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ANALYSIS OF TIMBER AS SUSTAINABLE MATERIAL FOR CONSTRUCTION

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Keywords: Timber, sustainability, construction, buildings, energy efficiency, life cycle analysis.

Abstract: Facing the climate change scenario, professionals and technicians of civil engineering and architecture are searching for ecological solutions and construction methods that would allow for higher energy-efficiency and then reduce environmental impacts. Timber represents one of the best choices for energy-efficient construction, since it also functions as a material with good thermal transmittance properties if compared to other construction materials. This work analyses the possibilities and benefits that wood offers for the construction industry, in terms of sustainability. On the one hand, the sustainable forest management system contributes to ensure the quality and well-management in the exploitation of the forest in order to produce timber and other sub-products such as cork, paper and tree resins. In relation to this, the construction industry has an important role to increase the level of sustainable products by demanding certified timber. On the other hand, due to its Life Cycle Assessment (LCA), timber has the lower energy consumption compared to other building materials, as well as the CO_2 stored and saved contributes to mitigate climate change. The LCA stages for the production of timber, the potential of saving carbon emissions and its comparison with other building products are presented. Concerning energy efficiency, once timber is implemented in a building taking part of the structure or as cladding material, it provides a high insulation decreasing the thermal transmittance of the walls, roofs, floors and windows. Its versatility as construction material also enables obtaining innovative solutions which can be implemented in buildings, as it is presented in this study. The optimum energy performance and low carbon emissions of timber make from this product a suitable and sustainable material to be highly considered for the construction industry.

Introduction

Environmental degradation forces the whole society to refocus its production and consumption guidelines. Building construction has produced huge changes in our territory, increasing the occupancy rates and artificial soil, which has determined the ecological footprint of the sector. Besides, we have to take into account the increasing demand of fresh water, materials and energy resources, with the consequent generation of emissions and waste.

The construction sector needs to make a significant shift towards sustainability. In a world increasingly concerned with reducing Greenhouse Gas Emissions (GHG), there is an increasing demand on the use of renewable and recyclable raw materials like wood, as they offer many advantages in the production and consumption compared to other materials such as steel, aluminum, concrete and oil products.

Professionals and technicians of civil engineering and architecture are searching for ecological solutions and construction methods that would allow for higher energy-efficiency and then reduce environmental impacts. Due to the fact that buildings present one of the largest energy consumers and greenhouse gas emitters, energy saving strategies related to buildings, such as the use of eco-friendly building materials, the reduction of the energy demand for heating, cooling and lighting and the reduction of GHG emissions, are highly recommended [1].

As a natural raw material requiring minimal energy input into the process of becoming construction material, timber represents one of the best choices for energy-efficient construction, since it also functions as a material with good thermal transmittance properties if compared to other construction materials. Moreover, it plays an important role in the reduction of CO_2 emissions, has good mechanical properties and ensures a comfortable indoor living climate.

Timber offers several environmental advantages over other common building materials. These are:

- Wood is a renewable resource, reusable and biodegradable;
- Wood products store carbon dioxide;
- Nearly half of the dry weight of timber is carbon, making it a carbon positive building product.
- Timber has one of the lowest embodied energy, as building material.
- Comparatively, the manufacture of most wood products requires smaller amounts of energy; and
- Residues generated through the processing of wood can be reused in a variety of positive ways.

On the other hand, timber presents some drawbacks, such as:

- The timber located in the open needs to be protected with a biocide.
- Wood is combustible
- Many wood products need to be bound with resins. Resin, if it is artificial, causes increasing environmental impact: higher energy consumption in manufacturing, CO2 emissions and difficulties in recycling.
- The transport of timber from great distances significantly increases the environmental impact.
- Lack of thermal inertia.

Sustainable forest management for producing timber

A sustainable forest is a system where the forest is managed in such a way that the amount of wood taken from a forest is in balance with the forest's natural production and does not contribute to the degradation of the soil, water cycles or future seed sources. Sustainable forestry attempts to ensure that human needs are met without damage to the forest.

Sustainable timber is harvested in such a way that each tree removed is replaced by another tree, either naturally grown or planted. But sustainability is more than just replacing trees as they are used: it is also ensuring that there is no ecological damage to other species and the forest maintains its biodiversity, its climate and water cycles. This type of forestry is called 'sustainable forestry'.

In order to ensure a sustainable forestry, it is necessary that an independent organism controls the production of timber (and other sub-products like cork, paper and tree resins) and deliver a recognized certificate. Therefore, third-party forest certification is an important tool to ensure that wood products chosen by the designer and purchased by the builder come from forests that are well-managed and legally harvested.

There are more than 50 certification standards worldwide, addressing the diversity of forest types and tenures. Globally, the two largest umbrella certification programs are:

- PEFC **(**Programme for the Endorsement of Forest Certification)
- FSC **(**Forest Stewardship Council)

All of them are voluntary certificates which are requested by forest managers. The process for obtaining the certification follows this scheme:

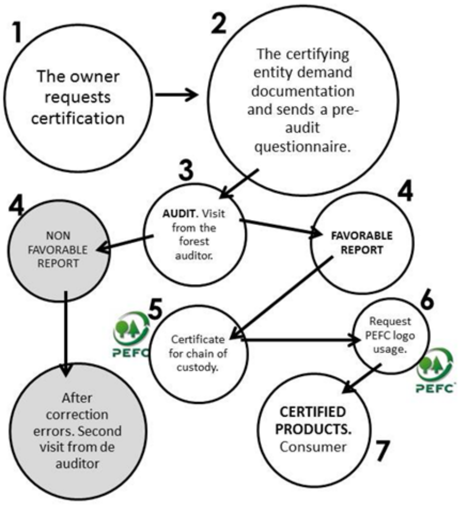


Fig.1 Process for obtaining sustainability certification [2]

Fig. 2 Certified surface in hectares in Spain [2]

The number of well-managed forests has increased in the last years. The evolution of the certified surface (in hectares) in Spain is shown in the graphic below:

Currently in Spain, there are 1.578.689 Ha of certified forest, which integrate more than 7.757 public and private managers.

In fact, the construction industry is the largest buyer of timber products and this means the sector has a huge influence on the type of timber in demand. The construction industry can help to increase the level of sustainable products by demanding certified timber. This gives a clear market signal that only timber from legal and sustainably managed sources is acceptable.

Choosing certified wood, consumers can contribute to combat illegal cutting and promote conservation of forest resources.

Governments and private institutions should promote these certificates, as is already being done through some initiative, such as:

- *PdC* (Perfil de Calidad), Instituto Valenciano de la Edificación y Conselleria de Medio Ambiente, Agua, Urbanismo y Vivienda. Valencia, Spain.
- *Distintiu de garantia de qualitat ambiental als productes I transformats dels suro*. Generalitat de Catalunya, Spain
- *Herramienta VERDE*. Green Building Council in Spain.

Life cycle assessment (LCA) and environmental impacts

A life cycle assessment (LCA) is a method used to measure the environmental impacts of building products. The aim of a LCA is to identify, quantify and assess the impact of the energy and materials used and wastes released to the environment throughout the life of a building product.

Wood has the lowest energy consumption along its LCA compared to other building materials. Then, the CO_2 stored and saved contributes to mitigate the climate change. Fig. 3 shows the stages the steps that comprise the LCA of the timber.

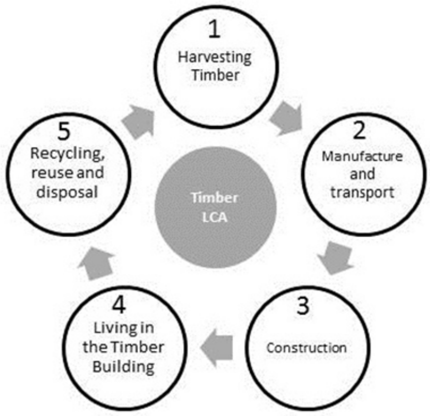


Fig. 3 LCA stages for production of of Timber

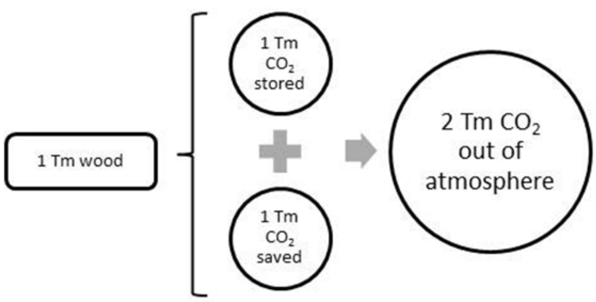


Fig. 4 Example of carbon positive building product

There are two ways to reduce de CO_2 to the atmosphere:
- Store it: absorbing from the atmosphere as a 'carbon sink'.
- Save it: reducing or eliminating the emissions in the extraction and transformation of the material.

Wood accomplishes both functions, as it is shown in Fig. 4 as an example.

Embodied energy

The embodied energy of materials in houses forms a significant component of the total life-cycle energy consumption. A building, which is constructed principally of timber, will require less energy to produce than buildings constructed of materials such as brick, concrete or steel. Table 1 compares the energy embodied by steel, concrete and aluminium with timber, as construction materials.

Table 1. Fossil fuel required to produce four common building materials [3]

Material	Fossil fuel energy (MJ/kg)	Fossil fuel energy (MJ/m^3)
Rough sawn timber	1,5	750
Steel	35	266000
Concrete	2	4800
Aluminium	435	1100000

Greenhouse gas emissions

The use of structural timber has a significant positive environmental impact with respect to greenhouse emissions. Carbon dioxide (CO_2), the most abundant of the greenhouse gases is absorbed by trees during photosynthesis. The carbon removed from the air is converted into the substance of the plant. Thus, trees (and other plants) act as carbon sinks, fixing carbon from the atmosphere in the form of wood.

Manufactured structural materials such as steel, concrete and masonry all involve very substantial use of energy in manufacture. See Table 2.

Table 2. CO2 released and stored of four common building materials [3]

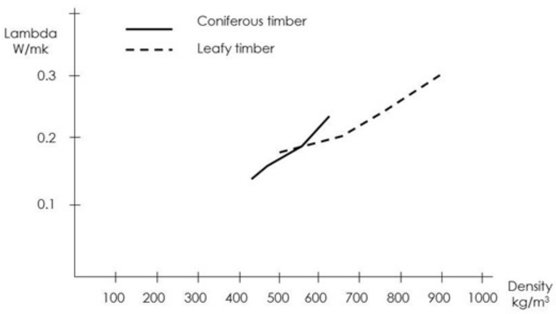
Material	Carbon released (kg/m^3)	Carbon stored (kg/m^3)
Rough sawn timber	15	250
Steel	5320	0
Concrete	120	0
Aluminium	435	0

However, we must take into account the origin of the wood. There is no point to use wood for the construction of a building in order to make it more sustainable, when the wood is brought from a remote tropical rainforest. The energy consumed in transport can break the chain of sustainability.

Energy efficiency

Given the need to change the energy model based on the burning of fossil fuels, wood construction is the best option as it saves energy at all stages of the building process. This is because for the manufacture wood uses solar energy; and for the process of transformation, transport and construction (due to their structure and low density), wood uses very little power and then, carbon emissions and other greenhouse gases generated are very low.

Moreover, once timber is implemented in a building taking part of the structure or as cladding material, it provides a high insulation, decreasing the *thermal transmittance* (*U-value,* W/m^{2}k) of the walls, roofs, floors and windows. *Thermal conductivity* (*lambda,* W/mk) depends on the density (kg/m^3) of materials so that as the wood density increases, the thermal conductivity also increases, and *thermal resistance* decreases. Table 3 shows the variation of the lambda depending on the type and density of the wood. The data provided is extracted from the database of LIDER, the national mandatory software to calculate de energy demand of buildings in Spain. The graphical representation is presented in Fig. 5.



		Density (kg/m^3)	Lambda (W/mk)
Coniferous timber	Light	430	0,13
	Medium	480	0,15
	Dense	570	0,18
	Very dense	620	0,23
Leafy timber	Light	500	0,15
	Medium	660	0,18
	Dense	775	0,23
	Very dense	900	0,29

Fig. 5 Variation of timber lambda depending on its type and density. Created by the author from [4]

Elements with high thermal insulation (it means low lambda) help to reduce the energy demand of heating (winter) and cooling (summer) inside a building, and also allow to achieve thermal comfort standards.

In relation to this, wood is one of the materials which provide high insulation, with the same thickness as others. As an example, two different elements made of brick and wood, with the same thickness: the insulation provided by the wooden one is four times higher than brick.

Besides, wooden elements contribute to regulate the moisture inside a home because of its ability to maintain balance hygroscopic.

Regarding with windows, wood has been the material of choice for the manufacture of window frames. Nowadays, it has been replaced by other material such as aluminium or PVC. However, wood has almost the lowest thermal transmittance, reducing at the same time the environmental impact.

Table 3. Thermal transmittance (W/m^{2}k) of different kinds of window frame [4]

Window frame	**Thermal transmittance (W/m^{2}K)**
Aluminium (without thermal bridge breakage)	5,7
Aluminium (with thermal bridge breakage, between 4-12 mm)	4
Aluminium (with thermal bridge breakage, more than 12 mm)	3,2
PVC (two chambers)	2,2
PVC (three chambers)	1,8
Wood (High medium density)	2,2
Wood (Low medium density)	2

Innovation

In warm temperate climates as Mediterranean one, timber-frame solutions can meet in the long run frustration for users due to the fact that lightweight structures behave in an unsuitable way in summer, failing to dissipate the heat that has been accumulated [5]. In a climate that features warm winters and hot summers, the houses that perform better are heavy houses consisting of heavy stone or masonry walls which work as thermal masses that guarantee winter comfort and absorb thermal loads in summer. This is not possible with the light structure of timber prefabricated buildings, with very low mass and then lack of thermal inertia, fact that represents a drawback to be considered.

To tackle this, there are some innovative solutions which minimize the problem, such the envelope developed by Team MED in Italy for Solar Decathlon Europe 2012. The solution consists of a wall with two layers: the inside layer with inertial mass formed by sand which allows heat accumulation, and the outer layer characterized by an insulating coat of wooden fibre which allows the insulation of the building from winter cold and from summer irradiation. In this case, the sand acts as the inertial mass element and complements timber-frame, solving the problem. See Fig. 6.

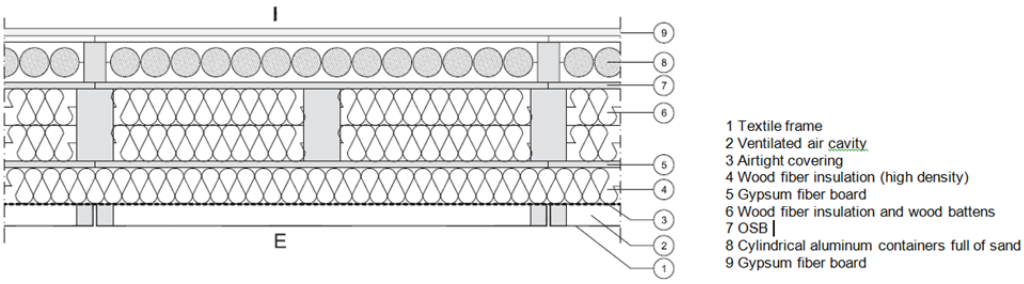


Fig. 6 Wall stratigraphy of timber frame and aluminium containers full of sand, used in Solar Decathlon 2012 [5]

In order to face other problems, such as the mechanical strength, the team équipe VIA-UJI for Solar Decathlon Europe 2014 has also developed a solution for slabs and walls made of timber. The structure of the slab consists of cold formed steel profiles and role steel profiles. It conforms a framework structure resistant enough to support all the estimated loads. The insulation is placed between the role steel profiles. On the top of this part it is placed a plywood sandwich which contain 10 cm insulation. Above this one the finish layer of the floor lies on.

Conclusion

This work presented an analysis of the timber as construction material from the point of view of sustainability. After considering the findings related to life cycle analysis, which demonstrate its benefits if compared to other building materials, and the low thermal transmittance, which improve the energy performance of the building in which takes part, timber could be considered as a suitable material that contributes to increase the sustainability in the construction process.

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