The environmental benefits of small-scale timber frame dwellings for utilization of forested and rural remote areas in Greece

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Abstract. Wood is the only renewable material produced by photosynthesis. Wood has the ability to preserve the stored carbon in its molecular structure as long as remain within a structure. Small-scalelightweight timber dwellings are gaining recognition in Europe after the dominance of concrete and steel since the second World War . Nevertheless, public is still sceptical on their environmental impacts, structural behavior and durability. In Greece, small-scale timber dwellings became popular at rural and forested areas for their touristic attraction, aesthetic superiority and compatibility to the natural landscape. Information from literature and industrial studies showed that the use of structural timber has beneficial environmental impacts as well as economical impacts. Specifically, compared to other common building materials, timber has competitive structural characteristics, due to its low weight to strength ratio, low embodied energy and allows an easy and fast construction with minimum disruption to the environment. Moreover, lightweight timber buildings may have a high potential of waste re-use and recycling, when designed for future ease of deconstruction. The successful waste management contributes to circular economy. Local economy benefits directly from the all the relevant applications of wood.

Keywords: Timber frames, embodied energy, waste management, circular economy- forest utilization.

1. Introduction

In most European countries after the second World War, timber has been replaced by reinforced concrete (Bergsdal et al. 2007a). This was also applied in Greece that led to rapid diminishing of sawmills and timber construction (European Commission, 2018). In addition, the early ecological movement has been absolutely opposed to forest logging operations. Greece's building codes, although in line with Euro-codes, lack of provision for the use of wood, in order to substitute other commonly used materials during a renovation-retrofitting and in most cases, construction permission is not granted due to lack of stability check by the authorities. Therefore, timber use in buildings is limited to floor layers, sheathing, cladding or stairs and roofs only. At the moment, the national timber industry is rudimentary, although 30.3% of the total land area consist of forests or forested areas (Mongabay, 2021). The new trend of timber buildings is small-scale precast dwellings up to one or two storey, mostly imported from other European countries according to EU building standards. These dwellings are usually lightweight frame structures and fewer are log-homes. The last decades the government promoted the use of small-scale timber dwellings in forested and rural remote areas for touristic, recreational and environmental awareness purposes in the form of " forest villages" (Villages in the woods, 2021). Most of these timber dwellings are vacation detached houses or touristic bungalows. After the re-introduction of timber in Greece, the public's acceptance is improved but still a considerable proportion of the public is not willing to use timber buildings for permanent living. The reasons are based on negative impressions about their structural performance, the perception of rot and fire susceptibility . In this article we review the relevant literature along with industry facts and reports, with respect to building characteristics, environmental impacts, and economic benefits from the use of light frame timber buildings in comparison to other common building materials.

2. Light frame timber structural characteristics

According to Ramage et al. (2017), timber is a renewable building material, provided that comes from certified sustainably managed forests. Fortunately, this is the case for most of the European and US forests. Wood has sufficient structural properties compared to concrete, masonry and steel. It has a strength in the direction parallel to log grain similar to that of reinforced concrete but lower compression strength and far less stiff and strong than steel. However, timber has a low density compared to concrete, masonry and steel. This property of high weigh to strength ratio shows that softwood performs similarly to steel by those measures. In an earthquake, a frequent phenomenon in south East Europe, the force imposed on the structure by shaking depends strongly on its mass, with heavier structures experiencing larger seismic forces (Ramage et al, 2017). Fire safety is another important issue. Timber use relies on fire engineering design, by assuming a rate at which the timber chars (Eurocode 5, 2015). This allows an estimation of the remaining intact timber after a given time to obviate deep incineration (Wells, 2011).

Table 1. Structural characteristics of timber compared to other common building materials

Building Material	Density kg/m^3	Compression strength/density ratio (N/mm^2)/(kg/m^3)	Elasticity modulus/density ratio (N/mm^2/kg/m^3)
Steel	7800	0.035-0.045	26-28
Reinforced concrete	2500	0.01-0.02	12-17
Timber hardwood	500-900	0,028-0.033	16-20
Timber softwood	350-850	0.037-0.042	23-28

source: engineeringclicks, EN 338 (2009)
Eurocode 2. (2014), Eurocode 3. (2009)

This is a good reason for designing larger structural timber members in the first place, in order to maintain its strength after a minor fire incident. Moreover, the resilience of wood is astonishing. The results of a survey of demolition contractors by the Athena Institute (2014) revealed that of the 27 wooden buildings over 100 years old, none were demolished because of a material problem. According to Cristescu et al. (2020), the light-frame timber structures are very simple, with studs and trimmers or using I-joists and finally, the stronger type, of post and beam system that enables large openings in façades. They are usually up to two storey buildings and do not require advanced lifting equipment. The walls are usually of a sandwich system, composed of an insulating layer of rigid core, glued on each side to sheathing (OSB) or other type of boards. Other important benefits, such as the energy

Figure 1. Example of onsite light frame timber house.

performance and thermal comfort of timber buildings are not addressed here. As long as a timber frame is constructed and maintained well, infestation will not arise (Designing Buildings Wiki, 2021). Finally, wood also has moisture-regulating properties and can even filter the air, making it especially suitable for people with allergies, thus, improving the indoor climate (Swisskrono, 2021). Timber is getting recognition as a building material, in Europe (Ramage et al. 2017)

3. Embodied energy of timber and carbon storage

Buildings and building materials are responsible for the consumption of nearly 40% of global energy (Dixit et al. 2012). According to Continuing Education Center (2013) the only building material that grows naturally and at the same time absorbs CO_2 is wood. Wood is, therefore, the only renewable material.

Ramage et al. (2017) state that the embodied energy (EE) is one of the most important measures for evaluating environmental impact. It refers to harvesting, manufacture and transport to the construction site. One of the advantages of using timber in construction is the potential for carbon storage in long-life structures. There is a growing number of literature showing that using wood-based materials results in lower energy use and CO_2 emissions when compared to other building materials. The same findings in 16 studies are presented by Bejo (2017) and conclude that wood buildings and their elements require less embodied energy and cause lower CO_2 emissions than equivalent brick, concrete or steel structures. According to Bejo (2017), the methods of calculating the EE are not exactly the same and there are also differences based on countries' characteristics (sources, manufacture level, transport ease etc), for example between Australia and Brazil (Table 2). Therefore, the numbers are not exact but mainly play the role of an indicator between different materials. Process energy requirement (PER) include the energy used in transporting the raw materials to the factory but_not energy used to transport the final product to the building site (Sattary and Thorpe, 2011).

Table. 2 Embodied energy of common building materials

Material	*PER embodied energy MJ/kg Australia	**Embodied energy and transport distance to site MJ/kg Brazil
Kiln dried sawn softwood	3.4	
Kiln dried sawn hardwood	2.0	1.5 (60km)
Air dried sawn hardwood	0.5	
Particleboard	8.0	
Plywood	10.4	8.0 (720km)
Cement	5.6	6.0 (15km)
In situ concrete	1.9	
Clay bricks	2.5	2.52 (10km)
Aluminium virgin	170.0	
Steel bars		16.7 (13km)
Steel	32***	

source: Milne G and Reardon Ch. 2013) **Stumpf et al. 2014, *** (Sattary S. and Thorpe D. 2011).

The drying process and production of adhesives expends a large proportion of the EE of engineered wood. Adhesives can be avoided in small light frame construction but not for mass timber construction. Drying can be accomplished in open air, known as seasoning and it is a low energy process (Make it Wood, 2018). Most studies on EE refer in concrete, although reinforced concrete is used in practice, so in reality EE is higher, as concrete contains 80-200 kg of steel bars per 1m^3 (The constructor, 2021). While concrete and steel industries are primarily powered by fossil fuels, many lumber companies use carbon-neutral wood waste to fuel their operations. Timber in structures result in carbon storage for decades, or longer (Continuing Education Center, 2013). Sathre and O'Connor (2010) state that for every 1 ton of carbon in a wood product that is used to substitute for a non-wood product, 2.1 tons of CO_2 equivalent is saved. Timber can be re-grown and renewed in relative short time, about 25-80 years. The raw material for bricks, concrete and steel can only be replaced over geological time.

Table 3. Fossil fuel consumption and co_2 release and carbon storage to produce 4 common building materials

Material	Fossil fuel Energy (MJ/m^3)	Carbon released (kg/m^3)	Carbon stored (kg/m^3)
Rough sawn timber	750	15	250
Steel	266000	5320	0
concrete	4800	120	0
Aluminium	1100000	22000	0

source: Ferguson et al. (1996)

When comparing life cycle embodied to operation energy, most studies place their relative proportion between 10:90 % and 20:80 %. Embodied energy is not occupant dependent, in contrast to operational energy (Bejo, 2017). Passive houses or low energy buildings, that are mandatory for new buildings by law, have much higher embodied energy content than traditional buildings due to their higher operating energy efficiency.

4. Construction time and waste management

The erection time of light frame timber buildings is faster than brickwork, masonry and reinforced concrete or similar to small-scale steel structures. (Hitchcock and King, 2021). A Building Research Establishment study on the construction of 106 similar homes at three sites, found that, on a site with limited access and storage, timber frame dwellings were built faster than brick and block or concrete formwork (CFS, 2021). Moreover, the site area required is less compared to reinforced concrete construction sites due to the need to accommodate mixture and pump trucks as well as cranes.

Monahan and Powell (2011) reported that 10-15% of timber materials transported to site were subsequently exported as waste. The European Parliament has established the cascade use principle for wood in order to take advantage of the energy benefits and its carbon sequestration. The repeated utilization of the used material, at the highest possible value, is called cascading (Frühwald et al., 2010). According to Ramage et al. (2017), re-use is the priority for wood products after one service unit. They can be re-used as products, if well maintained, either for the same purpose as before or for less demanding purposes after simple reshaping (e.g. from structural timbers to flooring). Wood that is not qualified for further use, can still be reprocessed as fibrous materials, corresponding to the 'recycling' phase. Therefore, wood products are encouraged to be designed with ease of disassembly and re-use as a consideration. In order to achieve the best environmental performance of wood, the waste management from construction, deconstruction or demolition should be conducted according to a waste hierarchy which indicates that depositing wood in landfills is the worst possible choice for the environment (Figure 2). Concerning energy recovery, non-contaminated wood wastes are allowed to be burned in normal power stations or private stoves.

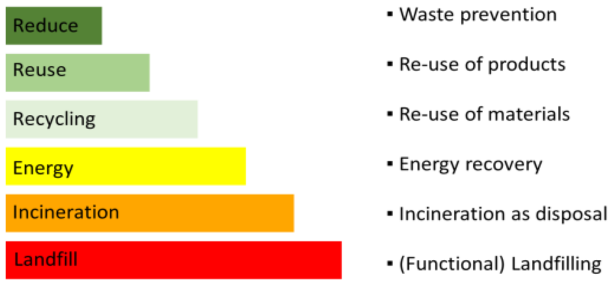

Figure 2. Waste hierarchy (Lansink, 2017)

Processing waste supplies in some cases account up to 72% of the energy production for sawmills in Norway and to similar percentages in U.S. (Hill and Zimmer, 2018). Additionally, ash is rich in valuable minerals and can be used as fertilizer. In contrast to other major building materials, the re-use of timber elements is possible without breakdown and complete re-manufacture (MakeitWood, 2021). Still, recycling timber is time-consuming and labor intensive. This is why the early design stage should be oriented in the Design for Deconstruction and Reuse (DfDR) concept (Continuing Education Center, 2021). Disassembly that aims at the reuse or relocation of building components or assemblies within a new or existing building is often termed as deconstruction (Long, 2014). According to Cristescu et al. (2020), DfDR is a tool for utilizing the circular use of timber in building construction and the Circular Economy (CE) in general. Specifically, the DfDR concept should be adopted at an early stage, best described as conceptual planning in the pre-design phase.

5. Circular and local economy potential

Circular economy is strongly connected to the waste hierarchy concept (Figure 2) and can be achieved through long-lasting design (Cristescu et al., 2020). Currently in Europe, only about one-third of C&D wood waste recycled into material for board products (Risse et al. 2017). According to Hradil et al. (2014) timber has the highest preferred reuse percentages among all construction materials. European Union, via the waste framework directive, as part of the Circular Economy Action Plan, propose revising material recovery targets set in EU legislation for construction and demolition waste (European commission, 2021). Based on Stergiadou (2001) the utilization of timber construction has profound local economy benefits. According to Hill and Zimmer (2018), the production of structural timber is usually located very close to the raw material, in rural areas. Forest operations, timber building construction and maintenance, as well as, the possible establishment of sawmills are going to create new Jobs to the local community. Furthermore, the application of DfDR waste management will enhance the local and national economy.

6. Conclusions

Wood is the only natural renewable building material that stores carbon. It is structurally adequate and resilient. Lightweight small-scale timber buildings have environmental benefits compared to other common materials such as low embodied energy, fast construction and minimum site disruption. Additionally, re-use and recycling of construction and deconstruction wastes could be accomplished when designed according to DfDR concept in an early stage, promoting the circular economy concept. The existing European buildings codes, should be revised in order to overcome the imposed limitations. Subsequently, the emerging trend of timber use in buildings is going to flourish.

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