.

The most obvious difference between the various proposals market is the variety in shapes and dimensions of the modules. We can find modules such as wide format 3x3m ModCell [Fig.8] or individual modules such as the new proposed experimental balabox, Spain. Again this has its pros and cons. Large modules allow us to quickly implement the closure of wall and less mounting screws, but we will be an additional cost for the machinery needed for handling, additional costs that we have with small modules. By contrast, small modules carry higher thermal bridges, structural problems and the use of an extra amount of wood, a scarce natural resource, a fact to keep in mind in our latitudes if we follow guidelines for sustainable building.



Fig.8 "Modcell, UK, prefabricated modules up to 3x3m" Source: www.modcell.com

3.2.- The proposal alfaWALL

The premises and European experiences led us to find a solution in this sense for our environment and apply to our reality.

We have straw, even in our region, we have a critical area, internationally noted. The burning of rice straw is a serious environmental problem caused in the Albufera of Valencia.

The consequences of political and economic disaster of recent years have left us interesting productive capacities in form of workshops and spaces of local industries that are largely unusable.

The okambuva company, a recently created co-operative, formed by professionals of building sector, which has faced the course of their work and research into the world of healthy and sustainable building, supported by the School of Engineering Building Polytechnic University of Valencia, has developed a proposal which is throwing excellent results.

The alfaWALL building system is a modular system for walls, based on slatted wooden structures containing straw bales [Fig.9]

Straw bales pressed with a minimum density of 120kg / m³, set within a wooden structure are structurally supporting, there are not necessary additional supporting structures for the building. The wooden structure and its dimensions allow easy mounting, with conventional manual tool and special construction screws.



Fig.9 "alfaWALL composition of a wall, from different types of modules". Source: okambuva.coop

The design, development and manufacture of prototypes was made by analyzing experienced in other European countries, specifically the Lithuanian company ecocon, documenting their tests, results and certifications comply with European regulations [6]. This proposal is morphologically attractive for the small wood use compared with other European elements. This is particularly important in Spain and especially in the Mediterranean area.

But they use "loose" straw pressed into the skeletons of wood. This solution involves major technical investment, in terms of presses, handling and matrices.

The main contribution is based on using conventional bales, considering that the German, Austrian or French regulations require a minimum of 80kg / m³ and the Lithuanian proposal certifies using 100kg / m³, we find that in Spain, in key growing areas cereal packaging machines are being used that are capable of compressing to a higher density of 120kg / m³, without affecting price or logistics.

This reduces manufacturing technology investment and wide the possibilities to use appropriate technologies available.

It was very important the choice of wood, especially using a system that requires a little amount, to rich the structural requirements of a bearing wall, wood C24, this being planed on all sides to get proper assembly of its parts: uprights, crossbars, strips, diagonal, etc. [Fig.10]

At present Spanish pine sawmills Soria is used. Also taken into account the type of screws to use, as the screws will not only fulfill the function of bound and assembly, in many cases are those who resist the load, axial or shear. In this case, it has been necessary to use European manufacturers of experience and prestige, with sufficient documentation, testing and technical guidance, such as the company Reisser [13], Germany. [Table 1]

The assembly in the workshop is using tools and conditions for conventional carpentry, for a yield of approximately 10m² of wall per day 4 operators are needed. Increased mechanization, with hydraulic matrices, etc., would undoubtedly improve that performance, but for the present state is completely satisfactory.

A house of around 100m² of floor area, need about 160m² wall, 50m³ volume translated into alfaWALL modules, a 8t for transport and handling with conventional logistics.

The modules can be manufactured specifically for each project [Fig.9], which can adapt its dimensions within a technological conditioned grid [Fig.11]. The walls can be plastered with clay mortar and / or lime, or covered with wood fiber boards as structural frameworks allow easy fastening.



Fig.10 "Mounting modules alfaWALL" Source: okambuva.coop

Structural wood	Pine C24
Plywood	UNE-EN 314
Straw	Rice, wheat, barley
Density	120kg/m ³
Relative humidity	< 15%
Construction Screws	certified according UNE-EN 10002-1

Table 1 "Used materials in alfaWALL modules". Source: okambuva.coop

3 types of modules are manufactured, basically the standard module wall, lintels and sills modules [Table 2]. Its dimensions allow a large number of combinatorial possibilities for different designs and space requirements. [Fig.11]

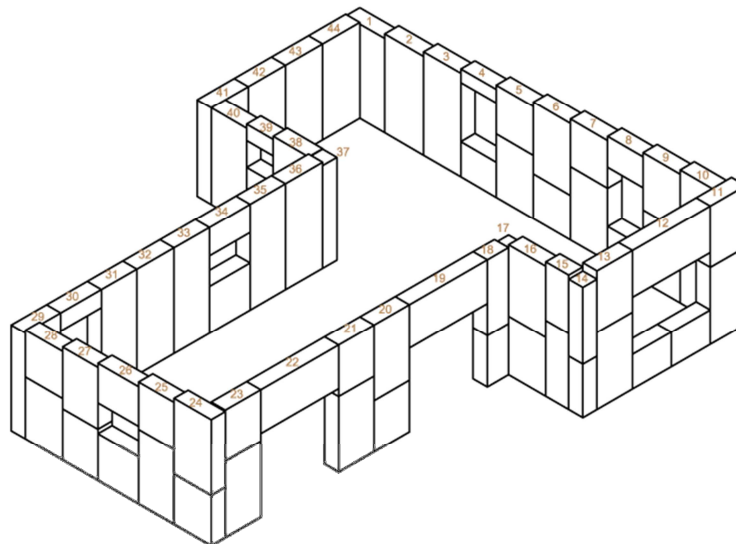


Fig.11 "Modulation for family house project". Source: okambuva.coop

Minimum width	0,40 m
Maximum width	1,05 m
Minimum height	0,40 m
Maximum height	2,90m
Maximum span of lintels	2,90 m
Maximum weight of a modul	250 kg
Maximum volume of a modul	1m ³

Table 2 "Dimensions and formal characteristics of the modules".

Source:okambuva.coop

The walls created with alfaWALL concentrate the best physical properties of the component parts, allowing a significant contribution to energy efficiency of buildings.

[Table 3] The calculations were made on the basis of models, experiences and current conventional systems calculation awaiting specific tests.

Thermal transmittance value (U)	0,166 W ^o /m ² °C
Thermal conductivity λ	0,067 W/m°C
Factor of water vapor diffusion resistance (μ)	3-6
Layer thickness equivalent to the vapor diffusion (S δ)	1,6-2,4m

Table 3. "Physical values of the panel, interior plastered with 4cm clay mortar and in the exterior clay mortar and natural hydraulic lime NHL3.5". Source: okambuva.coop

Importantly, the use of alfaWALL as construction system represents an important contribution to sustainable building by its environmental characteristics. [Table 4]

Consumption of energy resources	Total of primary energy	4.9E+02 MJ
	Renewable energy	4.91E+02 MJ
	Nonrenewable energy	7.87E+00 MJ
	Energy process	8.89E+00 MJ
Water consumption	Total water consumption	3.04E+01 litro
Environmental pollution	Climate change	-9.63E+00 kg equivalent CO ₂
	Air Acidification	9.04E-06 kg equivalent SO ₂

Table 4 "Environmental features (In its entire stroke and according to the agreed UF)". Source: okambuva.coop

4.- Conclusions

Because the quality of execution and the high insulating power of straw, it is possible to get high quality distinctive as the passivhaus certificate or Spanish counterparts, given the growing need and concern for energy efficiency, we must take it into account. [Fig.12] . These results are achievable with mainly local or nearby resources and appropriate technologies, representing a contribution of multiple effects. A concrete proposal ecological and socioeconomic consciousness.



Fig.12 "Mounting walls for a house" Source: ecococon.lt

A small business, as is okambuva can make these elements and build them without major investments or loans, while maintaining profitability and responding to a need for sustainable development of the building sector.

The project continues with tests, more research and new challenges in the search for optimization and diversification of solutions.

For now, it is carrying out the first draft detached house, in the town of Chiva, Valencia, with a design of Phi-Design, architects, Puzol, Valencia.

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