# USE OF WOOD IN SUSTAINABLE ARCHITECTURE

**Prof. Georgi Georgiev, PhD**
*New Bulgarian University*

**Abstract.** *Research background:* Importance of wood as a sustainable and renewable material presumed its large scale use in architectural structures for centuries. In order to analyze the potential of prospective application of wood in build environment in Bulgaria it is instrumental to investigate the regional specifics in historical development of wooden structures in traditional building practices of the Mediterranean region and in particular on Balkan region

*Purpose:* Understanding the evolution of building practices and identification of sustainable approaches. Many traditional building practices that involve the use of wood are inherently sustainable, incorporating low-impact and resource-efficient techniques. A historical review of the use of wood in architecture can identify these sustainable practices and help us learn from them. A historical review of the use of wood in architecture can provide insight into the stages of development of wooden structures over time and reveals specifics of use of wood according to different cultures and how the technology for working with wood has evolved over time.

*Methods:* Historical overview of traditional building practices and their potential prospective applicability .

*Findings and novelty:* The use of Life Cycle Analysis (LCA) and Life Cycle Cost Analysis (LCCA) methods to assess the performance of timber structures in the development of the built environment reveal the great potential of wooden structures for prospective use.

*Keywords:* timber structures; sustainable architecture; LCA, LCCA
JEL: Q01, R11, R31

## 1. Traditional building practices of the Mediterranean region and in particular on Balkan region

Wood is the oldest material used by humans for constructional purposes, after stone (Spišáková, Mačková 2015). Despite its complex chemical nature, wood has integral excellent properties. Throughout history, wood has been widely used as a building material due to its strength, lightweight, easy processing and perfect aesthetics. Another advantage of wood is its widespread availability which in addition created its exclusive importance and outstanding value.

Wooden structures together with masonry and clay are the mostly used in historical retrospective building systems, predominantly for vernacular buildings and in housing. In the past centuries, vulnerability of separate use of all three building materials been diminished by using a combined system consisting of timber framing filled with masonry/clay infill materials. As far as earthquake resistance is concerned, the concept of such systems is using timber to resist the tensile and the flexural forces, whilst masonry was used to resist the compression forces and provide confinement to slim timber elements (Bal, Vatan 2009).

Timber framed structures on the Balkans first emerged in the medieval and early Ottoman period, and were improved from the end of 16th century until 18th century when they became widely popular. Their general constructive features were established, successfully adapted and

tested within a wide geographic area extending roughly from Southern Central Anatolia to the Ottoman Balkans including Black Sea Coasts of Romania, Crimea, Bulgaria, North Macedonia and Bosnia Herzegovina to Greece in the west, regardless of significant differences in local climate regime (Aktaş 2017). Generally; masonry basement, masonry ground floor, timber framed floors and timber roof constitute timber framed houses which commonly are two or three story buildings. Timber frame is infilled with masonry such as clay bricks, adobes or stones. This type of construction has various examples around the world. Despite the diversity of typology between all these structures entitled as traditional timber framed infilled buildings, the structural behaviour basically is the same (Bal, Vatan 2009).

The masonry base of the traditional timber framed houses, including the ground floor and the foundations, is generally constructed in stone or mud brick and stone. The foundations are built with rubble stone in a continuous or discontinuous order, extended up to the ground floor level. The wall of the ground floor, which generally has 60 – 80 cm thickness, is constructed by stone or mud brick and combined with wooden tie beams (lintel) regularly placed at the intervals of 70 – 100cm. The lintels strengthen the walls against horizontal loads and earthquake action.

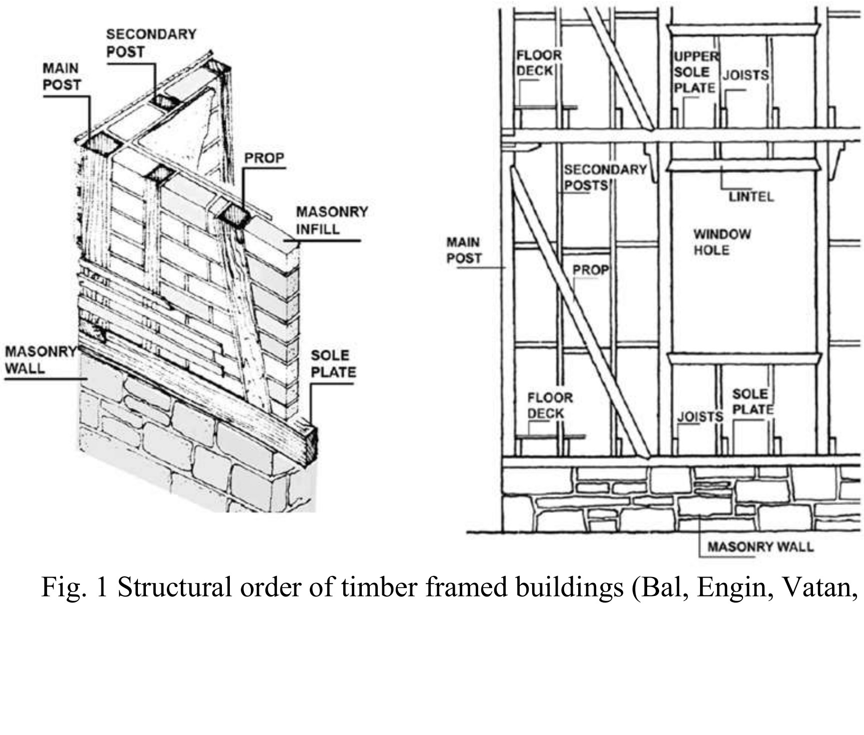


Fig. 1 Structural order of timber framed buildings (Bal, Engin, Vatan, Meltem)

Fig.2. Murray Grove Tower in London (waughthistleton.com)

## 2. Use of wood in modern times

### 2.1. Use of wood in building activities in the last centuries (19th and 20th centuries)

Regardless the well known fact that wood is one of the oldest and widely used building materials in traditional building all over the world, in late 19th century and mostly in 20th century, wood was being gradually neglected in building activities in the most industrialised countries in Europe and North America. This was caused by large scale development of steel structures increasingly took part in building activities alongside with increased overall use of steel as a main sign of rapid industrialization of most advanced economies in the world. Such use was mostly evident in transportation facilities (railways, bridges, road vehicles) manufacturing of machines for production of goods etc.

### 2.2. Revival in use of timber structures in modern building practice

In the recent decades, we have been facing all over the world growing number of weather disasters such as floods, droughts, ice rains, strong winds, which are the result of climate changes. All this is caused by mankind, who, following material gains, destroys the environment in which he lives. By intensive exploitation of fossil fuels and the production of energy-intensive materials (cement, steel, aluminum, plastics), the greenhouse gases (methane, nitrogen oxide, fluorocarbon compounds, water vapor, carbon dioxide) are discharged into the atmosphere and disturb the Earth's natural balance. In order to avoid disasters, we must act decisively and reduce greenhouse gas emissions. Reducing could be achieved if natural building materials, such as stone and wood are in main use. Over the last decades, thanks to the new technologies and growing concern for the environment, wood is becoming more important again. Modern advances in construction know-how and fire suppression techniques coupled with concerns over sustainability of other options, have created conditions wherein timber is re-emerging as a major construction material. Timber has begun to be used in construction of relatively tall urban buildings, rather than being regarded as only suitable for small buildings, and occasional large showpieces that are well isolated from neighbouring structures (Smith, Snow 2008). The trees need sun, water, air and soil to grow, and after they are planted they do not require almost any investment. During growth, wood absorbs carbon dioxide from the atmosphere and binds it to its structure, making it the only constructive building material with negative CO2 printing. If we compare all the building materials, we can see that only wood bonds with carbon dioxide (CO2 reduction) and helps maintain standards and technological development with minimal environmental and human impact. Because of this, the significance of building wooden structures today is much greater than ever before. The use of wood in building has undergone great revival in recent years.

### 2.3. Advantages of using timber as building material:

**Sustainable building material:**

Wood usage is in accordance with the principles of sustainable development. In the forests it produces solar energy from the CO2 (photosynthesis), and objects built from it can store CO2 for decades. Contribution to further reduction of CO2 emissions is also the fact that building wooden structures needs several times less energy than building in materials such as cement, steel, brick, stone and glass wool. In the final calculation, one cubic meter of built-in wood contributes to two-tone reduction of CO2 in atmosphere, while the cubic meter of reinforced concrete increases concentration of CO2 for several times! Therefore, the use of wood as building and insulation material significantly reduces the emission of greenhouse gases. A wooden house of average size, equipped with wooden furniture in a 60-year lifespan, stores approximately 50 to 70 tons of CO2 (depending on the size). If proportion of newly constructed wooden houses increases for 10% in a year, that would decrease 25% of CO2 yearly emissions, according to the Kyoto agreement.

Wooden building elements have a large bearing capacity with relatively low weight. Because of this, the walls of wooden structures are thinner, which significantly increases the useful space in the interior. Bearing in mind the function of forests and the fact that forests, in some countries cover over 30% of the land there is no doubt that rational use of wood as a forest product represents a vital state interest. Wood elements, after processing and drying, have a density of 400 to 800 kilograms per cubic meter. Transportation of such elements requires less energy and has a lower degradation effect on the road than the steel mass of 7.5 tons per cubic meter, or a concrete mass of 2.5 tons per cubic meter. Local availability of wood, besides further reduction of transport costs, develops the industry in rural areas and contributes to the development of small and medium-sized enterprises traditionally prevailing in the wood processing industry.

Throughout the whole process of obtaining construction products, processing of semi-finished raw building materials usually requires the most energy and is the only process that has negative impact on the environment. The costs and energy needed for the exploitation and processing of wood as raw material are extremely low compared to oil, iron and even crushed stone. Energy costs and demands on wood processing are much smaller because wood does not require complex processing, such as steel melting or cement baking. During the production of wooden building elements, about 35% of the logs are used in hardwood species, such as oak or 45% in softwood species, such as spruce. It is important to emphasize that the rest of the timber does not throw away, but is exploited to the smallest pieces of sawdust for the production of various other products, from sound insulation in the form of wood wool, all the way to heating pellets. Utilizing the timber completely eliminates the costs of waste disposal and added value is added to the new products.

**Construction advantages:**

Modern wood-based technology, such as prefabricated construction with semi-finished elements and machining of elements, enables fast and efficient building, and because of its low weight the elements of such a building require less dimensional foundation. The advantage of constructing in semi-finished elements is that the production and preparation of elements can take place in parallel with the process of obtaining building permits. After obtaining all the required approvals, the finished elements are delivered to the construction site, where they are incorporated into the building in a very short time, thus reducing the cost of the construction site.

Due to less weight, building with wood is possible even on softer terrain, such as areas around the water or mountain areas. Wood is up to 5 times lighter than concrete, but it has a high bearing capacity and can withstand high pressure and tensile forces. Because of this, wood is considered a flexible material.

Apart from a positive influence on the climate, the wooden house also has other advantages. Building is fast and can be run all year long, even at low temperatures. The high degree of prefabrication allows the facility to be set within a few days, and the time from start to finish is shorter than the conventional construction. Due to the excellent structural and insulation properties, the wooden massive walls can be thinner and at the same external dimensions, up to 10% more residential surfaces can be obtained. Exceptional structural properties of wood have also shown in testing on earthquakes and fires. Small weight, pressure and tensile strength of the wood makes earthquake-resistant wooden buildings and adding carbonated layer on the surface makes them also much safer than reinforced-concrete.

Quick building and moving in is possible in a month or two from drafting, while only the drying phase of a masonry house lasts that long.

**Living Comfort:**

Wood provides a pleasant and healthy living environment and therefore this type of building is so popular in all world. Spruce timber has very good antiallergic properties. Wood generally exhibits excellent electrostatic properties, and will not electrify and attract microparticles of dust and pollen, which is especially important for people with various forms of allergy since this creates an ideal antialergic environment. The houses are made of quality spruce containing 13% moisture, which results in wood stability, better mechanical properties and prolong the durability of the house. Wooden walls keep the air humidity in all rooms, so no additional air conditioners or room humidifiers are needed because wooden houses absorb moisture when moisture is too high and release it when the air is dry. That's why air in wooden houses is ideal throughout the year.

Fig.3. Murray Grove Tower in London - the tallest contemporary wooden building (waughthistleton.com)

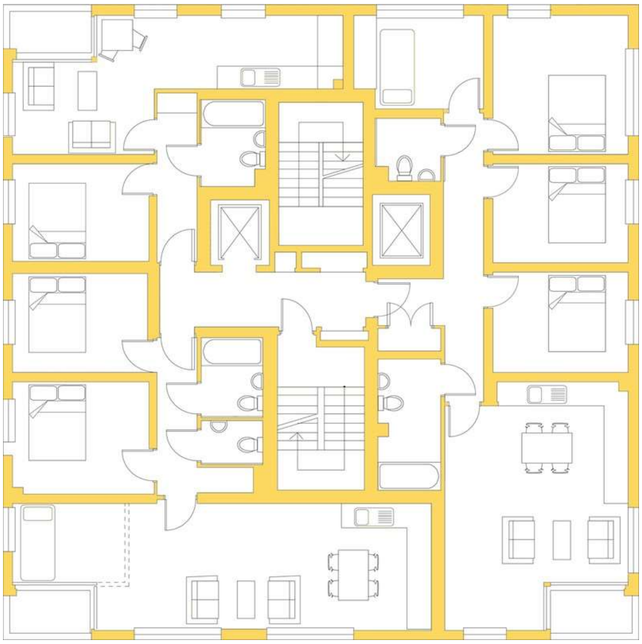

Fig.4. Murray Grove Tower in London - layout (waughthistleton.com)

## 3. Lifecycle/Life Cycle Cost Analysis endorsing sustainability of wood as building material

Life cycle analysis (LCA) is a method defined as an analysis of the overall performance of a facility (building) that considers all the inputs and outputs of materials and energy in the building over the lifetime of the building. A full LCA considers all inputs of materials, energy, water and outputs (air, water and solid waste emissions). A major component of the inputs is primary energy and global warming potential (GWP). In analyses of this type, the study is structured in several stages:

- acquisition of the raw materials for construction
- production of the building materials, installation and construction
- operation of the building and its elements
- demolition of the building and reuse of the building materials

The determination of the quantities of energy resources used, water and waste generated in the production of the building materials and the use of the building are important, focusing on primary energy and GWP, which are two important indicators of the overall environmental impact of housing construction and use. Other significant aspects include:

- What is the relationship between the energy consumed in the production of building materials and that consumed in the operation of the dwelling
- Which building improvements lead to the greatest reduction in energy consumption over the life cycle
- How different projections of future energy costs affect the life-cycle cost analysis of the dwelling

- How home maintenance and improvement projects affect life cycle costs

A similar approach, LCCA – Life Cycle Cost Analysis, is used to determine all the costs in monetary terms associated with a product (the dwelling) and the materials used to build it. Life cycle costs are all costs charged to the owner and include:

- the cost of all materials and labour used
- the purchase of the land
- the supply of energy for the use of the building
- maintenance of the building

LCCA is a tool for determining the most cost-effective option among various competing alternatives for purchasing, owning, operating, maintaining, and demolishing a facility, all technical conditions being equal. All costs are typically discounted to a present value, known as net present value (NPV). LCCA is also a method for economically analyzing the efficiency of a building project associated with constructing, operating, and maintaining the building. A percentage is charged to account for the projected increase over time in the cost of operating and maintaining the building. Future costs are discounted to current prices by applying a discount rate that reflects the value of money invested elsewhere. In this way, all costs and savings can be directly compared.

LCA/LCCA are confirming the great integral advantages of the wood as building material. Building a wooden house is not only good for reducing greenhouse gas emissions but also for thermal insulation of buildings. Solid wood walls represent excellent heat insulation. Wood has remarkable overall thermal insulation characteristics. Wood is 6 times better insulator than brick and 15 times better than concrete. Thus, for example, 6,5 cm thick coniferous wood has the same thermal insulation as 40 cm of full bricks [2]. Wooden houses require much less energy for heating and cooling because the feeling of cold or heat in the space compensates for about 2° C, which in addition saves energy. In the last years, we see increasing efforts and funds invested in new construction of reinforced concrete and brick wall buildings where building envelope is insulated with external layer of mineral or stone wool. Production of such materials is associated with big amount of energy and CO2 emissions, that will be compensated only after several decades of building lifetime. However, by use of LCA - counting the entire energy/CO2 emissions for the producing of materials and the exploitation of a building, such type of concrete/brick wall low energy building is completely non-comparable with a wooden building, because it contributes to the deterioration of climatic conditions, rather than mitigating them.

A research investigation calculated the environmental impacts of a building situated in Graz, Austria (Hoxha 2022). It was aimed at evaluation of the benefits of wood reuse compared to conventional building construction solutions. Four different scenarios were considered. The first scenario was a fully reinforced concrete building. The second scenario is a structural beam-column made from reinforced concrete with walls made of concrete blocks. The third scenario is a beam-column made from reinforced concrete with external walls based on clay blocks. Finally, the last scenario is a fully wooden building. Following the standardized life cycle assessment (LCA) method, global warming potential (GWP) was calculated. These evaluations were made possible by correlating the impacts released from producing wooden elements and the uptake of biogenic carbon from the forest. Without considering the possibility of material reuse, the wooden structure has a 5 % lower GWP value than the reinforced concrete building. Comparatively, the other building scenarios have almost similar impacts as the building in reinforced concrete. In the case of material reuse, the wooden structure building shows potential to develop projects with 44% lower environmental impacts.

The research activities using Life Cycle Analysis shows the greater potential of wooden structures/buildings compared to conventional buildings to reduce buildings' environmental impacts. The use of concrete blocks shows an insignificant reduction in impacts; however, the use of clay bricks, on the other hand, increased and showed higher impacts than the building scenario with reinforced concrete. In addition, building scenarios with timber components presented the solution with a lower GWP score. To further reduce the impacts of buildings with timber elements, the reuse of components was considered in consecutive building life cycle phases. By reusing some building elements, the GWP score of the timber scenario reduced by 18 %. Moreover, due to the tree regrowth, building impacts reduced by 44 % in total.

Further research may still be needed to identify more specifically the quality of wood components in the end of life of building and alternative options to reuse these elements in other construction sectors.

**Conclusion**

Efforts being made against climate changes, presume that absolute advantage in the future should be given from widening of use of wooden structures up to rising the number of newly built entirely wooden houses, which throughout the life cycle have a biggest positive impact on the environment. The share of construction of wooden houses is growing everywhere in the world, especially in developed countries: Canada, USA, Scandinavian countries etc. In Sweden they are already being built four wooden seven-flour buildings, and are planning to build thirty four-floor buildings out of wood. A good example is also Austria, which has fewer wood amount per person, but its application in building predominates several times in comparison to neighboring countries.

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**Prof. Georgi Georgiev, PhD**
ORCID ID: 0000-0002-8607-8030
New Bulgarian University
Sofia, Bulgaria
E-mail: gngeorgiev@nbu.bg