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Feasibility of a Local Production Chain for Structural Timber in Sardinia, Italy

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Abstract: The construction sector is currently responsible for over 30% of the consumption of natural resources and the release of solid waste and pollution into the environment. This situation is even more serious in closed communities such as islands, economically highly dependent on the outside world. One of the possible interventions to reverse this trend is the use of eco-sustainable construction materials such as wood, produced through supply chains with a low environmental impact. This paper reports on a research activity that analyzed the feasibility of implementing a sustainable local supply chain in Sardinia to produce Cross-Laminated Timber (CLT) panels made of locally grown wood. This research has experimentally carried out the entire supply chain process: (i) choice and collection of the raw material in the forest for producing strength-graded boards to manufacture laminated timber, (ii) manufacturing of CLT panel prototypes, and (iii) determination of CLT panels' mechanical performance through laboratory tests. This experimentation allowed, on the one hand, to evaluate the performance and competitiveness of CLT panels made of local wood, and on the other hand, to identify the criticalities that currently hinder the implementation of this supply chain in Sardinia, and to propose possible actions to solve them.

Keywords: sustainability; building sector; timber buildings; short production chain; circular economy

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1. Introduction

Currently, the construction sector annually consumes an average 35% of resources—raw materials, water, and energy—and produces about 30% of the solid waste and pollution worldwide. This impact is incompatible with the concept of sustainability, which now permeates all sectors of human activity.

Sustainability is a complex concept, which concerns both the needs to be met and the capacities to be guaranteed over time, and the capital to be protected and enhanced, such as the environmental and human–social ones. The most widely recognized definition of sustainable development is reported in the report *Our Common Future* [1], commonly called the *Brundtland Report*, which identifies as sustainable the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Based on this definition, the four pillars of sustainable development are identified as environmental sustainability, economic sustainability, social sustainability, and institutional sustainability, which protect and enhance the natural, economic, and human–social capitals with the aim of implying the maintenance of the quality and renewability of natural resources, guaranteeing job, income, and equally distributed well-being (safety, health, education, etc.) for the population, ensuring conditions of democracy, stability, and participation. Currently, climate change and environmental degradation pose a huge threat to Europe and the world. To overcome these challenges, the EU introduced the European Green Deal [2], a package of strategic initiatives that aims to put the EU on the path to a green transition, with the goal of achieving climate neutrality by 2050. The European Green Deal aims at transforming the EU into a modern, resource-efficient, and competitive economy by ensuring that no net greenhouse gas emissions are generated by 2050, and that economic growth is decoupled from use of resources. In this context, since sustainable development is clearly not compatible with the degradation of the environmental heritage and natural resources, it becomes mandatory for the construction sector to move toward a sustainable dimension. The turning point that can become the real driver of a process towards sustainability in the building sector is the circular economy model. The circular economy is based on cradle-to-cradle production and consumption models, which include the extension of the life cycle of products, the reduction of waste to a minimum, and the reintroduction of recovered materials into the economic cycle, according to the production–consumption–treatment–reuse chain, and in clear contrast to the current linear economic model, which instead acts according to the production–consumption–waste chain. As highlighted by the European Parliament [3], the circular economy would not only drastically reduce the EU's carbon dioxide emissions but would also stimulate economic growth and create new job opportunities in Europe. It has been shown that the European New Circular Economy Action Plan (CEAP 2.0) would create 700,000 jobs across the EU by 2030 and the EU's Gross Domestic Power (GDP) growth would increase by 0.5%. The circular economy model is particularly suitable in small and interconnected territorial realities such as islands, which face specific challenges due to their geographical and climatic conditions. These conditions result in the increase in the cost of living, fewer job opportunities, and overall lower economic results compared to continental ones. As stated by the European Commission [4], due to their small size and isolated energy systems, islands face a major challenge regarding energy supply. They typically depend on imported fossil fuels for electricity production, transportation, and heating, resulting in negative environmental and economic impacts. The transition toward a more sustainable energy supply, through the sustainable management of resources, would improve the efficiency, self-sufficiency, and level of protection of the islands' environmental heritage. The use of local resources by the construction sector, therefore, appears to be a fundamental driver for sustainable and resilient economic growth and for the development of local skills and jobs for island communities. Especially in isolated communities, the high impact of the building sector and the prospects linked to the implementation of circular economies push actions toward two main directions: (i) the implementation of short production chains, and (ii) the use of eco-friendly, recyclable, locally available, and energy-efficient building materials.

The local dimension of the production chains entails various advantages in terms of sustainability. Easier logistics and faster delivery lead to better control over deliverables, and lower transport and storage costs lead to a reduction in the overall costs of logistics, thus increasing revenues. Companies are more aware of their environmental and social footprint and can more easily comply with local rules and ethical sourcing, and local sourcing leads to a reduction in carbon emissions of the supply chain process, thus reducing the environmental footprint. With all investments circulated locally, the short supply chain provides a great advantage to the local economy and to the individuals who live in the area.

Natural materials have found increasing interest over the years. According to Allied Market Research [5], the global green building materials market was valued at USD $237.3 billion in 2020, and is projected to reach USD $511.2 billion by 2030, growing at a CARG (compound annual growth rate) of 8.1% from 2021 to 2030. Natural building materials are recyclable products that promote the conservation of non-renewable resources and reduce the environmental impact of the production chain's segments. The preeminent natural materials are those deriving from agro-forestry supply chains, eco-sustainable, renewable, recyclable, and with reduced LCA (Life Cycle Assessment) costs. The production of most natural materials, for example, involves a limited consumption of natural resources, energy, and carbon dioxide. In some cases, such as for wood, straw, and sheep wool, the impact can even be negative, as carbon dioxide can be sequestered and not dispersed into the environment. In this regard, in 2020, the European Commission launched the Renovation Wave Strategy [6], a program to improve the energy performance of buildings. One of the cornerstones of this strategy is the so-called life cycle thinking and circularity, that can be achieved by minimizing construction's footprint by using resources in an efficient and circular way and transforming the construction sector into a sink of carbon dioxide, encouraging the use of green infrastructure and organic building materials able to store carbon, such as sustainably sourced timber. The main actions of the strategy include expanding the market for sustainable construction products and services, also resorting to new materials and nature-based solutions, and further developing the framework for eco-design to increase the offer of efficient products to be used in buildings and to promote their use.

Among natural load-bearing materials, timber is optimal from the point of view of environmental sustainability, as it is a naturally eco-friendly material characterized by appreciable mechanical and thermo-acoustic performance and ease of handling and installation. In Italy, the tradition linked to the use of wood in buildings was mostly limited to floors and roofs, but in recent decades there has been a renewed diffusion of wood in construction thanks also to the development of engineered products such as laminated timber. Nonetheless, almost all the wood used in construction is imported, with extremely negative consequences from the economic, environmental, and social points of view due to the costs, energy consumption, and pollution linked to transport, and the penalization of local development. In this context, the implementation of a short production chain for the use of locally grown timber in construction would certainly meet sustainability needs.

1.1. Sustainability of Timber as a Building Material

Wood, together with stone, is the oldest building material, and has been long and widely used due to its specific technical properties, availability in nature, renewability, and ease of processing and handling. Following industrialization, in some countries the use of wood has been downgraded or abandoned in favor of materials such as steel and reinforced concrete, but the notable technological evolution that has affected the wood engineering sector has determined the revamping of wood as a structural material in recent decades. From the point of view of environmental sustainability, the natural renewability of the raw material, the ability to extract carbon dioxide from the environment and store it for the entire service life of the material, even when it is transformed into a secondary and final product through manufacturing processes, and the recyclability, biodegradability, and the absence of toxic contents [7] represent advantages that allow timber to minimize its environmental impact. From the point of view of economic sustainability, timber is a light material, installed with dry connections and on small foundations, and easily prefabricated. These properties benefit timing, assembly, and logistics, and determine the general reduction of construction costs. From a performance point of view, timber can be used as a structural material, without reinforcing materials, in compressed elements such as pillars, bent elements such as beams, and stretched elements such as tie rods, unlike what happens with concrete and masonry. This is due to timber's appreciable mechanical strength both in compression and in tension, which makes it an excellent competitor even for modern steel or reinforced concrete structures. Timber is also characterized by natural hygroscopicity, high thermal inertia, and low conductivity, therefore contributing to environmental comfort [8,9]. Owing to these positive issues, the wood industry is constantly expanding in Europe. In Italy, the timber construction sector is growing, and today, the turnover of the timber construction industry exceeds 1 billion euros, marking +33% compared to 2020, and Italy is currently the third European manufacturer of prefabricated timber buildings [10]. The spread of timber in the construction sector is favored by the production and development of laminated timber, an engineered wood that combines the characteristics of industrial products subject to quality control, such as high and constant performance and reliability, with the intrinsic advantages of a natural material. The main structural product in laminated timber is the GLT (Glue-Laminated Timber) beam, composed of overlapping boards glued in the direction of the grain (Figure 1).

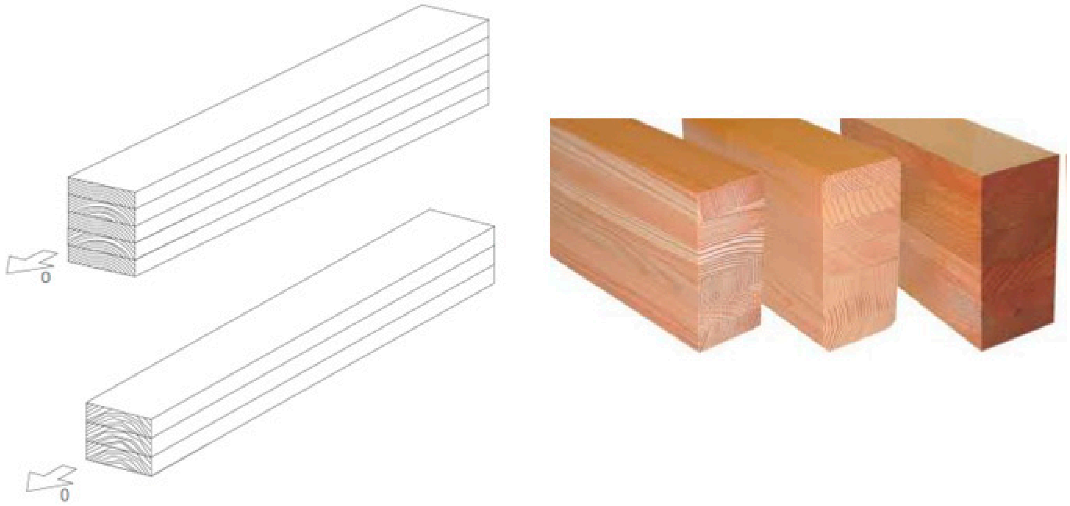

Figure 1. Glue-Laminated Timber beams.

To produce GLT, boards cut from fresh logs and then artificially dried are used, selected according to the proper mechanical strength grading. The boards undergo an initial check that identifies their defects (knots, clusters of knots, resin pockets, grain deviation, deformations) and, in the event of exceeding the threshold values defined by the standards, the defective part is eliminated by truncation. The boards reclaimed from defects undergo a finger jointing and then pass to planing, and finally, to gluing. This production process ensures that the final product has superior mechanical characteristics compared to the parental solid wood. A further evolution of laminated timber technology is Cross-Laminated Timber (CLT), manufactured by superimposing layers of boards orthogonal to each other (Figure 2). The typical effects of wood anisotropy are attenuated by the cross-layer configuration, which also allows the use of CLT as a load-bearing element both in vertical structures such as walls and in horizontal ones such as floors and roofs. The benefits brought by the cross-layer configuration to the mechanical characteristics of the CLT also allow the use of wood species with poor mechanical properties. This has a positive impact in terms of sustainability, as it favors the use of local wood species that have mechanical characteristics lesser than those of Central Europe species traditionally used in the production of laminated timber [11,12]. CLT is very suitable for prefabrication, as it allows most elements to be produced in the factory and essentially only the connections to be left to construction site operations.

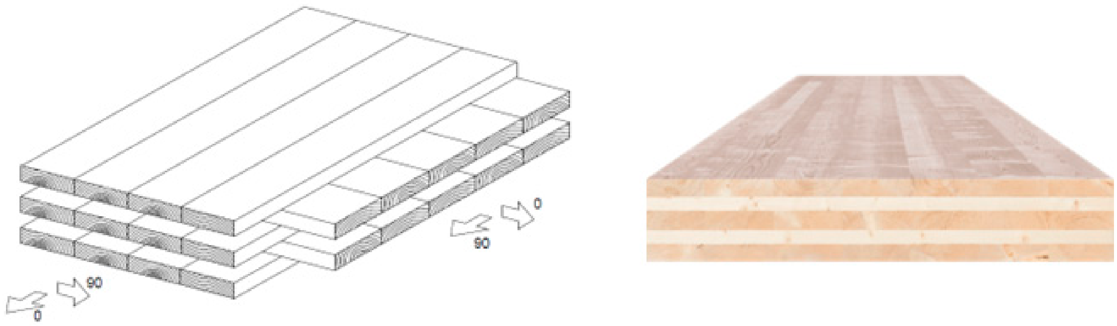

Figure 2. Cross-Laminated Timber panel.

1.2. Timber Production Chain in Sardinia (Italy)

Despite the positive market trend, the advanced technological solutions, and the availability of raw materials, with the Italian forestry area being over 35% of the total territory, among EU countries, Italy is the least self-sufficient in the supply of wood raw material, producing less than one-third of its needs. Dependence on foreign countries entails a highly unfavorable economic balance for the wood construction products, such as logs and sawn wood, veneers, panels, and semi-finished and finished products, which is overall positive only thanks to the Italian furniture industry and the considerable added value generated by this sector. Italy imports two-thirds of its needs from Austria, France, Switzerland, and Germany, and is the leading European importer of industrial timber, the leading world importer of firewood, and the fourth world importer of wood chips and scrap wood. Sardinia is in line with this trend, also due to the further handicap of its insular condition. The level of harvesting of Italian forests is one of the lowest in the EU, being less than 25% of the annual increase, compared to the EU average of 65%. Overall, the supply of Italian wood is quantitatively low, characterized by qualitative and quantitative inhomogeneity and generally not directed toward adequate technological and economic valorization [13].

In line with the general Italian trend, Sardinia Island (Italy) is currently witnessing a continuous growth of the timber construction market, evidenced by the growing number of local companies operating in the sectors of assembly and marketing of timber buildings. Furthermore, Sardinia is characterized by a forest area equal to approximately 40–60% of its total surface area, with a prevalence of Oak and Eucalyptus among the broadleaved trees and Aleppo Pine, Stone Pine, Radiata Pine, and Corsican Pine among the conifers [14]. Despite these aspects, currently, no structural timber production chain is present in Sardinia, and the wood used in timber buildings is almost 100% imported.

The present paper analyzes the opportunities that the local production chain of structural timber could offer in Sardinia. The possibility of developing a model of a short production chain, including forest management, transformation of material, and production of building elements and other wood-based products, is discussed. Given that there is no structural timber production chain in Sardinia at present, in order to analyze the benefits and criticalities of the supply chain, the research simulates the entire production process of structural timber through experimental activities. The research considers the production chain of CLT panels. The choice of these structural products arose from the previously presented qualities of CLT technology, especially the ability to provide high-performance structural elements even when the parental wood is not of excellent quality. This research made it possible to highlight the opportunities offered by the possible implementation of the timber supply chain and the critical issues that currently hinder such implementation. The importance and novelty of the research lie in the feasibility analysis of the local production chain of structural timber in Sardinia. In fact, the development of this supply chain would foster: (i) A reduction of the costs of timber buildings, thanks to the possibility of producing them locally rather than importing them from abroad, thus promoting the sustainability of the Sardinian building sector with great environmental advantages. (ii) An increase in demand for structural timber and a consequent increase in the Sardinian forest area, with important environment and tourist benefits and mitigation of hydrogeological and fire risks. (iii) The creation of new jobs in the structural timber supply chain, with significant social impacts on the territory. (iv) A reduction of pollution, by removing carbon dioxide from the atmosphere, in compliance with the requirements of the international protocols to which Italy adheres.

2. Experimental

The research consisted of two main work packages: (i) the preliminary analysis, aimed at identifying the main steps of the production chain together with the factors that influence the criteria for its implementation, and (ii) the experimental activity, aimed at manufacturing the CLT panels and determining their performance.

2.1. Preliminary Analysis

First, the main stages of the production chain were identified as follows:

- Choice of wood species and identification of stands,
- Selection of the pick-up area,
- Selection of the plants,

- Knocking down the plants,
- Cutting the logs into boards,
- Board drying,
- Board grading,
- Selection of the boards to produce laminated timber,
- Manufacturing of the CLT panels.

The choice of the wood species and the identification of the stands were jointly carried out with Local Agency Forestas, the local authority that deals with forest management. The choice fell on the Maritime Pine (*pinus pinaster*), a conifer widely spread in Sardinia and throughout the Mediterranean area, very versatile and widely used in forestry interventions, as it has acclimatized over a much wider range than the original species [15]. Then, the factors that influence the criteria for developing the production chain were analyzed and identified, also with reference to related literature and similar studies [16–19]. Results are reported in Table 1.

Table 1. Factors influencing the criteria for developing the structural timber production chain.

Stages	Criteria						
Pick-up area selection	land morphology	accessibility of the area	ease of site management	stand renewal capacity	stand density	stand potential yield	certified forest
Plant selection	limited stem curve	slightly branchy stem	adequate stem height	suitable stem diameter			
Plants' knocking down	annual period with minimal vegetative activity						
Log-cutting strategy	log diameter	log defectiveness	required board thickness	boards' admissible deformation	admissible waste volume	sawmill equipment	
Board drying	environmental thermo-hygrometric conditions	board-stacking strategy					
Board grading	board defectiveness	boards' physical parameters	boards' mechanical parameters				
Board selection	final product expected performance	available board grades					

2.2. Experimental Activity

A large experimental activity was performed concerning the following segments of the production process:

- Identification of suitable wood species,
- Definition of cutting criteria,
- Definition of boards' grading rules,
- Experimental determination of the mechanical and morphological characteristics and properties of the boards,
- Manufacturing of prototypes of laminated timber elements,
- Experimental determination of the mechanical properties of the structural products.

The experimental activity was structured as follows, according to the criteria reported in Table 1. The analysis of the stands suitable for structural uses was conducted, and the areas for the supply of the wood resource were identified. The criteria for choosing and felling the plants were then elaborated and, following on-site surveys, it was established in which categories of stems it is possible to obtain boards suitable for the intended structural purposes. Based on the criteria developed, approximately 20 m^3 of logs were cut, which were visually checked to make the choice of the more effective material. The material suitable to produce CLT panels was sawn into 520 boards edged and dried to a wood moisture of 12%, compatible with the gluing process. For each board, grading was carried out according to [20] by measuring the geometric and physical characteristics (width of growth rings, single knots and groups of knots, grain deviation, density, sonic speed) and carrying out mechanical bending tests on 5% of the boards, to experimentally determine the Modulus of Elasticity (MoE) and the Modulus of Rupture (MoR). Following the definition of appropriate criteria for the design of Sardinian Maritime Pine CLT panels, derived from the specific structural needs, standard requirements, and environmental conditions reported in the standards [21–24], 63 prototypes of these panels with 3 and 5 layers consisting of 20 and 40 mm-thick boards were manufactured in the laboratory, to represent the most used typologies in buildings up to three floors, and which would be those most used in a local market. The CLT panels were then subjected to mechanical tests to determine the main mechanical characteristics, such as strength and stiffness. In detail, 21 panels were tested by means of a free-vibration-based dynamic identification procedure [25] and 42 panels were bending-tested according to [26].

3. Results and Discussion

The experimental activity allowed, on the one hand, determining the technical performance of the CLT panels made of local wood and evaluating their competitiveness against similar products already on the market. On the other hand, the activity allowed analyzing the feasibility of the local production chain, highlighting the critical issues that currently hinder its implementation and identifying possible solutions. These issues are analyzed in the following subsections.

3.1. CLT Technical Performance

The experimental tests carried out on Sardinian Maritime Pine boards showed the basic physical–mechanical properties of this species, as reported in Table 2. Based on these values, the Sardinian Maritime Pine boards can be sorted in strength classes C14–C16, according to [27].

Table 2. Basic physical–mechanical properties of Sardinian Maritime Pine boards.

Average Density at 12% Moisture Content	Average Modulus of Rupture (MoR)	Average Static Modulus of Elasticity (MoE)
466 kg/m^3	26.3 N/mm^2	7160 N/mm^2

The experimental tests on manufactured prototypes of Sardinian Maritime Pine CLT panels demonstrated the mechanical performance of these engineered products [11,28], as reported in Table 3, where the mechanical performance is expressed through the Effective Bending Stiffness (EI_{ef}), a property that considers the modulus of elasticity, E_i, and the moment of inertia, I_i, of the individual layers that make up the panel, as well as the effects of the crossed-layer arrangement [24,29].

Table 3. Mechanical performance of Sardinian Maritime Pine CLT panels.

Number of Layers	Layer Thickness (mm)	Total Thickness (mm)	Boards' Strength Class	Effective Bending Stiffness (kNm^2)
3	20	60	C16	138
5	20	100	C16	528
3	40	120	C16	1109

Table 4 illustrates the comparison between the characteristics and the mechanical performance of the Sardinian Maritime Pine five-layer CLT panel and those of a typical CLT commercial panel.

Table 4. Sardinian Maritime Pine five-layer CLT panel vs. typical CLT commercial panel.

Product	Wood Species	Number of Layers	Layer Thickness (mm)	Total Thickness (mm)	Boards' Strength Class	Effective Bending Stiffness (kNm^2)	Density (kg/m^3)
Typical Commercial Panel	Spruce	5	20	100	C24	792	480
Sardinian Local Chain Panel	Pine	5	20	100	C16	528	350
Sardinian Local Chain Panel MOD1	Pine	5	22	110	C16	703	350
Sardinian Local Chain Panel MOD2	Pine	5	23	115	C16	803	350

The comparison between the data relating to the typical commercial panel and those relating to the Sardinian local chain panel showed that the latter has a decidedly lower Effective Bending Stiffness, in agreement with the use of boards of a lower strength class (C16 instead of C24). However, it can be seen that the increase in the thickness of the individual layers by 2 mm (Table 4, Sardinian Local Chain Panel MOD1) or 3 mm (Table 4, Sardinian Local Chain Panel MOD2), with an increase in the total thickness of the panel by 10 mm and 15 mm, respectively, determines the achievement of Effective Bending Stiffness values in line with those of the typical commercial panel. It is important to emphasize that the increase in the panel thickness does not affect its weight, given the lower density of Sardinian Maritime Pine compared to the Spruce commonly used in commercial CLT panels. Thus, despite that Sardinian Maritime Pine turned out to be a medium–low-quality material, especially compared to the woods of central Europe commonly used for manufacturing laminated timber, its use in the form of CLT panels allows to obtain a final product with mechanical characteristics more competitive than those of the parental boards.

3.2. Feasibility of the Local Production Chain

As previously mentioned, a supply chain relating to the production of CLT elements based on Sardinian Maritime Pine is not currently in place, nor are there similar supply chains in Sardinia for producing laminated elements from other wood species. For this reason, an analysis of the production process was conducted through the following steps:

- Definition of the fundamental segments of the process itself.
- Experimental reproduction of the segments, if possible.
- Consequent identification of the main nodes that currently hinder the implementation of the process.

The main critical issues pointed out by the analysis and experimental activities concern:

- Forest management, currently not oriented to the production of structural timber.
- High percentage of boards that cannot be strength-graded for structural purposes due to the high wood defectivity.
- Problems related to the drying process of the boards.
- Inadequacy of local enterprises that work in the timber sector.

These issues are analyzed in the following subsections.

3.2.1. Forest Management

Data from the National Inventory of Forests and Forest Carbon Pools [30], which represents the complete and homogeneous reference framework for the quantification and qualification of the forest resources at the national and local levels, show that about 50% of

Sardinian territory is affected by forest and pre-forest formations. The category of conifers covers an area that is around 56,000 ha. The analysis of the uses of the forest resources in Sardinia provided the data shown in Table 5.

Table 5. Uses of the forest resources in Sardinia.

	Softwood for Primary Use (mc)	Hardwood for Primary Use (mc)	Wood for Energy Production (mc)	Losses during Forest Work (mc)	Total (mc)	Forest Available for Wood Supply (ha)	Current Increment (mc/ha/Year)	Unit Pick-Up (mc/ha/Year)
Sardinia	1613	1000	121,277	4038	127,928	528,628	2.00	0.24
National average (Italy)	65,771	54,159	232,905	14,237	6092	368,627	4.10	1.00

It can be noticed, on the one hand, the high availability of material against a withdrawal rate below the national average, and on the other hand, the main use of the material for energy production (firewood, etc.) at the expense of more noble uses (work wood).

In Sardinia, the average growth of trees is limited, being estimated at 2 (+/−5%) cubic meters per hectare per year, about half the average value in Italy. The potential to produce firewood is relatively large and traditionally exploited, whereas currently, the profitable production of wood for other uses would only be possible in very limited areas. Therefore, this production has so far not really been considered relevant in the local silvicultural tradition, and almost all the wood used in Sardinia for structural purposes is currently imported. The current extension of conifers is almost entirely the result of their artificial introduction. In fact, Sardinia has been experimenting with Pine planting for at least a century. Most of these artificial areas share a common problem, which is not receiving the necessary care during growth from young areas to mature areas. Public financial support has so far considered only the need to ensure the survival of trees in the initial phase of growth, without planning the thinning and pruning interventions essential for the correct growth of trees suitable for diversified uses, mainly because the economic value of the resulting waste from these operations is not sufficient to offset the costs. The negative consequences of this management are now evident in various respects: (i) ecological development has slowed down, (ii) excessive amounts of dead wood facilitate pathogens and fires, and (iii) the stems are underdeveloped and poorly shaped, and the trees are overall fragile. The possible use of conifers, specifically the Maritime Pine, for structural purposes, requires changing the strategy in the forest management, orienting it first to improve the quality of the trees, and second to optimize the characteristics of the pick-up areas, considering that the criteria that influence their choice are those already highlighted in Table 1.

3.2.2. High Percentage of Discarded Boards

Sardinian Maritime Pine is affected by a significant degree of defectiveness, which involves percentages of boards that cannot be strength-graded for structural purposes according to current standards averaging around 45%. Table 6 shows the incidence of defect types on the percentage of discarded boards, as it resulted from the experimental activity. The presence of nodes, both as single nodes and as grouped nodes, is the cause of the exclusion for over 70% of the discarded boards. Therefore, actions are needed to remedy this problem.

Table 6. Defect incidence on the percentage of rejection of the boards.

	Knots	Grouped Knots	Spring	Bow	Twist
Percentage of rejection (%)	32	40	18	9	1

3.2.3. Drying Process

Sardinia does not have a drying plant suitable for boards' artificial seasoning. This results in either natural drying, which unfortunately involves extended timing and difficulty in controlling the environmental thermo-hygrometric conditions, or the delocalization of the drying process, transporting the boards to other national or international areas equipped with suitable plants. This solution entails an economic and environmental cost that hardly combines with the concepts of sustainability, short supply chain, and circular economy, especially considering the insularity of Sardinia.

3.2.4. Inadequacy of Local Enterprises

The companies potentially interested in the Sardinian structural timber supply chain are essentially sawmills, carpentries, companies that sell final products and that are also equipped for some finishing processes (carving, impregnation, coloring) of imported laminated timber, small construction companies, and retailers of building materials. Therefore, some basic elements of the supply chain are missing, such as the subjects of proper forest management and the companies for manufacturing laminated elements starting from the boards, as well as, obviously, a structured network to effectively guarantee the transition from the forest to the final product installation on-site. In addition, since companies have never dealt with the production of laminated timber, they are not properly equipped for the transformation of semi-finished products into final products. Furthermore, it is worth noting that companies dealing with the production and installation of natural building materials have a generally artisanal character, and they are not used to neither the regulatory framework relating to products' certification nor to the implementation of quality-control procedures for products or production processes. These frameworks and procedures are essential to obtain the certifications that allow natural building materials to be widely marketed and included in tender specifications and technical documents.

3.3. Discussion

The supply chain for producing structural timber is a complex system including activities often very heterogeneous from each other, such as forest management, first and second wood transformation in semi-finished and final products, transport and logistics, marketing, and others.

An element of weakness of the Italian production system is the lack of production continuity, which proceeds with alternating trends, along with the scarcity of internal quantities of wood, highly insufficient compared to the needs of the first and second processing companies. Therefore, the foreign offer is often more competitive both in terms of prices and for the guarantee and consistency of supplies. At the level of the supply chain and of the production process, the purchase of already finished or semi-finished material is generally preferred, and it is difficult to exploit the possibilities offered by the local market, both due to the lack of standardized production and, above all, the continuity over time, factors that affect the final costs of the products. Moreover, since the sector is mainly of the artisanal type, it is affected by the operational uncertainties of the supply chain, including those of a technological nature, which are manifested in all their evidence. The need to change production processes by directing them toward technological products, such as blockboard or laminated material, and no longer toward less versatile products such as solid wood, requires significant economic investments, so in many cases, purchasing on external markets appears easier. Focusing the attention on the industrial wood sector, these aspects are even more incisive in Sardinia, since there is not any structural timber supply chain, neither for laminated timber nor for mass timber, except for few application in the furniture and building accessories sector; therefore, import is the only option. Currently, both nationally and locally, import is perceived as advantageous, as only the economic perspective is considered. A change of perspective is, therefore, needed in the conception of the function of the forest, whose wealth should be considered in terms of multifunctionality, as it is reductive to consider only the production function, and the territorial context is fundamental. The forest can become an instrument for achieving goals of different policies, such as environmental and climate change, territory defense, energy, tourism, and employment. Active and multifunctional forest management should also be economically advantageous. The economic convenience has gradually decreased over time due to the decrease in international timber prices and the increase in the costs of use, a situation aggravated in Italy by the persistence of insufficient systemic conditions. The main problems, amplified in the Sardinian insular context, are the following [30]:

- Of the forests, 95% are in hilly or mountainous areas, resulting in technical and economic limits of active management.
- Forest land ownership is highly fragmented, resulting in small and isolated private properties, and scarce representation in decision-making.
- Landowners are often disengaged, resulting in abandonment of the territory, lower productivity, degradation of resources, and increased environmental risks, such as fire and hydrogeological instability.
- Only 15% of the forest area benefits from a management plan, resulting in a lack of general forestry strategic planning.
- The Sardinian regulation and restriction framework is rather complex.

In Sardinia, most of the forest area is private property (65%), and only 35% is owned by public bodies. Of the latter, about 45% is managed by the Local Agency Forestas. This articulation of the forestry area means that the achievement of an adequate and sustainable physical and economic dimension is very complex, linked either to the increase in individual properties through the purchase of new areas, or to associations and consortium by the owners. The latter imply voluntary membership, which normally does not exist both for cultural reasons and for actual difficulties, such as the impossibility of tracing many owners. It should be said that in Sardinia, until the recent past, there was a political and cultural approach strongly linked to simply conserving the environmental heritage, which has often resulted in an aggravation of restrictions and limitations, which have in turn led to a non-management of forest resources and territory. This attitude is partly due to the insufficient attention once paid to the sustainable use of resources and to the adequate care of the infrastructural works and forest management. As regards accessibility and mobility, in Sardinia, only in 2016 was a local law enacted that recognizes the importance of forest roads for an adequate management of forest areas, as well as to guarantee access to vehicles for fire prevention and extinguishing [31]. The development of all forestry chains, and among these the structural timber chain, depends on the creation of proper infrastructures and adequate forest road networks, which should have the general goal of maintaining forestry territory and not of modifying the landscape, as it would be functional to guarantee active protection of the territory and landscape, and prevention and intervention against natural and anthropic risks. Forest management not oriented toward production has repercussions on the quality of the logs, often unsuitable for structural use due to the high degree of defectiveness, in particular knots in the Maritime Pine. The increase in yield percentages for the Sardinian Maritime Pine, therefore, appears to depend on the possibility of reducing the extent of the knot defect. To obtain this result, two strategies can be adopted:

- Preventive activity, consisting of the management of the forest and of the single tree, aimed at improving the quality of the logs. Attention should be paid to the sowing site, preferring sheltered slopes, to the spacing between the plants, and to the cleaning of the tree from any suckers and incipient branches during its growth.
- Postponed activity, consisting of procedures, such as cutting of boards' defective parts and joining of healthy parts, capable of eliminating defects from the boards. Obviously, these procedures must consider the dimensional reductions that the board undergoes following the cutting of the defective parts, which could lead to board lengths not suitable for manufacturing laminated timber.

Another element of weakness of the system is given by the connotation of the companies (small and artisanal, mainly family-run) that operate in the first and second processing of wood (sawmills, carpentry, etc.). Companies are very small in size, poorly mechanized, and equipped with inadequate technological equipment. Machines for cutting wood are often insufficient to produce structural elements (boards, strips), having dimensions and volumes suitable for the needs of industrial production, and throughout the region, there is not any drying system suitable for the artificial seasoning of wood to be used for structural uses.

These weaknesses, combined with the difficulty in sourcing raw materials, determine poor competitiveness and dependence on foreign markets for the supply of semi-finished and finished products.

3.4. How to Support the Feasibility of the Supply Chain

As highlighted in the previous discussion, the main factors that currently hinder the development of the structural timber production chain are (i) forest management and (ii) technological and organizational inadequacy.

Forest management could be upgraded by improving forest roads, reorganizing forest property, mapping forestry areas to be aware of the potential production volume, and raising the awareness of landowners, through their involvement in the management of first wood processing. Forestry companies, currently few and small, could be encouraged to set up a business network to manage larger construction sites and offset costs, and to achieve product certification. First and second processing companies, affected by the very small size, insufficient mechanization, difficulty of finding local raw materials and semi-finished products, and burdened by foreign competition, could be supported by centralizing the most demanding technological operations, such as drying and industrial sawmill, through the creation of technological hubs available to interested companies. All involved companies should be supported through proper professional development. The regulatory framework should be completed and improved by streamlining bureaucratic procedures in the context of simplified planning, authorization, and sales procedures. Policies could be implemented to facilitate meeting the supply and demand with incentives that reward the use of local wood in public tenders. In all cases, the intervention of the public administration is necessary and indispensable.

Some similar studies carried out in other regions of the Italian territory [32,33] support the previous suggestions and help summarize the measures useful to trigger or improve the supply chain in the following points:

- Improvement of forestry management,
- New production models, including associative and sharing models, both in first and second wood processing,
- Technological innovation, especially in second processing,
- Valorization of waste for secondary uses, such as non-structural construction, road paving, furniture, and energy,
- Support to companies in forestry, environmental, and product certification processes.

The implementation of a sustainable local production chain for structural timber would be part of the enhancement of the forest–wood system. The system cannot be based only on the market and on unstructured policies, but it should focus on fostering strategies that involve both the public and private operators. In fact, despite the critical issues that have emerged, the Italian wood production chain is currently a resource for the country and presents ample opportunities for growth and development as well, and above all, in territories such as Sardinia, burdened by the gap of the condition of insularity, and traditionally disadvantaged from the perspective of development and employment.

4. Conclusions

This paper described a research activity aimed at analyzing the possibility of implementing a sustainable local supply chain in Sardinia to produce CLT panels made of locally grown timber. Since there is currently no structural timber production chain in Sardinia, the research experimentally implemented all the segments of the production chain process, obtaining the following results.

First, the mechanical performance of CLT panels made of Sardinian Maritime Pine was determined. This wood species is of medium–low quality compared to those traditionally used to produce laminated timber, but its use as CLT allows the manufacturing of structural elements with a mechanical performance comparable to those of typical CLT panels already present in the market. The comparison between the mechanical performance of CLT commercial panels and Sardinian Maritime Pine CLT panels showed that, although the latter had a lower Effective Bending Stiffness, the increase in the thickness of the panel by 10–15 mm allowed obtaining the Effective Bending Stiffness of the commercial panels without affecting the weight, given the low density of Sardinian Maritime Pine.

Furthermore, an analysis of the critical issues that currently hinder the implementation of the structural timber production chain in Sardinia was carried out. Obstacles are mainly linked to forest management that is not properly oriented and to the technological and organizational inadequacy of local companies. From the analysis, some possible measures for fostering the feasibility of the supply chain have been proposed. The measures are mainly based on the enhancement of the role of the public administration, which should become proactive in the search for solutions and in the implementation of instruments aimed at promoting the supply chain system, such as active forest management, strategic coordination between sectors of the supply chain, and scientific, technological, and commercial support to the companies involved.

The proposed research examined, for the first time in an organic and structured way, the feasibility of the local supply chain to produce Sardinian structural timber, highlighting its strengths and weaknesses and providing the tools for its implementation.

The local production of structural elements made of locally grown timber, besides the environmental benefits linked to wood properties, would bring ecological, social, and cultural advantages, such as better forest management and new job opportunities related to timber production, processing, and construction. These aspects are of paramount importance in isolated economies such as islands and become crucial in disadvantaged regions, such as the inner parts of Sardinia, currently prone to depopulation and a decline in rural land.

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