

Sustainability of the Timber Supply Chain on the Island of Sardinia

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Abstract. This paper illustrates the potential of using wood as a structural material in terms of sustainable construction and analyses the opportunities offered by the plant of production processes based on the use of locally-grown wood to the end of promoting the development of sustainable economies in narrow and interconnected communities like those of the islands. In detail, the convenience of planting in Sardinia a supply chain for manufacturing structural laminated timber elements made of locally-grown maritime pine is addressed, also by referring to the results of a research activity devoted to this purpose.

Keywords: Timber buildings · Circular economy in Islands · Local supply chain

1 Introduction

The issue of sustainability is now a paradigm that informs all human activities. It is closely linked to the concept of development, in the sense that currently the only conceivable development is the sustainable one. In fact, in an era such as the contemporary one, in which anthropic processes are marked by the depletion of raw materials, by the increase in polluting emissions and by the increase in waste, it has become a mandatory requirement, as well as a moral duty, the attention to development models oriented to environmental, economic and social improvement.

The concept of sustainable development was made explicit, for the first time, in a document presented by G.H. Brundtland in a meeting of the World Commission on Environment and Development [1]. The document, better known as the Brundtland Report, Our Common Future, highlighted the need to implement a strategy capable of integrating the needs of development and the environment. This strategy was defined with the term *sustainable development*, whose precise definition was as follows: development is sustainable if it meets the needs of the present without compromising the ability of future generations to meet their own needs. This definition contained a new concept relating to sustainable development, able to reconcile aspects such as expectations of social well-being, economic growth, maintenance of natural resources, and respect for the environment. To guarantee all this, it is necessary to fulfil ethical principles and moral responsibility, touching on fundamental elements for eco-sustainability such as maintaining existing resources and the planet's environmental balance.

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Sustainability is therefore a multifaceted concept, both as regards the needs to be satisfied and the capacities to be guaranteed over time and as regards the capitals to be protected and enhanced, such as in particular the environmental and human-social ones.

Sustainable development revolves around four key concepts (Fig. 1):

- environmental sustainability, understood as the protection and enhancement of natural capital, that is the maintenance of the quality and renewability of natural resources;
- economic sustainability, understood as protection and enhancement of economic capital, i.e. guarantee of income and work for the population;
- social sustainability, understood as protection and enhancement of human-social capital, that is guarantee of well-being (safety, health, education, etc.) equally distributed among the population;
- institutional sustainability, understood as protection and enhancement of human-social, economic and environmental capital through the guarantee of conditions of democracy, stability and participation.

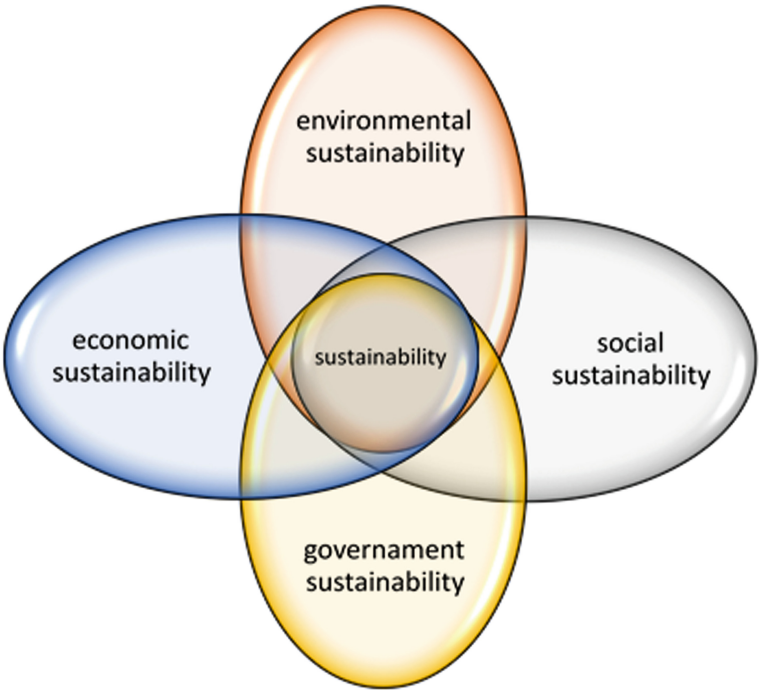

Fig. 1. Sustainability pillars.

A key point of sustainability is the idea of a limit to the exploitation of a resource or capital, but it is possible or necessary to admit that the stocks of capital at stake (environmental, economic and human-social) can be considered interchangeable with each other, for example admitting that a reduction in environmental capital can be counterbalanced by an increase in human-social capital, and vice versa.

In the context of sustainable development, it is necessary to highlight the role of the construction sector. Currently, this sector is globally responsible on average for over 35% of the consumption of raw materials, soil, water and energy and for over 30% of pollution and the production of waste. The buildings built in the second half of the last century and in the first decade of this century are characterized by the enormous consumption of energy and natural resources, so that the consumption of natural resources, the production of a considerable amount of waste, and the pollution of air and water are the largest undesirable effects related to the construction industry. The construction sector expands at a rate of around 2 billion of square meters per year, producing pollution and consumption of resources to create buildings which in turn require energy to be habitable and comfortable.

To promote the effective reduction of the impact of the construction sector, a synergic action is needed both on the production front (supply of raw materials, saving of energy resources, waste management) and on the design front (construction techniques, energy saving, maintenance and renovation).

The need for sustainability is further amplified in territories such as the islands, which are often particularly vulnerable to climate changes and over-dependent on fossil fuels and energy imports. As stated by the European Commission [2] many of European islands are small isolated systems and have small markets, are more vulnerable to the effects of the anthropic impact and must produce a considerable effort to implement policies and practices to reverse it. Therefore, it is essential that the islands manage their resources in a sustainable way, to become increasingly efficient, self-sufficient and be able to protect their environmental heritage.

The now unavoidable need to produce in a sustainable way is finding in the circular economy paradigm a strong conceptual key that can become the real driver of a process of change of epochal importance. In fact, an economy model is placed at the centre which, starting from the awareness of the finite nature of resources, reduces or eliminates waste, differentiates the sources of supply of materials, recovers and recycles the materials, makes consumer products as durable as possible maximizing their use value. The cradle to cradle approach of the circular economy involves all phases, from design to production, distribution, use and possible reuse, and then ends with the recycling and recovery of raw materials thus making the whole process sustainable and interconnected. It therefore clearly differs from the traditional paradigm of the linear economy in which raw materials, through the application of energy and work, are processed with the sole objective of obtaining marketable products, dealing waste of production secondarily and conceiving it as end of use products (Fig. 2).

One of the aspects on which to intervene to make the construction sector sustainable is therefore the use of construction materials that are themselves sustainable, such as for example materials of natural origin. Among these, wood is one of the most effective materials in terms of environmental sustainability because of its natural ecocompatibility, mechanical and building physic performance, ease to install.

In light of the foregoing considerations, this paper illustrates the potential of using wood as a structural material in terms of sustainable construction, also analysing the opportunities offered by the plant of local supply chains that allow implementing production processes based on the use of locally-grown wood, promoting the development of sustainable economies in narrow and interconnected communities like those of the islands.

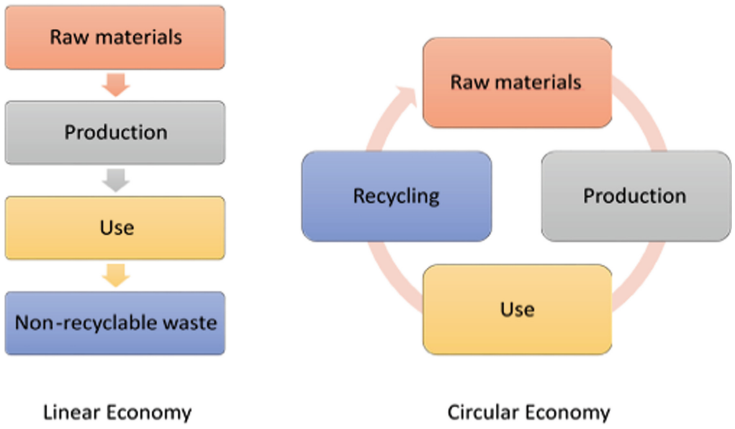

Fig. 2. Linear economy vs Circular economy

2 Timber Buildings and Sustainability

Timber in construction has a series of advantages linked to the origin and intrinsic characteristics of the material itself. Aspects such as the renewability of the raw material, which requires only land, water and sun to develop, and the positive effect on the environment, linked above all to the ability to sequester carbon dioxide from the atmosphere and store it for proportional times to the life of the material itself, make it one of the most suitable building materials to meet the current requirements of eco-compatibility and sustainability, as it minimizes the environmental impact at all levels as it is recyclable, renewable, biodegradable, and free of toxic contents [3]. Starting from the assumption that the reduction of climate-changing emissions (carbon dioxide and other greenhouse gases) and the expansion of carbon reservoirs, the term carbon reservoir meaning any stored form of carbon dioxide, are the two possible approaches to mitigate actual climate changes, wood allows both roads to be travelled [4, 5]. Due to photosynthesis, a tree stores large amounts of carbon dioxide in the wood. It is estimated that 1 cubic meter of wood stores approximately 1 ton of carbon dioxide, which continues to be stored into the material throughout its life, even when the wood undergoes the processes that make it a product, for example, for the building industry. Therefore, the use of wood in construction generates two advantages: on the one hand, the gradual replacement of the most energy-intensive and polluting building materials with timber reduces the climate changing emissions associated with the production and

management of these materials; on the other hand, the management of forests aimed at the use of wood in industrial sectors such as buildings involves the continuous renewal of the forest itself with an increase in the capacity to extract carbon dioxide from the environment and with significant added value with respect to firewood, landscape improvement, reduction of hydrogeological hazard [6].

In terms of economic sustainability, the high ratio between timber mechanical performance and weight, combined with the possibility of dry connections and achieving high levels of prefabrication, allows to significantly reduce construction times and storage spaces for materials on site, to facilitate handling, transport and assembly operations and to reduce the size of the foundation structures. All these aspects favourably affect the abatement and minimization of costs, as well as the environmental impact. There are numerous studies aimed at evaluating, through LCA approaches, the environmental impact of timber constructions in relation to other materials, especially concrete and steel, with reference to the consumption of raw materials and primary energy, to the production of carbon dioxide and in general to the emission of greenhouse gases in all phases of the useful life of the material [7–18]. The general result is the lower level of environmental impact of timber, especially considering the carbon dioxide storage capacity of the wood. Assuming that the trend in the construction sector does not vary, only 0.5% of new buildings will be built with timber by 2050. If wood production increases, this could be pushed up to 10% in a conservative scenario and could involve the storage of around 10 M tons of carbon dioxide per year. Assuming that the use of cement and steel in construction continues and assuming an increase in the surface area per person, the cumulative emissions due to these building materials could reach up to 1/5 of the carbon dioxide emissions balance up to 2050. Shifting towards timber buildings can reduce cumulative greenhouse gas emissions from steel and cement production by at least half. This may not seem like much compared to the current amount of around 11,000 M tonnes of carbon dioxide emissions per year, but the move to timber would make a difference in achieving climate stabilization goals [19]. In addition, wood contributes to environmental comfort due to its low conductivity, high thermal inertia, and natural hygroscopicity. Natural materials such as wood or cork are already comfortable at room temperature, while those like stone or cement are perceived as comfortable only at higher surface temperatures. In this regard, it is interesting to note that there are several studies concerning the link between the use of wood in locations and the psychophysical well-being of the occupants. Some of these studies point out that nature stimulates the reward brain system by reducing stress and consequently cortisol levels, heart rate and blood pressure, with a better immune system response [20], and the use of wood inside a building has clear physiological and psychological benefits that mimic the effect of spending time outdoors in contact with nature [21]. Other studies highlight that offices with wooden interiors convey sensations of innovation, energy and comfort. This results in increased worker happiness, decreased stress and reduced sick leaving with a 15% increase in productivity [22]. There is a connection between architecture, materials and health; there is indicative evidence that wood used in hospital settings can have effects on improving healing processes and other results such as shorter length of stay [23].

3 Timber in Architecture

Wood is the oldest of building materials. In the past the great availability of material, the ease of manufacturing and handling, the renewability and some others specific qualities, have made it the most widespread construction material. This spread has seen a halt since the nineteenth century, especially in some countries such as Italy where reinforced concrete and steel have monopolized the attention of researchers, technicians and consequently the market. The reasons for this downgrading of wood in construction are due to various cultural, economic and environmental factors. These include natural degradability, combustibility, shape and size restrictions dependent on the starting tree and the general mistrust of a natural material that has innate defects that affect its mechanical performance, in spite of the large number of works carried out in the past which have demonstrated remarkable strength and durability. In Italy for example, although belonging to the construction tradition of this country especially for floors and roofs, for a long time since the post-war period wood has been relegated to a secondary role in construction, being used mainly in the context of the recovery of historical or rural buildings or for provisional uses, being effectively excluded from the list of materials of engineering interest, similarly to what happened to masonry.

In recent decades, however, there has been a notable revival of wood in structural uses, thanks above all to the introduction of laminated timber, an industrial product that reconciles the great qualities of wood such as naturalness and sustainability with the reliability and high performance of a material industrially manufactured. In fact, laminated timber allows the most defective and unreliable parts to be discarded and provides for a certified production control that includes repeated mechanical tests; this allows to overcome the defects of solid wood, such as lower reliability due to uncertainty about the content of defects and the variability of physical characteristics over time, as well as the limits of use linked to the natural dimensions of the elements. The production virtually does not limit the size and shape of the structural elements, which can be made with high precision thanks to the numerical control machines, conferring ample freedom to architectural forms.

Besides that, timber buildings guarantee considerable mechanical performance and high durability, even in case of response to seismic actions, so that, also from a structural point of view, timber constructions are excellent competitors even for the most modern structures in reinforced concrete or steel. Timber is characterized by good mechanical strength both in tension and in compression, so it can be used for the manufacturing of elements prone to bending such as beams, compressed like the pillars, stretched like tie rods, without the need to combine it with other materials, unlike concrete and masonry.

3.1 Cross Laminated Timber

Among the various timber construction typologies, it is worth mentioning the CLT (Cross Laminated Timber) technology, which consists in the production of flat structural elements made by gluing layers of boards mutually oriented at 90° (Fig. 3). This arrangement in crossed layers mitigates the typical effects of anisotropy of the wood and gives the structural element the possibility of being used as a load-bearing element

both for floors and roofs and for vertical walls. The positive effect of the cross lamination on the mechanical performance makes it is also possible to use wood species with non-high mechanical characteristics, favouring the exploitation of local species, even with modest basic mechanical performance, other than those coming from central Europe traditionally treated for the manufacturing of laminated elements [24].

CLT is particularly suitable for advanced prefabrication, allowing all parts to be made off-site, and reserving for the construction site almost exclusively the connections and finishing.



Fig. 3. Glue laminated timber (left) and cross laminated timber (right)

3.2 Building Information Modeling

Currently, the request for buildings or infrastructures is strictly connected to specific needs, such as accurate design, speed of construction, energy efficiency, ease of management and maintenance, and durability. In the rapidly evolving global construction market, clear and precise rules are needed to help all actors of the construction supply chain to adapt skills to change and to innovate successfully.

The importance of Building Information Modeling (BIM) in this context is widely recognized. BIM is a process that permits to create and manage information about a building throughout its life cycle. It is witnessing an increasing diffusion in the construction market because it leads to considerable savings in realization times and building management costs. BIM also allows interchange of data for interoperability between various computer applications for the most varied purposes and uses (management, monitoring, performance calculation) [25].

As will be illustrated in the next section, the global timber construction market is rapidly growing and technologically evolving, but this still does not match with a growth in sector interoperability. The technological development of the last few years has led to an increase in the speed, precision and efficiency of the production plants for prefabricated timber elements. However, two important differences still remain compared to other strictly industrial products [26]:

1) the behavior of the wood depends on the environmental conditions in which the construction arises, and this must be taken into account by any standardization process;

2) the timber construction industry is very fragmented, made up of many small companies that produce highly specialized components and services, very often focused on particular territorial areas.

These two aspects can be greatly improved by the diffusion of BIM methodologies capable of optimizing the design, production and management of wooden structures. In fact, the growth and optimization potential offered by BIM is remarkable, especially as regards to prefabricated building systems, such as CLT and other timber building systems. The development of BIM in the structural timber sector would allow to obtain various advantages in terms of design flexibility, prefabrication process, management of construction, use and maintenance phases.

4 Timber Market in Italy

The wood sector in Italy is worth about 1.6% of the gross national product, involves about 15% of companies and generates a turnover greater than 30 billion euros, of which about two thirds are relating to the wood-furniture sector. The timber construction sector is growing and today the turnover of construction companies exceeds 720 million euros, marking a + 5% compared to 2017 [27]. The number of timber houses is growing, currently corresponding to about 7% of residential construction, with CLT constructions representing about 50%. Italy is currently the fourth European manufacturer of prefabricated timber buildings, with positive exports, highlighting a market aimed towards excellence and resilient to the crisis of the building sector. In addition to these considerations, it is interesting to note that in Italy the forestry area corresponds to over 35% of the total territory.

Despite the positive market trend and the availability of raw materials, Italy is the EU country with the lowest degree of self-sufficiency in the supply of wood raw material (<1/3 of needs). The dependence from abroad is such as to result in a highly unfavorable trade balance for the wood products sector (logs and sawn, veneer, panels, semi-finished products and components for furniture and construction) which is counterbalanced only thanks to the Italian furniture industry and the significant added value generated by this sector. The level of extraction of Italian forests is one of the lowest in the EU with an annual share of less than 25% of the increase, compared to 65% of the European average. In general, the supply of Italian timber is quantitatively low, generally characterized by a lack of quantitative and qualitative homogeneity and, overall, not addressed towards adequate economic and technological enhancement [28].

With reference to the situation on the island of Sardinia, although the constructions entirely made of wood do not belong to Sardinian building tradition, focused above all on the use of masonry for vertical load-bearing structures and on the use of wood limited to floors and roofs, the timber buildings market of the island is following the national trend, marking a continuous growth also evidenced by the large number of companies involved in the marketing and installation of timber prefabricated buildings (Fig. 4). To this must be added the fact that Sardinia has a forestry area between 40% and 60% of the total, the main wood species being oaks, other broadleaves such as eucalyptus, and conifers such as stone pine, Aleppo pine, Corsican pine, maritime pine



Fig. 4. Sardinian wooden structures: traditional truss (upper left), common roof (upper right) and modern CLT building (down)

and radiate pine [6]. Despite these aspects, in line with the national trend the wood used for prefabricated buildings in Sardinia is almost 100% imported.

5 Timber Supply Chain in the Island of Sardinia

Sardinia, as emerges from the document related to the Smart Specialization Strategy S3 [29] is characterized by an economic and productive system of modest competitiveness and with little propensity for innovation. This connotation also involves the building sector, which is affected by historical problems connected to insularity, employment difficulties, lack of economic resources, as well as the contingent and more general economic-productive crisis. The crisis in the building sector has serious repercussions on the entire supply chain of the construction industry, investing companies, producers, artisans and traders. Moreover, Sardinian building sector, one of the least eco-efficient in Europe, is responsible for 30% of the region's total energy consumption and 25% of carbon dioxide emissions into the atmosphere. Then the awareness emerges that the reversal of the negative trend that invests the building sector can effectively combine with the policies aimed at stimulating energy efficiency and the use of natural materials in the sector, which have now become a necessity and no longer just an intellectual or ideological choice. The use of local resources by the

building industry, moreover of natural origin such as wood, as well as meeting the needs of green building, is revealed as a real chance of development that would directly invest the building sector and consequently the employment, environmental, social and cultural context. This choice of circular economy in the building sector is also the best path towards the sustainable development of the islands. The islands in fact have a greater fragility with respect to the effects of the anthropic impact and must produce a considerable effort to put in place systems of resilience, so it is essential that there are more and more circular systems to effectively exploit islands natural resources [2].

On the basis of the framework described above, a research activity, funded by the Sardinian local administration and still ongoing, has been launched in Sardinia aimed at verifying the possibility of using local wood as structural timber. The research involves an experimental agenda carried out on locally-grown maritime pine (Pinus Pinaster), which is a widely spread and relatively fast growing conifer available in Sardinia, in the rest of Italy and also in several Mediterranean regions. This Sardinian species has never been considered as a structural material before this research started.

Sardinian maritime pine is generally characterized by medium-low quality due to the presence of defects (knots, clusters of knots, resin pockets, grain deviation etc.), so the research has proposed to verify its performance when used in CLT elements with and without natural fibers reinforcement.

The research activity has been divided into several phases, such as:

- identification of the areas from which to take the material;
- selection and cutting of plants;
- cutting of logs in boards;
- drying;
- laboratory experimental tests on boards (Fig. 5) in order to define a grading rule for this material (i.e. attribution to the material of a performance profile containing the mechanical, elastic and physical properties as a function of the defects);
- manufacturing of CLT structural elements in the laboratory (Fig. 6);
- mechanical tests on the structural elements (Fig. 7);
- study and implementation of numerical models;
- extrapolation of design formulas.

Very briefly, the main results achieved so far have shown that [6, 24, 30–35]:

- the mechanical performance of the CLT elements is comparable with that of similar elements already on the market;
- the CLT elements reinforced with natural fibers allow, with the same mechanical performance, a reduction in thickness, with consequent economic and dimension advantages;
- it is possible to implement a supply chain process aimed at the manufacturing of laminated timber elements based on Sardinian maritime pine.



Fig. 5. Boards testing



Fig. 6. Manufacturing of CLT structural elements



Fig. 7. Mechanical tests

A further step in the direction of improving sustainability of Sardinian building sector is taking place through a further research line concerning the development of eco-sustainable building solutions for energy-efficient walls and floors. This research aims to study the energy performance of CLT Sardinian maritime pine elements conjugated with layers of thermo-acoustic insulation made with local and natural

materials, such as cork, sheep's wool, etc. [36]. In addition, it will be of interest to study the possibility of using in the construction industry the other Sardinian wood species, in order to make the development of the production chain of timber elements economically more advantageous and make these elements more competitive on the global market.

6 Discussion

The research conducted so far has allowed, as well as to formulate the conclusions illustrated in the previous section, to simulate the entire supply chain process for the manufacturing of CLT elements in Sardinian maritime pine, allowing the detection and analysis of the inherent critical issues.

The study has highlighted that the use of locally produced wood can allow to reduce the energy consumption linked to import wood from abroad, a factor particularly important for island regions such as Sardinia, and at the same time can allow to create employment in areas often economically depressed. The potential of the studied structural products is high. The timber market is in fact continuously expanding, in Europe and in Italy, given the considerable possibilities of use, the performance characteristics and the progress of technology. The use of timber allows the construction of buildings that meet the requirements for energy efficiency and environmental sustainability.

The development of timber structural products based on local wood can allow:

- the reduction of the costs of timber structures, thanks to the possibility of producing them on site rather than importing them from afar, thus promoting the sustainable construction sector in Sardinia with great environmental advantages;
- an increase in the demand for structural timber, with a consequent further increase in the Sardinian forestry area and with important environmental, tourist and hydrogeological protection advantages - as already underlined, the forestry potential of Sardinia is significant, being currently the fourth Italian region by extension of the forestry surface;
- the creation of new jobs in the timber chain, such as activities related to forest maintenance, new plants for the production of sawn wood (sawmills) and manufacture of structural components (prefabrication workshops), new specialized assembly companies, currently almost absent in Sardinia, with important repercussions in terms of employment in the Sardinian territory and a significant social function to reduce unemployment and abandonment of depressed areas;
- certification of the construction quality in all phases of the process (materials, production, installation).

7 Conclusions

The potential of using wood as a structural material in terms of sustainable construction has been analyzed and discussed. In detail, the opportunities offered by the plant in Sardinia of a supply chain for manufacturing structural laminated timber elements made of locally-grown wood has been addressed, also by referring to the results of a research activity devoted to this purpose.

Beside the specific scientific goals of the research, the collateral results and the positive effects of the supply chain can be summarized in the promotion of an industrial, occupational and social growth determined by the use of local resources and the innovative and transversal use of traditional products, all in terms of all-round sustainability.

What has been discussed appears even more significant if considered with a view to optimizing the strategies to be implemented in the islands in order to respond to the challenges currently imposed by the pillars of sustainability.

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