Use of timber for the sustainable city growth and its role in the climate change.

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Abstract. According to the predictions of United Nations (2017) there are more than 7 billion people on Earth and this number will reach 9.7 billion by 2050. Today, most of the population lives in the urban areas and the rapid growth entails more construction in a housing sector. Since the industrial revolution the world has experienced countless technological attainments and on the other hand risky increase in natural resources use, energy consumption, greenhouse gases emission, ozone depletion, toxification and global temperature rising. The question how the cities can respond to urban growth is related to the sustainable goals of Agenda 2030. This research discusses potential of the usage of timber as construction material and it also brings the answer to this question. The wood is 100% renewable, recyclable and nontoxic material with capacity to absorb CO2 and perform low embodied energy. The increase of timber use in the construction contributes to sustainable development and to the reduction of waste, CO2 emission, as well as energy consumption. The aim of this paper is to discuss the advantages of using timber as a sustainable solution in urban context, in comparison with most commonly used concrete. The findings demonstrate the value of timber as sustainable construction material.

1. Background

Analyzing the key facts mentioned by United Nations in the revision of Word Urbanization Prospect in 2018 [1], nowadays there is 55% of global population residing in urban settlements and this number is predicted to rise significantly by 2050 (figure 1), resulting in two thirds of population living in the

![Figure 1. Population profile 1950-2100. [33]](image)
cities [2]. The expansion of cities brings the social and economic development and hence, leads to the growth of built environment as its fundamental component [3]. The rapid progress entails more construction and generates the demand for adequate housing [2]. The increase of urban density causes the cities to become wider and taller, turning the tall buildings into more common and adequate [4]. Intensive and fast expansion in this sector, using existing built systems, brings a negative contribution to the environment, mainly by consumption of large amount of raw material and unrenewable energy, as well as generation of millions of tons of direct CO₂ [3, 5, 6].

These heavy environmental impacts of construction industry are one of the causes of climate change effects such as ozone layer depletion generated by greenhouse gases emission, air, water and soil toxification as well as global warming [7]. The global energy consumption of buildings, both residential and commercial, increased between 20% and 40% in developed countries after the 90’s. Growing population increases demand for building services and comfort levels, consuming more energy and producing more CO₂ as a direct consequence, what can be observed in the figure 2 [8]. However, the most critical concerns relate to production of the most common construction materials: concrete, steel, glass and aluminium. Therefore, the awareness of the necessity for a greater use of renewable materials is growing. In this viewpoint, climate change becomes a key issue in order to respond to Sustainable Development Goals of Agenda 2030. Thus, it is essential to seek a renewable and sustainable alternative to concrete and steel [9]. This paper analyzes possible advantages of the use of timber for high-rise buildings, following the Sustainability Development Goals from Agenda 2030.

Timber is associated with sustainability as it is a renewable material [4, 10] It has been used since prehistoric ages all over the continents, giving the footprint for masonry techniques and resulting in the shape of shelters and temples [11]. Timber buildings were found suitable for diverse climates, from severe winter of Scandinavia to warm and humid Asia. It became dominated by steel and concrete only in the modern era of industrial revolution, due to its impression of fragility, although there can be found Japanese wooden architecture that has survived over 1300 years [5].

Despite all the achievements of industrial boost, due to dangerous depletion of scarce natural resources, negative consequences of construction industry and as the response to the pressing environmental imperatives, during last decades timber has gained importance and become a concurrence material to concrete and steel in the construction of high-rise buildings [8, 11].

Due to natural qualities and diversity of engineered wood-based and composite materials, timber possesses the ability to respond to growing interest in sustainable and bio-based construction [12]. It is not only tactile, visual and olfactory qualified but most importantly, it is a renewable alternative.

Figure 2. Primary energy consumption, CO2 emissions and world population. [8]
Much of structural wood is sourced from sustainably managed forests and plantations, which are priceless habitats for wild life and sources of innumerable contributions to climate change, such as air purification, reduction of droughts, floods and soil erosion [13].

European forest is growing more wood nowadays than it is used. Through planting and management of sustainable forestry, the selective harvesting and economic productivity are possible without compromising its size and even the construction of all new buildings in timber will not affect negatively the annual wood supply [5, 11]. However, The Global Forest Resources Assessment states that the world’s forest area decreased by 1% between 1990 and 2015, and that the loss has lowered in recent years with help of sustainable management plans, as it can be seen in the figure 3.

According to Food and Agriculture Organization of the United Nations, forests have a decisive role in reduction of greenhouse gases in the atmosphere, as they absorb yearly unevenly 2 billion tonnes of carbon dioxide [14].

![Figure 3. Forest area as a proportion of total land area in 1990, 2010 and 2015 [14]](image)

2. Timber as constructive material
2.1. Timber properties

The life span of a timber structure is described by its durability. Wood as the natural material is vulnerable to biodegradation caused by bacteria and fungi, particularly under moisture condition. Therefore, it is crucial to maintain it in a dry state, with constant water content $\leq 20\%$, not exceeding fibre saturation point (28-35%), in order to prevent these natural processes from degradation and preserve the structure in a right form for hundreds of years [11, 12, 15]. Furthermore, physical and chemical treatments can be applied to improve the performance of timber in terms of durability. Maintaining the constructive elements in a dry state is essential for the timber structural properties. When the moisture content increases, the resistance decreases, as it can be seen in Figure 4.

![Figure 4. Effect of water content on wood resistance](image)
Nevertheless, timber as a material presents outstanding strength-to-weight ratio [7, 9, 15]. Comparing it to other materials, equivalent steel structure can weight 20% more than timber and a concrete structure even 600% more [17]. Moreover, the strength of timber is similar to reinforced concrete, however, it cannot contest modern high-strength concrete in compression. Furthermore, it is also less stiff than concrete and much less stiff and strong than steel. Notwithstanding, timber has a lower density, resulting in efficiency for long-span or tall structures [18]. The development of revolutionary construction techniques, using cross laminated timber and laminated veneer lumber, allows to minimize wood’s anisotropic consequences and thus, the dimensions and shape of the building elements depend solely on the manufacture ability and transport limitations [12].

During the production and processing of all the materials, significant quantities of CO\(_2\) are released into atmosphere increasing global warming. The reduction of CO\(_2\) from the atmosphere can be achieved by decrease in emissions of CO\(_2\) or by its extraction and storing [12]. Wood sequestrates carbon and keeps it away from the atmosphere, diminishing the effects of climate change, therefore it can also contribute to CO\(_2\) reduction in both ways [5, 12]. The amount of carbon absorbed by the wood used for construction is verified and subtracted from the total number of carbon emitted in life-cycle assessment. Trees convert CO\(_2\) (0.9 tons), water (0.5 tons) and sun energy into one cubic meter of biomass through photosynthesis, where carbon consists of the half of it (225 kg). Despite that, it can be stored during its operational life until it is decayed or burned. Only after its final disposal the incineration greenhouse gases are calculated. In this way, the timber building is considered to be climate neutral [12].

Apart from providing load-bearing stability, timber also needs to respond to other requirements such as fire resistance, thermal insulation and noise protection. Despite that timber is perceived as combustible construction material, it does not inherent fire risk. Its behaviour in case of fire depends strongly on proportions of surface to cross section and the wood density. While burning, timber generates the charred layer on the fire-exposed surfaces, protecting and keeping cool the inner areas while preserving load-bearing capabilities. The thicker the elements are, the higher fire protection can be achieved. Additionally, it is easy to slake the fire on the solid timber elements without the risk of re-ignition [12]. Therefore, it is possible to construct high-rise buildings in timber that fulfil all fire prevention requirements.

Timber owns limited heat conductivity and functions as excellent natural thermal insulator. Its \(\lambda\)-value is equal to 0.11-0.17 W/mK and b-value varies between 0.4-0.5 KJ/Km\(^2\)√s which means that wood surfaces are assumed as warm [12]. Buildings constructed in timber perform balanced energy use over their lifetime, using much less than those made of other conventional material [5, 11, 19]. Due to its hygroscopic capabilities, timber can help to regulate the indoor climate by absorption and release of air moisture. In some studies, the calming effect of wood was proved, having a positive result on health [12, 20].

European Union Regulation states “that noise perceived by the occupants or people nearby is kept to a level that will not threaten their health and will allow them to sleep, rest and work in satisfactory conditions”[19]. The value of “satisfactory” condition varies across the countries, based on the basic noise level of 25dB. As timber does not inherit the heavy dead weight, it is easier to stipulate its mass with sound waves or impact stress. However, there are many methods that can be applied in order to take advantage of this material in terms of acoustic performance, and combined with suitable solutions they can achieve soundproofing purpose [12, 22].

Wooden buildings are gaining recognition even in zones with the risk of earthquakes occurrence. Despite that, there are no specific recommendations found in Eurocodes regarding seismic resistance, construction details or factor to be used in seismic design for this constructive system. Due to wood’s lightweight, the seismic performance of timber building presents positive results. [18, 23]. Timber elements, used together with steel connections, allow to build dissipative structures with appropriate ductile behavior [16].
2.2. Advantages
Apart from the positives derived from the natural properties of timber, its eye-friendly appearance, natural smell and pleasant texture, it also presents some advantages considering its construction time, application flexibility and competitive overall cost. Additionally, it is even more desirable due to the fact that it total embodied energy is comparably low [11, 24]. Only 1.5 mJ/kg is required to transform wood into the construction material whereas steel requires 35mJ/kg and aluminium as much as 435mJ/kg [5]. Concrete blocks present the lowest value of embodied energy per kilogram, only 0.6 mJ/kg. However, the concrete is much heavier than wood, resulting in higher value of total embodied energy [25]. According to Dixit [26, 27], residential buildings constructed in timber present the embodied energy range 0.9–6.6 GJ/m² only, while residential buildings created of bricks perform 0.9–16.3 GJ/m², 0.9–23.1 GJ/m² in concrete and 0.9–19.2 GJ/m² in steel. Low embodied energy results in less fossil fuel used and thus, less CO₂ emitted into atmosphere.

The European Directives established the normative, calling to re-use or recycle as much material as it is possible. Not contaminated, free of chemicals or preservatives timber can be reused, expanding the extent of carbon sequestration. Timber not classified to reuse can serve to generate energy, diminishing overall construction waste [12].

The assessment conducted by the Hermann Kaufmann [12] demonstrates that buildings made of renewable raw materials are 35-50% lighter than conventional buildings, where two timber slabs with flooring have the weight equivalent to one concrete slab. Due to this relatively light weight, it is possible to conduct constructions on the top of existing buildings, the example is presented in figure 7 [28]. Timber construction can convert and densify urban areas by additional storeys, extensions and alterations, not only due to its relatively light weight, but also because the material itself is easy to work with. Recent innovative methods allow fast modular assembly, with prefabricated elements, that can be transported efficiently, reducing the CO₂ emission and performing low embodied energy [12, 29]. Efficiency of manufacturing and prefabrication affect directly the economic factor and the speed of the construction. Thus, more and more high-rise timber buildings can be found already erected (figure 5 and figure 6).

![Figure 5](image5.jpg)  **Figure 5.** Treet, wooden high-rise building in Bergen (Norway) [30].

![Figure 6](image6.jpg)  **Figure 6.** Haut, residential wooden tower located in the Amstelkwartier (Netherlands) [31].

![Figure 7](image7.jpg)  **Figure 7.** Example of the extension of existing building with timber structure, DU Office Flachgasse, Vienna (Austria) [32].
3. Conclusions
The timber structures fulfill demands of modern buildings in relation to height and rapidity of assembly and proof potential to be well-spreading typology in the cities. Contemporary innovative solutions enable a simple, fast and dry onsite construction process as well as reduction of the load of the structure and consequently, smaller foundations leading to the overall lower cost and shorter time of construction [8, 11].

Wood derived from sustainable sources used with wise management contributes positively to environmental strategy. Timber buildings can last for a long time without risk of biological degradation, if kept and maintained in proper condition. This renewable, non-toxic and biodegradable material is clearly structurally efficient and functions as carbon sink.

Therefore, it is necessary to implement this material in construction sector at a great scale. Timber can help to respond to the need of the expansion of cities, contributing positively to the reduction of depletion of raw materials, increase of sustainable managed forest and balance of carbon footprint. Considering required amount of housing for growing population, buildings in timber can provide fast solution without compromising the environment and responding to three main sustainability targets: environmental, financial and social [4].

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