*Publishing Series in* PROJECT | Essays and Researches
On Sustainable Built Environment
between Connections and Greenery
vol. 07 | 2022 | paper 10 | pp. 172-191

ISSN (print): 2704-6087
ISSN (online): 2704-615X
ISBN (print): 978-88-5509-445-0
ISBN (online): 978-88-5509-446-7

# THE PROMOTING OF SHORT SUPPLY CHAIN WOOD PRODUCTS PROTECTING BIODIVERSITY

Tiziana Ferrante, Teresa Villani

section
Architecture

typology
Research & Experimentation

DOI
doi.org/10.19229/978-88-5509-446-7/7102022

Abstract
The Italian forest area, about 40% of our territory, represents a resource that requires sustainable management plans focused on the protection of biodiversity, with timber for the construction sector coming as much as possible from native wood species, exploiting the opportunities offered by the forest bio-economy. The paper starts from the national wood supply/demand gap and presents a survey of local species potentially usable for Vertical Perimeter Walls with exposed wood. Analysis and evaluation of the case study solutions adopted in buildings that foresaw the use of short supply chain species for the external and internal cladding layers in line with sustainability criteria and functional and architectural characterisation (Availability, Recyclability, Integration Maintainability and Appearance). The structure of a multi-criteria analysis to apply to them, providing relevant references for developing a 'repertoire of technical solutions' of Vertical Perimeter Walls, as a tool for making sustainable design choices.

Keywords
forest bio-economy, biodiversity, wood technology, short supply chain products, vertical perimeter walls

**Tiziana Ferrante**, Architect and PhD, is a Full Professor in Technology of Architecture at the Department of Planning Design Architecture Technology of the 'Sapienza' University of Rome (Italy). She conducts research and experimentation on the themes of design quality in the building process in terms of process and product innovation in planning, programming, design and evaluation in the operational phase for health and social services. She participates as an Expert in institutional commissions for project evaluation, drafting of guidelines and technical regulations. E-mail: tiziana.ferrante@uniroma1.it

**Teresa Villani**, Architect and PhD, is an Associate Professor in Technology of Architecture at the Department of Planning Design Architecture Technology of the 'Sapienza' University of Rome (Italy). She carries out research activities mainly in the field of building quality control through methods of detection and performance evaluation of the technological components of buildings and tools for the technical control of the project. Mob. +39 349/59.50.221 | E-mail: teresa.villani@uniroma1.it

The scientific community has been studying the anthropogenic impact on biodiversity and natural systems for decades and, particularly in recent years, is increasingly mobilising to propose solutions to reverse the biodiversity loss curve (WWF, 2020). The protection of ecosystems and biodiversity plays a crucial role in implementing the European sustainable growth policy in the context of the European Green Deal (European Commission, 2019). The European strategy fits into the global context outlined by the 2030 Agenda for Sustainable Development (UN, 2015) whereby the achievement of environmental (biosphere) goals is considered a necessary condition to achieve all others (Folke et alii, 2016). The new European Biodiversity Strategy 2030 Bringing Nature Back into Our Lives (European Commission, 2020), stems from these considerations, a highly renewed instrument whose pillars pay particular attention on areas with high biodiversity potential. The forests, as carbon-rich ecosystems, with a commitment to increase their extent, quality and resilience by 2030, respecting ecological conditions consistent with native woody flora and local natural vegetation potential. Enhancing timber supply chains and incorporating these resources into the bio-economy ensure economic growth and the satisfaction of social needs through the sustainable use of renewable biological resources (European Commission, 2012).

Forests, wood and other services and products from forest ecosystems (forest bioeconomy), recognising them as fundamental tools for mitigating global climate change, represent an essential resource in our country. Italians' forests are among the richest in biodiversity in Europe; they have recently become part of a Sustainable Forest Management (SFM) process and a crucial ecological 'rewilding' phase, leading to the doubling of our forest area to about 12 million hectares, or almost 40% of the national territory. As a result, the mitigation role of Italian forest ecosystems has increased positively, storing about 4,5 Gt of $CO_2$, and absorbing 12% of all Italian emissions annually (Comitato Capitale Naturale, 2021). Despite occupying 40% of the national territory, timber harvesting is far below the EU average and far below the growth and ecological productivity of our forests. They contribute only 0,08% of GDP, a figure that only partly reflects what our forests can be used for, considering the enormous potential of wood utilisation in the construction sector (Osservatorio per il Capitale Naturale, 2020).

National forest planning, although virtuous, shows a timber harvest for the construction sector that is very low compared to European standards. The result is a gap between the import and export of timber products for structural and non-structural use, especially for the timber construction market, which maintains a growing trend[1] also thanks to a more widespread and consolidated technical knowledge (Ferrante, 2008), but which goes along with the prevalent use of fir. This sector is still too much characterised by spruce products from the sometimes indiscriminate use of central European forests.

Promoting a short supply chain (Scarascia Mugnozza et alii, 2019), using only the species that are most widespread in our country, might contribute to activating virtuous

**Fig. 1** | Pizzolato Winery in Villorba (Italy), designed by Made Associati (2013-2016). In this project, the use of beech wood for the building's cladding and external flooring was experimented with in an ecological way. This is PEFC-certified wood from the nearby Cansiglio beech forests. The wood was left natural for the floors and furniture (about 1,500 square metres), while for the exterior cladding it underwent a thermo-baking treatment that makes it more resistant to atmospheric agents, without precluding its recycling at the end of its life (credit: madeassociati.it, 2019).

**Fig. 2** | Cetic Offices in Châlon sur Saône (France), designed by Atelier Architecture (1972). For the external cladding of the building, strips of heat-treated local poplar were used to improve durability and give the grey colour, a guarantee of colour uniformity in anticipation of ageing (credit: le-gallee.fr, 2019).

mechanisms for the forest-timber supply chain in view of a circular bio-economy (Hetemäki et alii, 2017), generating economic resources for local territories and allowing the establishment of wood industry clusters, business networks and consortia, while responding to the environmental emergency with actions appropriate to the ecological transition. Detailed forestry planning capable of enhancing our utilisation of wood for non-structural use is in line with the protection of natural capital, ecosystems and biodiversity, as well as promoting excessive forest cover monitoring (Fares et alii, 2015) as one of the causes of the fragility of territories towards extreme climatic events.

This paper intends to present the results of the research funded by the PRIN 2015 entitled 'The short supply chain in the biomass-wood supply chain: supply, traceability, certification and carbon sequestration – Innovations for green building and energy efficiency' (Scarascia Mugnozza et alii, 2021), which promoted the use of short supply chain species for the revitalisation of local production through the multidisciplinary contributions of the fields of forest ecology and silviculture together with those of structural engineering and architectural technology. It shows the potential of using 'exposed wood' in buildings (Figg. 1, 2), In the study of tools to aid sustainable design choices and in the proposal of a repertoire of technical solutions for the finishing of Vertical Perimeter Walls (VPWs) made of wood or wood derivatives, the research group of the Sapienza University of Rome uses products made of short supply chain species.

The focus on VPW as a symbiotic integration between natural materials/products and the building identifies a field of investigation to illustrate application possibilities and criticalities of wood products. A dimensional development, a substantial part of the building, for the functions performed, highlights the technical issues related to durability (Paoloni, Ferrante and Villani, 2018), as well as represent the principal architectural characterisation of the building. For this purpose, VPW solutions with wood cladding applied in many recent buildings were assessed with respect to several significant criteria of quality in terms of sustainability (Findability of the wood species, Recyclability) and functional as well as architectural characterisation of the building (Integration, Maintainability, Appearance).

Subsequently, for an objective comparison of the solutions themselves, we performed a multi-criteria evaluation to weigh the quality of the technical solutions adopted with respect to each criterion and as a whole. The assessment adopted for the case studies has allowed the structuring of a repertoire of technical solutions with reference to the external/internal cladding of VPW, to promote the innovative use of products obtained from the processing of short supply chain species (beech for interiors and chestnut, poplar, local pine for exteriors) to illustrate the performance of the different functional models, the material compatibility between components, their durability and recyclability. Considering that each design context requires to relate to specific locational, functional, performance and architectural factors, the repertory intends to provide clients, designers and operators in the sector with an initial structured set of technical solutions for the choice of VPW cladding and the possible use of local woods of proven technical and morphological quality.

**Short supply chain and quality assessment of technical solutions for Vertical Perimeter Walls: case studies** | To promote innovative and rational use of wood species from the local forest heritage[2], in addition to supporting the eco-systemic conversion of our construction sector, it was first necessary to proceed with a survey of the most widespread wood species on the national territory[3], and analyse their main characteristics for use in wall cladding components. During the first stage of the research, properties and characteristics of native species such as chestnut, beech, local pine and poplar were defined, adopted in many case studies analysed, their respective territorial diffusion, and their possible use for VPW 'visible' claddings (Tab. 1).

Given this analysis, the second stage concerned the search for architectural constructions requiring interior and/or exterior cladding layers to use the identified species, with particular emphasis on those examples where the woods had a local provenance. To highlight the expressive possibilities of the application of wood claddings, the case

| SPECIES | SPREAD | FEATURES | USES IN EXTERNAL WALLS |
|---|---|---|---|
| 'Chestunt' | It is found along the entire Alpine arc up to altitudes of 800-900 m above sea level, along the Apennine ridge as far as Calabria, in Sicily on the slopes of Mount Etna and in Sardinia | A tree species native to Mediterranean countries, it can reach a height of 10/30 m<br>Mass density: 530kg/m$^3$<br>Durability: class 2<br>Hardness: 18 N/mm$^2$<br>Use: class 3<br>(outdoor, not in contact with the ground)<br>Shrinkage: medium-low<br>Dimensional stability: good | Due to its durability and resistance to humidity, it is very well suited for both exterior and interior cladding elements, mainly used in planks and beads, without the need for special treatments |
| 'Beech' | It is among the most widespread species in Italy. Beech is most widespread in the regions of Abruzzo, Emilia Romagna and Liguria<br>High forests are more widespread in the south, while in the north coppices, largely initiated or in the process of being initiated into tall trees, account for almost all over-grounds | In closed stands, with a high crown, the beech reaches up to 35 m in height<br>Mass density: 680kg/m$^3$<br>Durability: class 5<br>Hardness: 34 N/mm$^2$<br>Use: class 2<br>(indoors or under cover)<br>Shrinkage: marked<br>Dimensional stability: low | Its use in solid wood is found exclusively for interior cladding. More widespread is its use in plywood panels for wall panelling, furniture<br>If suitably treated (thermo-treated) it can also perform well in exterior applications. Surface treatments allow for numerous varieties of colouring |
| 'Larch Pine' | It is most widespread on the Silan Plateau in Calabria, but large quantities can also be found in Sicily and Corsica | An evergreen tree, it usually reaches a height of 20-25 m, and only occasionally can grow to 40 m<br>Mass density: 760kg/m$^3$<br>Durability: class 4-5<br>Hardness: 25 N/mm$^2$<br>Use: class 4 (outdoor)<br>Shrinkage: Medium-low<br>Dimensional stability: medium-low | It is a difficult wood to process<br>It is used in structural elements (especially glulam and CLT) in reconstituted particle boards<br>Some innovative production lines offer cladding elements (staves, beads, boards) made of charred pine wood in a single ply (18-20 mm) or 3-ply (20-25 mm) |
| 'Poplar' | It is very widespread in the Po Valley area, but also in Lombardy, Piedmont, Veneto and Friuli Venezia Giulia | Poplars range in height from 15 to 30 metres and more, with trunks that can exceed 2.5 m in circumference; very workable softwood<br>Mass density: 480Kg/m$^3$<br>Durability: class 5<br>Hardness: 11 N/mm$^2$<br>Use: class 1 (interior, dry)<br>Shrinkage: low<br>Dimensional stability: good | Its widespread use can be found in the production of plywood and multilayer panels for interior cladding. Due to thermo-treatment at temperatures between 180 °C and 200 °C, its ability to be exposed outdoors can increase significantly. For interior cladding, poplar bark is also widely used |

study selection process drove the desire to illustrate the morphological-formal aspects as well as the technical and functional characteristics of the cladding systems for VPWs, highlighting how the solutions employed envisaged the use of certain wood species within the scope of their peculiar features and/or criticalities (cf. use of woods with low durability levels and the need for prior treatment to be exposed outdoors). In many cases, great attention is paid to the use of wood from neighbouring supplies, alongside a design development of technical elements coordinated with local wallcovering manufacturers.

The selected projects include different climatic zones, where thermal and hygrometric variations, atmospheric precipitation and winds were studied as the principle agents to consider the design of VPW solutions involving exposed wood. Various uses were also examined to demonstrate the versatility of the claddings (Figg. 3-5), with a particular interest in public works, in view of the incentive of the NAP GPP – National Action Plan on Green Public Procurement (MATTM, 2007), which has given rise to many initiatives in the field of timber architecture. In particular, the collection activity concerned approximately 50 works intended for various functions (schools, health facilities, office buildings, collective residences, hotels, museum facilities, etc.), built in the last 10 to 15 years, considering this a sufficiently large period in which to assess the durability of the claddings applied.

To obtain a comparison as homogeneous as possible between the various cases examined, we set up a structured data collection method that, starting from general information (so as to allow for the correct framing of the set of design choices based on the climatic zone and context conditions), goes on to investigate the specific construction solutions adopted for the VPWs and the technical characteristics of the individual wood and/or wood-derived components making up the organisation of the functional layers. The data collection on the case studies was necessary to ‘abstract’ the properties and characteristics that enabled the realisation of the timber structures and to appreciate the technical choices through the systematisation of quality indicators.

In the third phase of the research, we then defined some qualitative criteria to evaluate the solutions to highlight the possibilities of using timber wall claddings. These Criteria emphasised different aspects of the performance response of wood applications in cladding solutions: a) environmental and economic sustainability with Recoverability and Recyclability criteria; b) functional and architectural character of the building with the criteria of Maintainability, Integration and Appearance.

More specifically, Availability is related to the raw material and the products to use in the construction solutions (first, second and subsequent processing products, distribution systems, etc.), as well as local know-how and technical capacities for installation, maintenance, recovery and end-of-life. Recyclability is less to do with the raw

**Tab. 1** | Characteristics of the main Italian wood species potentially usable in external wall solutions (source: National Inventory of Forests and Forest Carbon Sinks; credit: Research Group elaboration, 2020).

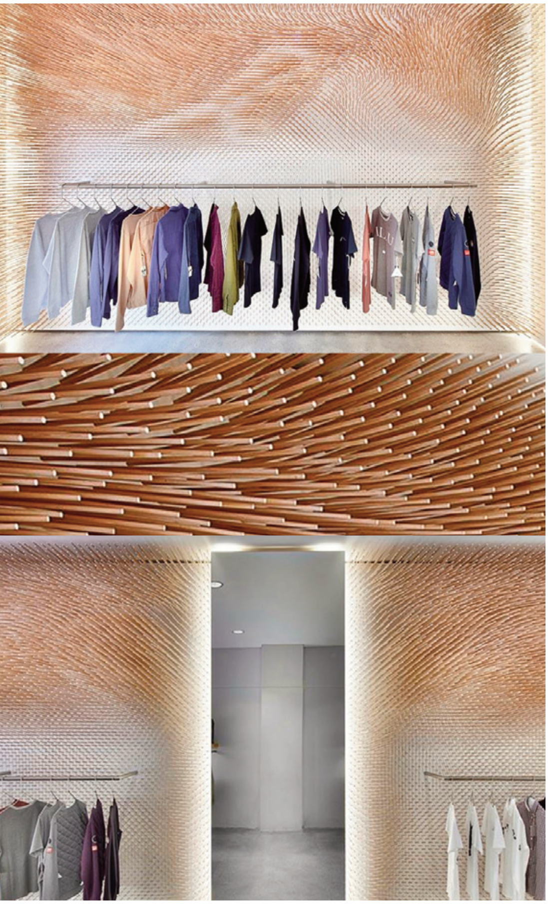


**Fig. 3** | New Damiani Holz headquarters in Bressanone (Italy), designed by Modus Architects (2011). External cladding in Kerto elements fixed on an OSB layer and shaped using CNC techniques; for the interiors, some rooms were designed to leave the XLam panels of the load-bearing structure visible, working with milling techniques (credit: A. Merotto, 2020).

**Fig. 4** | Norwegian Wild Reindeer Centre Pavilion, designed by Snøhetta, 2011. Part of the exterior and interior cladding is pine. The exteriors were treated with pine tar, while the interior wood was oiled; Hardangerfjord shipbuilders made organic shapes from digital 3D models interoperable with milling machine software; the connections between the elements are all-wood with pegs (source: snohetta.com, 2018).

**Fig. 5** | MRQT Boutique in Stuttgart (Germany), designed by Studio Rok (2013). Interior cladding made from a texture of 22,000 beech wood sticks; the holes on the backing layer were made with CNC machines defining the precise direction of each stick; the extension of the wooden sticks in various directions and of different lengths create a fluid form (source: rok-office.com, 2018).

material wood, which is characterised by many recycling possibilities, than with how the components of functional layers are connected and how treatments of layers visible on the outside might compromise disassembly and reuse. Serviceability, relating to Life Cycle Thinking logic, refers to the durability and reliability of wood products, to the use of solutions already in the design phase, which have foreseen the performance efficiency and possible maintenance activities (treatments, replacement, etc.). Integration relates to connections of the functional layers of the VPW and links between them and other technical elements of the building system (horizontal closures, fixtures, false ceilings, etc.), structural and plant engineering elements, with reference to the inspectability of the parts; integrability with furniture and/or equipment elements (fixed furniture, wooden panelling, etc.) is considered for interior claddings. The criteria of appearance for VPW claddings embrace a broader spectrum of characteristics referring to the peculiar colours of the chosen wood species, dimensional stability, and the ability to maintain the required performance over time, and also considers morphological features, the arrangement of cladding elements, architectural integration with other materials, etc.

For each criterion, we defined possible qualitative evaluation ranges (from low to very good; Tab. 2) to select, from the broad range of national and international realisations analysed, the study cases providing as complete an overview as possible of the application opportunities of timber VPWs due to climatic conditions, exposure and technical solutions. As a result of the analysis and evaluation of the case studies concerning the criteria described above, two types of files are systematically compiled (Figg. 6, 7).

The first one illustrates the general characteristics of the intervention and the solutions adopted for the use of exposed wood: a) framework of the work and all the construction, structural and plant engineering aspects and a summary description to highlight the use of wood and/or wood-derived products; b) definition of the VPW functioning scheme (based on the case studies analysed, three functional models emerged: wall insulated from the inside, wall insulated from the outside, and ventilated wall). The second describes the technical solution adopted, according to criteria identified: a) identifying and analysing functional layers and their components, material and performance characteristics required in compliance with the technical regulations in force; b) technical-performance analysis of the elements: based on the information found for each of the functional layers of the VPW, general performance is described with reference to the products used; c) evaluation of the technical-constructive solution according to qualitative criteria (Availability, Recyclability, Integration, Maintainability, Appearance) according to the ranges identified. The analysed solutions were then subjected to a Multi-Criteria Analysis to provide a further, more objective level of evaluation to support the qualitative considerations defined in the first analysis.

**The Evaluation of Technical Solutions for Vertical Perimeter Walls: Design Alternatives and Multicriteria Analysis** | In the development of the design process and in

| CRITERIA | DESCRIPTION | IDENTIFIED QUALITY LEVELS |
| --- | --- | --- |
| AVAILABILITY | The issue of availability is linked to both the raw material and the products to be used in construction solutions (industrial processing, distribution, etc.), as well as to the local technical capabilities for processing, installation and maintenance, and the possibilities of recovery at the end of life. The choice of local wood implies the acquisition of local know-how on application possibilities, processing, and treatment of visible components | Low: imported material<br>Sufficient: local material<br>Good: local material with LCA assessment<br>Very good: local material with adequate characteristics in terms of use and durability |
| RECYCLABILITY | Wood is a completely recyclable material, so the end-of-life of a technical wooden element can present many possibilities for recovery, manifesting itself as a valuable resource in many areas<br>During the design phase, it is essential to define the organisation of the different functional layers according to the external wall functional model adopted, as well as the connection methods between the layers and the surface treatments applied to the outermost layers that guarantee the disassembly/recovery of the individual elements for their possible reuse | Low: non-recyclable material<br>Sufficient: generally recyclable material<br>Good: LCA of product and use of a relevant percentage of recycled<br>Very good: technical elements that can be dismantled and recovered |
| INTEGRABILITY | Integration between functional layers, referring to the number, quality, and manner of connections<br>Integrability of the external wall with the other technical elements of the building organism (horizontal closures, fixtures, false ceilings, etc.) as well as with the structural and plant-engineering elements, referring to the inspectionability of the plant passages and the ability not to interfere with the load-bearing characteristics of the structural elements<br>Integrability of furniture and/or equipment elements, especially with regard to interior cladding | Low: problematic connections and poor inspectionability<br>Sufficient: good connections but inspectionability not guaranteed<br>Good: widespread integrability (connections, inspectionability, coordination, etc.)<br>Very Good: total integration between elements |
| MAINTAINABILITY | The maintainability criterion is profoundly linked to Life Cycle Thinking, in that it obliges the designer to foresee the criticalities of the use and management phase of the system, implementing design solutions aimed at minimising the impact of maintenance activities<br>The maintainability criterion of external walls is declined according to the performance efficiency of the elements and is therefore linked to the durability (useful quality: maintenance of quality over time) and reliability (probability that the spontaneous lifetime of a component is actually such) of the designed systems | Low: poor durability of the solution as a whole<br>Sufficient: treatments to improve the durability of the material, but difficult maintainability/replaceabiliy of the element<br>Good: adequate treatments, maintainability of the element<br>Very Good: adequate treatments, serviceability in situ, disassembly |
| APPEARANCE | The appearance criterion is particularly linked to the cladding layers (external and internal) to be interpreted as the overall quality of the technical solution, together with the material quality of the specific wood species applied<br>Characteristics of the wood species used: the ability to maintain its own characteristics such as colour, consistency, dimensional stability, etc. over time<br>Characteristics of the technical element: the ability to maintain the required performance over time, the quality of the connections between the different elements, the technical solutions for defining the critical points (ground connection, roof connection, connection with fixtures, etc.) | Low: inadequate wood quality for the technical solution<br>Sufficient: good quality of the species and geometr of the technical element<br>Good: quality of details for connections and critical points<br>Very Good: particular relevance of the technical solution |

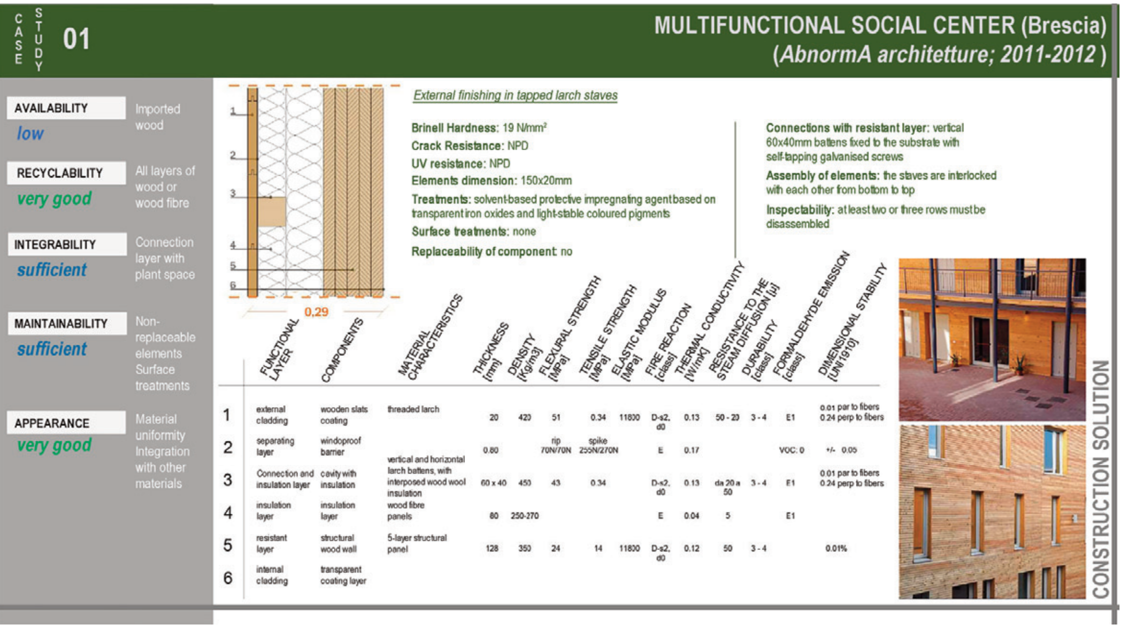
**Tab. 2** | Evaluation criteria for external wall solutions (credit: Research Group elaboration, 2020).

an overall vision of the project to ensure its overall quality, the technical and economic feasibility phase is enriched (increasing its operational complexity) by decision-supporting assessments (MIMS, 2021). These assessments can cover different aspects of the project (environmental, technological, economic, managerial, etc.) with the help of specific analytical tools (Fattinnanzzi and Micelli, 2019). Multi-Criteria Analysis (MCA) methodologies are a particularly appropriate and sufficiently rapid tool for structuring the decision-making phase of the designer and have long been used in evaluations of the sustainability and overall effectiveness of architectural works (Ogrodnik, 2019). Their applicability to the assessment of building technologies and especially efficiency in façade design is relatively recent (Moghtadernejad, Chouinard and Mirza, 2018).

In the fourth research phase, we used the Analytic Hierarchy Process (AHP), relying on a range of pairwise comparisons for each hierarchy level (goal; criteria, sub-criteria; alternatives to be tested). Each matrix generated by the pairwise comparison results in scores given by the sum of the comparisons (Al-Saggaf, Nasir and Hegazy, 2020). To assess the overall quality of the design solutions adopted in the case studies for the cladding layers (external and internal) with the use of short-chain wood, we identified the different levels of the hierarchy, the weights attributed over several criteria and sub-criteria were indicated, obtained using a pairwise comparison carried out for each criterion, highlighting for the sub-criteria the importance with respect to the objective and with respect to the reference criterion (Fig. 8).

To increase the effectiveness of the comparison, we defined a balanced number of sub-criteria (max 3 o 4); studies showed that considering less than 3 sub-criteria would lead to an imbalance of the sub-criteria; equally unbalanced would be the distribution of the criterion weight over an excessive number of sub-criteria, leading to them assuming a roughly similar value. Weight assignment took place after numerous analyses of the data from the case studies examined, direct interviews with designers and technicians from the production sector and companies, trying to make even very inhomogeneous data comparable in terms of description and method of measurement, comparing qualitative and quantitative elements. Subsequently, a series of possible pairwise comparisons for each level of the hierarchy came about: 1) the pairwise comparison matrix was drawn up for every criterion, arranging the relative sub-criteria (the sum up of the weights for the sub-criteria of each criteria, must always give 1.00); 2) to the overall target, it arranged the 5 criteria previously described in the qualitative evaluation (the sum up of the weights of the criteria describing the target must always give 1.00).

Considering that the different criteria and sub-criteria are hardly comparable since they are defined by heterogeneous measurement scales (qualitative or quantitative), it required a normalisation process to bring them onto a common scale and to make the necessary comparisons; a-dimensional indexing made it possible to compare the different evaluation elements (Della Spina, 1999). Case studies were analysed using pairwise matrices for each sub-criterion, whose weight is already standardised to that of the reference criterion and the objective. To complete the assessment, a synthesis of judge-

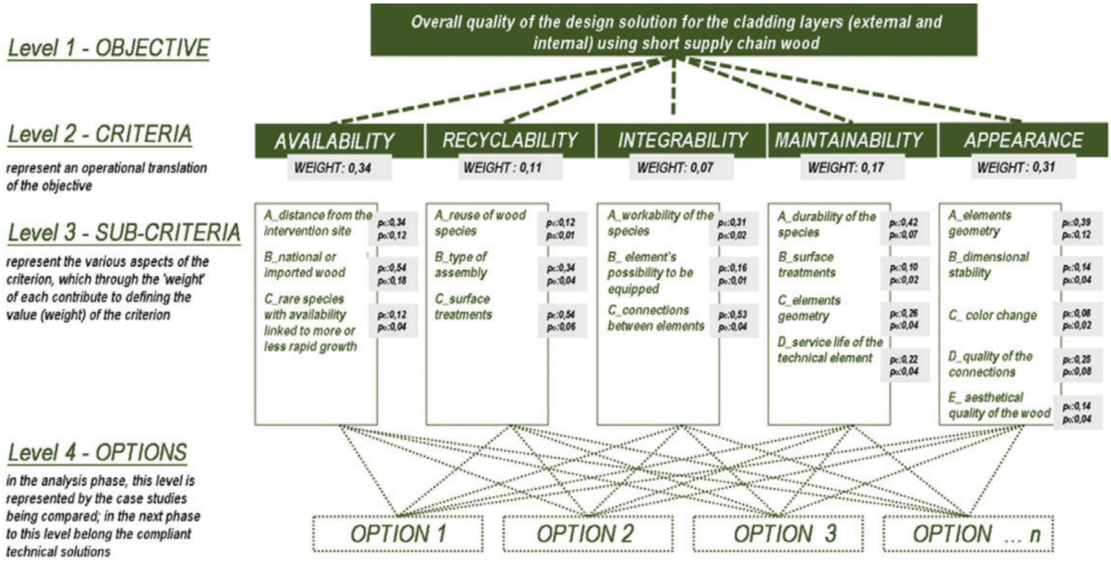




| | FUNCTIONAL LAYER | COMPONENTS | MATERIAL CHARACTERISTICS | THICKNESS [mm] | DENSITY [Kg/m3] | FLEXURAL STRENGTH [MPa] | TENSILE STRENGTH [MPa] | ELASTIC MODULUS [MPa] | FIRE REACTION [class] | THERMAL CONDUCTIVITY [W/mK] | RESISTANCE TO THE STEAM DIFFUSION [μ] | DURABILITY [class] | FORMALDEHYDE EMISSION [class] | DIMENSIONAL STABILITY [UNI1910] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | external cladding | wooden slats coating | threaded larch | 20 | 420 | 51 | 0.34 | 11800 | D-s2, d0 | 0.13 | 50 - 20 | 3 - 4 | E1 | 0.01 par to fibers 0.24 perp to fibers |
| 2 | separating layer | windoproof barrier | | 0.80 | | rip 70N/70N | spike 255N/270N | | E | 0.17 | | | VOC: 0 | +/- 0.05 |
| 3 | Connection and insulation layer | cavity with insulation | vertical and horizontal larch battens, with interposed wood wool insulation | 60 x 40 | 450 | 43 | 0.34 | | D-s2, d0 | 0.13 | da 20 a 50 | 3 - 4 | E1 | 0.01 par to fibers 0.24 perp to fibers |
| 4 | insulation layer | insulation layer | wood fibre panels | 80 | 250-270 | | | | E | 0.04 | 5 | | E1 | |
| 5 | resistant layer | structural wood wall | 5-layer structural panel | 128 | 350 | 24 | 14 | 11800 | D-s2, d0 | 0.12 | 50 | 3 - 4 | | 0.01% |
| 6 | internal cladding | transparent coating layer | | | | | | | | | | | | |

**Figg. 6, 7** | Analysis sheets and first evaluation of the case studies (credits: Research Group elaboration, 2019).

*Next page*

**Fig. 8** | Diagram of the hierarchies between the levels of the Multicriteria Analysis adopted (credit: Research Group elaboration, 2020).




ments was carried out, where the scores of each case study were multiplied by the weight assigned to the criteria and based on this synthesis, the case studies themselves were progressively ranked. To better understand the applied methodology, we provide an AHP application to five case studies as an example (Fig. 9), considering those that offer the highest differences in the use of wood for the VPW cladding layers. The examples are described as a whole of the construction solution adopted for the VPW, down to the analysis of the external cladding layers to which AHP is applied (Fig. 10).

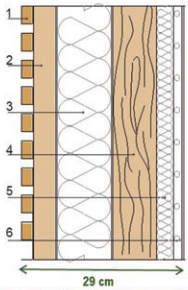
It can be seen from the values shown in the figure how, in general, case study 1 (Woody, Saint Maurice, 2019) is of a higher quality than the others, although it shows low values in recyclability, due to the numerous individual elements (shingles) each fixed with metal connections that make disassembly difficult. While the case study 5 (Multipurpose Social Centre, Brescia, 2011-12) presents in general numerous criticalities in all the evaluation criteria, especially on the criteria of Product Availability (from abroad) and Maintainability, due to the way in which the cladding elements are connected to the support layer (unprotected metal connections). Case Study 4 (Municipal Centre in Estonia, 2010), although presenting a low overall assessment, is characterised by high quality in the Appearance criterion, not only due to the particularity of the morphology of the cladding system used but above all due to the way in which it is manufactured and the special colouring treatment of the elements, which mitigates the effect of time on the colour performance and dimensional stability.

Figure 10, therefore, demonstrates the importance of defining evaluation criteria that investigate the different aspects of the technical-constructive and morphological solution of the VPWs cladding, linked to the choice of raw material and products, the construc-

**CASE STUDY 1**

***WOODY – Saint Maurice (FRANCE) (Atelier DuPont; 2019)***

*Client: Santé Publique France*
*Design: Atelier DuPont*
*Quadriplus Groupe (opere strutturali)*
*Surface: 4.270 mq*
*Cost: 10,9 mln di €*

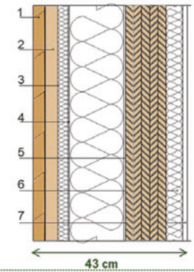



1_External Slavonian oak cladding (2cm)
2_Connection layer with galvanised steel profiles (4cm)
3_Thermal insulation layer made of sandwhich panels (10cm)
4_Wood fibre panel thermal insulation layer (4cm+12cm)
5_X-Lam load-bearing layer (5 layers; 12.8cm)
6_ Internal plasterboard wall with acoustic insulation (5cm+1.25cm)

**CASE STUDY 2**

***KINDERGARTEN (S.Frediano, Settimo) (Colucci & Partners; 2012-2013)***

*Client: Amministrazione comunale di Cascina*
*Design: Colucci & Partners; H.S.Ingegneria s.r.l. (opere strutturali)*
*Realization: Campigli Legnami (Empoli)*
*Surface:740 mq*
*Costi: 1,1 mln di €*

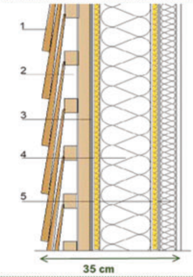



1_ Exterior cladding in larch strips (6cm)
2_ Connecting layer made of untreated larch strips (4cmx4cm)
3_ Wind and UV protection film
4_ Wood fibre thermal insulation layer (4cm+12cm)
5_ X-Lam load-bearing layer (5 layers; 12.8cm)
6/7_ Internal plasterboard wall with acoustic insulation (5cm+1,25cm)

**CASE STUDY 3**

***OFFICE COMPLEX ''TORTONA 37'' (Milano) (Matteo Thun & Partners; 2007)***

*Client: Pioneer Investment Management SRG*
*Design: Matteo Thun & Partners; B.C.V Progetti (opere strutturali)*
*Realization: Di Vincenzo – Mangiavacchi*
*Surface: 25.000 mq*
*Cost: 45 mln di €*

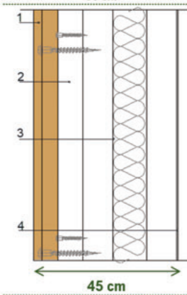



1_Exterior cladding in larch shingles (2cm)
2_Connecting layer made of untreated larch strips (4cmx4cm)
3_Wind and UV protection film
4_Load-bearing layer made of OSB panels and mineral fibre insulation in between (18cm)
5_Internal plasterboard wall with acoustic insulation (5cm+1,25cm), and vapour barrier on OSB board

**CASE STUDY 4**

***MUNICIPAL CENTER IN ESTONIA (Salto Architects; 2004-2010)***

*Client: Someru Parish*
*Design: Colucci & Partners*
*H.S.Ingegneria s.r.l. (opere strutturali)*
*Surface: 2.400 mq*
*Cost: 3 mln di €*

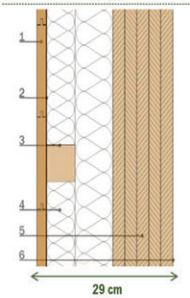



1_Variable-height (5cmx5cm) pine bar covering, attached to the support by means of galvanised steel pins
2_Ventilated cavity (7-9cm)
3_Prefabricated concrete panel (15+15 +12cm) with polystyrene thermal insulation in between
4_Interior finish in enamel paint

**CASE STUDY 5**

***MULTIFUNCTIONAL SOCIAL CENTER (Brescia) (AbnormA architetture; 2011-2012)***

*Committenza: Immobiliare sociale bresciana*
*Design: AbnormA architetture*
*DM Studio (opere strutturali)*
*Surface: 2700mq*
*Cost: 3,9 mln di €*
*Wood elements production: Ka Konstruct*




1_External cladding of tapped larch slats (2cm)
2_Separation layer, wind barrier
3_Supporting substructure for the cladding (6cmx4cm)
4_Thermal insulation layer made of wood fibre panels (8cm)
5_X-Lam load-bearing layer (5 layers; 12.8cm)
6_Interior paint finish layer

| EVALUATION CRITERIA | SUB-CRITERIA | SUB-CRITERIA WEIGHT | | CASE STUDIES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | normalised values from pairwise comparisons matrices | | | | | values compared to the normalised weights of the sub-criteria | | | | |
| | | relative weight on the criterion | total weight on the objective | CASE 1 | CASE 2 | CASE 3 | CASE 4 | CASE 5 | CASE 1 | CASE 2 | CASE 3 | CASE 4 | CASE 5 |
| AVAILABILITY | A_distance from the intervention site | 0,34 | 0,12 | 0,27 | 0,23 | 0,30 | 0,13 | 0,08 | 0,03 | 0,03 | 0,03 | 0,01 | 0,01 |
| | B_national or imported wood | 0,54 | 0,18 | 0,38 | 0,18 | 0,22 | 0,15 | 0,07 | 0,07 | 0,03 | 0,04 | 0,03 | 0,01 |
| | C_rare species with availability linked to more or less rapid growth | 0,12 | 0,04 | 0,32 | 0,26 | 0,20 | 0,15 | 0,08 | 0,01 | 0,01 | 0,01 | 0,01 | 0,00 |
| | **WEIGHT Criterion 1** | | 0,34 | | | | | *EVALUATION Criterion 1* | 0,11 | 0,07 | 0,08 | 0,05 | 0,03 |
| RECYCLABILITY | A_reuse of wood species | 0,12 | 0,01 | 0,33 | 0,31 | 0,19 | 0,11 | 0,07 | 0,005 | 0,004 | 0,003 | 0,002 | 0,001 |
| | B_type of assembly | 0,34 | 0,04 | 0,25 | 0,34 | 0,19 | 0,14 | 0,08 | 0,010 | 0,013 | 0,008 | 0,005 | 0,003 |
| | C_surface treatments | 0,54 | 0,06 | 0,27 | 0,34 | 0,19 | 0,12 | 0,08 | 0,016 | 0,021 | 0,012 | 0,007 | 0,005 |
| | **WEIGHT Criterion 2** | | 0,11 | | | | | *EVALUATION Criterion 2* | 0,031 | 0,039 | 0,022 | 0,014 | 0,009 |
| INTEGRABILITY | A_workability of the species | 0,31 | 0,02 | 0,30 | 0,22 | 0,22 | 0,14 | 0,13 | 0,006 | 0,005 | 0,005 | 0,003 | 0,003 |
| | B_ element's possibility to be equipped | 0,16 | 0,01 | 0,34 | 0,26 | 0,15 | 0,14 | 0,11 | 0,004 | 0,003 | 0,002 | 0,002 | 0,001 |
| | C_connections between elements | 0,53 | 0,04 | 0,30 | 0,26 | 0,19 | 0,13 | 0,13 | 0,011 | 0,010 | 0,007 | 0,005 | 0,005 |
| | **WEIGHT Criterion 3** | | 0,07 | | | | | *EVALUATION Criterion 3* | 0,021 | 0,017 | 0,013 | 0,009 | 0,009 |
| MAINTAINABILITY | A_durability of the species | 0,42 | 0,07 | 0,29 | 0,25 | 0,22 | 0,17 | 0,08 | 0,020 | 0,017 | 0,015 | 0,012 | 0,006 |
| | B_surface treatments | 0,10 | 0,02 | 0,33 | 0,28 | 0,18 | 0,12 | 0,10 | 0,006 | 0,005 | 0,003 | 0,002 | 0,002 |
| | C_elements geometry | 0,26 | 0,04 | 0,34 | 0,27 | 0,22 | 0,08 | 0,09 | 0,015 | 0,012 | 0,009 | 0,004 | 0,004 |
| | D_service life of the technical element | 0,22 | 0,04 | 0,31 | 0,29 | 0,19 | 0,14 | 0,08 | 0,012 | 0,011 | 0,007 | 0,005 | 0,003 |
| | **WEIGHT Criterion 4** | | 0,17 | | | | | *EVALUATION Criterion 4* | 0,052 | 0,045 | 0,035 | 0,023 | 0,014 |
| APPEARANCE | A_elements geometry | 0,39 | 0,12 | 0,33 | 0,19 | 0,13 | 0,30 | 0,05 | 0,040 | 0,022 | 0,015 | 0,036 | 0,006 |
| | B_dimensional stability | 0,14 | 0,04 | 0,33 | 0,11 | 0,19 | 0,27 | 0,09 | 0,015 | 0,005 | 0,009 | 0,012 | 0,004 |
| | C_ color change | 0,08 | 0,02 | 0,31 | 0,16 | 0,17 | 0,28 | 0,08 | 0,007 | 0,004 | 0,004 | 0,007 | 0,002 |
| | D_quality of the connections | 0,25 | 0,08 | 0,36 | 0,13 | 0,24 | 0,21 | 0,06 | 0,028 | 0,010 | 0,019 | 0,016 | 0,005 |
| | E_ aesthetical quality of the wood | 0,14 | 0,04 | 0,36 | 0,26 | 0,19 | 0,11 | 0,07 | 0,016 | 0,012 | 0,008 | 0,005 | 0,003 |
| | **WEIGHT Criterion 5** | | 0,31 | | | | | *EVALUATION Criterion 5* | 0,106 | 0,053 | 0,055 | 0,076 | 0,020 |
| | | | | | | | | *TOTAL EVALUATION* | 0,32 | 0,22 | 0,21 | 0,17 | 0,08 |

**Fig. 10** | Summary table of the multi-criteria evaluation developed on the 5 case studies (credit: Research Group elaboration, 2019).

tion method of the cladding system and its behaviour throughout the entire life cycle. Following the application of the AHP for a critical observation/assessment of the case studies, it was possible to identify the performance levels of the different solutions adopted for the wooden claddings based on the criteria of Recoverability, Recyclability, Integrability, Maintainability, and Appearance. The AHP applied to the case studies has highlighted good design and construction practices, correct applications or, in some cases, inadequate performance responses, representing an important reference for an initial structuring of the Repertoire of compliant technical solutions for WPWs with an external and internal facing layer in visible wood, built on Vertical Perimeter Walls whose resistant layer is made of 3 or 5-layer beech X-lam panels (Sciomenta et alii, 2021).

**The construction of a Repertory of possible technical solutions of wood Vertical Perimeter Walls** | The fifth and last phase of the research concerned the elaboration of possible technical solutions of wood claddings to organise the Repertory, highlighting, precisely through the application of AHP, how the use of certain wood species (or wood-derived products) selected from those most widespread in Italy, can be 'guided' in the design phase through conforming solutions. The repertory is structured in macro-groups of solutions that refer to the most widespread functional models of VPWs; each functional model is then proposed with various alternatives for the cladding layers, intervening in the choice of short-chain wood species, wood-derived products, connection systems between the components, the geometric conformation of the elements, the thickness, etc.

*Previous page*

**Fig. 9** | Summary table of the multi-criteria evaluation developed on the 5 case studies (credit: Research Group elaboration, 2019).

| PPV_01 | _A | _a |
|---|---|---|
| Indicates the functional model of the wall | Indicates the arrangement of the cladding elements | Indicates how the cladding is made |
| Specifically, it is a ventilated external wall with an X-lam structure and (external and internal) wood cladding | Specifically, it is a horizontal element arrangement | Specifically, these are staves/tables placed on top of each other |

**Tab. 3** | Identification code key of the Repertory card on the external cladding of external walls (credit: Research Group elaboration, 2020).

| RVI_A | _a |
|---|---|
| Indicates the arrangement of the cladding elements | Indicates how the coating is made |
| Specifically, it is a horizontal element arrangement | Specifically, these are staves/tables placed on top of each other |

**Tab. 4** | Key to the Repertory card identification code for interior claddings of the external walls (credit: Research Group elaboration, 2020).

The repertory is structured in two parts, dividing the technical solutions for external cladding from those for internal cladding. Solutions combinations for the external cladding with different possible options for the internal cladding can then be evaluated for each specific design ‘context’, also depending on the conditions of use of the various rooms. Each technical solution is described by means of two sheets. To facilitate this, each sheet contains an identification code for the solution (Tabb. 3, 4). The first part of the code describes the functional model of the VPW as a whole, in the three main macro-groups: Exterior insulated wall, Interior insulated wall and Ventilated wall. The second part refers more specifically to the arrangement of the wooden elements: horizontal elements, vertical elements, diagonal elements, and single elements (shingles, small panels, etc.). The third part describes how the different elements are arranged in relation to the support layer (overlapping element system, tongue and groove, juxtaposed elements, etc.).

All technical solutions proposed in the Directory feature two sheets: the first illustrates the characteristics of the construction solution of the wooden cladding; the second focuses on the potential/criticality of each material/product that can potentially be used for the specific technical solution, considering short supply chain wood species: larch pine, beech, chestnut and poplar.

Claddings characterised by wood-derived products obtained from the successive processing of veneers, sliced veneers, flakes and particles of short-chain species (WP, C, OSB, KERTO, HPL) were also taken into consideration since for some of the species studied, the use 'au naturel' may entail problems of durability, dimensional stability, etc., while the product derived from the same woods presents better characteristics than the original wood, especially in the case of outdoor exposure. In fact, following discussions with the technical managers of manufacturing companies, it has emerged that there is a considerable diffusion of cladding elements derived from local woods with greater durability; for example, in the case of poplar (a soft, workable, light wood) the market offers products of great interest (plywood, LVL, etc.) suitable for application on walls both indoors and outdoors.

Finally, the sheet shows a summary table with the ratings obtained with the AHP for the various materials/products. As an example, the two descriptive sheets of a Compliant Technical Solution of the Repertory developed for external claddings are shown below (Figg. 11, 12). The AHP, as a support tool for design choices, can be used to make various comparisons: it is possible to compare the applications of various materials/products to a specific technical solution, but it is also possible to compare the different construction methods for the same material/product. The very structure of the Directory highlights strengths and weaknesses for each solution, exposing the different application possibilities of short supply chain woods and leaving the designer, according to his own needs/constraints/objectives, the opportunity to read and use the AHP in the most useful way to provide a concrete aid in the choice of sustainable design alternatives.

The repertory illustrates, for each wood species, the possible methods of use, highlighting, however, greater or lesser applicability of the solutions themselves: for example, in those involving the use of small cladding elements (strips, thin staves, shingles, etc.), the evaluation showed a preference for more workable woods, preferably first-process, as the small dimensions do not allow good yields for wood-derived products. A further point for reflection concerns the variety of surface treatments that can be applied to local woods to improve their ability to resist external agents; in the case of beech, for example, the industry has developed thermo-treatments, treatments based on natural substances and nano-particles to improve its durability (Fioravanti, Goli and Togni, 2019).

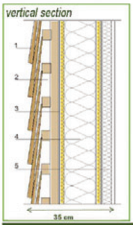
**Conclusions** | As part of the PRIN 2015 research project entitled 'The short supply chain in the biomass-wood sector – Supply, traceability, certification and Carbon sequestration – Innovations for green building and energy efficiency' the structuring of the Repertory represents one of the research products of the group of Technology of Architecture 'Sapienza' University of Rome that has operated within the Operating Unit of the University of Aquila and, as illustrated previously in this paper, not only constitutes a set of technical solutions to guide the design and realisation of claddings for VPWs in visible wood but aims to highlight in a dynamic way how, for each of the solutions presented, the different wood species present in the national territory can be used effectively and sustainably to pursue the technical and morphological quality of the interventions.

## Ventilated façade with X-LAM structure and external cladding in overlapping horizontal elements — PPV_01_A_a

### LEGEND

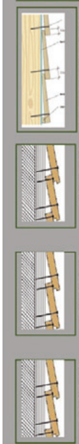
1. External cladding in overlapping horizontal slats, fixed to wooden supports with stainless steel nails
2. Ventilation cavity whose size varies according to height. Inside there are wooden elements (vertical battens) supporting the cladding
3. Thermal insulation layer, the thickness and type of material of which will be chosen according to the thermal analysis of the façade and the location. In the case of a ventilated wall, if you wish to use wood-fibre materials (low or high density), you must take the precaution of providing a protective layer
4. Structural panel in X-LAM with 3 or 5 layers according to structural and/or fire resistance requirements
5. Internal cavity for acoustic insulation and/or passage of equipment
6. Interior cladding mounted on wooden battens, connected to the X-LAM wall by means of elastic clips (60x60mm)

*vertical section*




This horizontal stave solution is shown here in its most common schematic form, but it can present different variants depending on the wood species chosen.
The main strength of the solution is its **maintainability** as the staves can be replaced without the need to work on the entire façade.
The weakest point can be found in the durability of the element, as water flow is interrupted and excessive stagnation on the element due to capillary rise.

### IMPLEMENTATION METHODS



Staves of varying thickness to make the overlap less noticeable.
Fastening is limited to one nail per plank (to be made at least 3.5 cm from the edge).
The correct overlap of the staves is at least 3 cm.

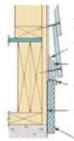
Constant-section slats with double fixings for each slat, one of which is completely hidden by the upper slat.

Constant-section slats with double fixings for each slat, one of which is completely hidden by the upper slat.

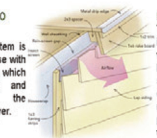
Constant-section slats with double fixings for each slat, one of which is completely hidden by the upper slat.

### CRITICAL POINTS

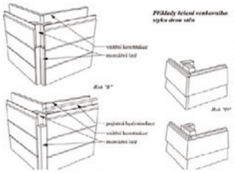
**The organisation of construction solutions will necessarily vary in consideration of aesthetic, functional, etc. reasons.**
**Therefore, the critical points associated with the solution under consideration, which are outlined below, are treated in a general manner and are summarised as types of compliant construction solutions.**



ATTACHMENT TO THE GROUND
The shingle system is closed at the base with a wooden dowel, which in turn seals and protects the waterproofing layer.

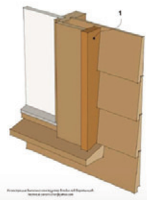


ROOF CONNECTION
The system envisaged includes an edge ventilation, placed between the linear shingles and the frontal closing element of the roof. In this way it remains protected from the weather.



CORNER SOLUTIONS
Depending on the expected aesthetic result, it is possible to work the corners in different ways: either by shaping the cladding elements themselves, or by inserting a vertical closing batten.

WINDOW CONNECTIONS
In this solution, the frame is framed against the wooden cladding, creating a flat closing surface for the linear shingles. In other cases, the addition of this element can be avoided by shaping the window frame itself.



## Ventilated façade with X-LAM structure and external cladding in overlapping horizontal elements — PPV_01_A_a

### MATERIALS

Theoretically, there are numerous application possibilities for timber in horizontal lamella format.
The solutions selected on the side represent those that seem to best meet the characteristics of the building system as a whole

*1_Larch Pine*
In general, it is the material solution with the best characteristics, because it offers a variety of grains and guarantees good maintainability.
Moreover, its availability is reasonably widespread throughout the country.
The multi-criteria analysis, however, does not take into account the specific aesthetic needs that might prefer woods with other colour renditions, which cannot be obtained with treatments on this type of wood.

*2_WPC*
It represents an excellent solution especially in terms of durability and maintainability.
Among wood-derived material solutions, WPC is perhaps the one with the widest range of applications.

*3_Poplar*
Among the most widespread wood species in the country, it certainly presents difficulties in terms of durability, however, thanks to specific treatments, it has also become very popular in recent years in outdoor applications.

*4_Chestnut*
Per la sua colorazione decisa, rappresenta una possibilità applicativa di forte impatto estetico.
Per effetto della sua natura, risulta meno adatto a una lavorazione in elementi sottili, tuttavia, se ben protetti, i singoli elementi possono garantire una notevole durabilità.

*5_Kerto*
A very interesting wood-derived solution, but one that requires more complex processing cycles.
Moreover, due to its characteristics, it is less suitable for application in thin linear staves.

### MULTICRITERIA EVALUATION

The table below illustrates the comparison made between the different material applications.
The evaluations made on the 5 hypothesised solutions, while presenting an objective character of mathematical comparison, leave room for the specific interpretation of the individual application case.

| EVALUATION CRITERIA | SUB-CRITERIA | SUB-CRITERIA WEIGHT: relative weight on the criterion | SUB-CRITERIA WEIGHT: total weight on the objective | CASE STUDIES (wood species used) — normalised values from pairwise comparisons matrices: CASE 1 | CASE 2 | CASE 3 | CASE 4 | CASE 5 | values compared to the normalised weights of the sub-criteria: CASE 1 | CASE 2 | CASE 3 | CASE 4 | CASE 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AVAILABILITY | A_distance from the intervention site | 0,34 | 0,12 | 0,27 | 0,23 | 0,30 | 0,13 | 0,08 | 0,03 | 0,03 | 0,03 | 0,01 | 0,01 |
| | B_national or imported wood | 0,54 | 0,18 | 0,38 | 0,18 | 0,22 | 0,15 | 0,07 | 0,07 | 0,03 | 0,04 | 0,03 | 0,01 |
| | C_rare species with availability linked to more or less rapid growth | 0,12 | 0,04 | 0,32 | 0,26 | 0,20 | 0,15 | 0,08 | 0,01 | 0,01 | 0,01 | 0,01 | 0,00 |
| | WEIGHT Criterion 1 | | 0,34 | | | | | EVALUATION Criterion 1 | 0,11 | 0,07 | 0,08 | 0,05 | 0,03 |
| RECYCLABILITY | A_reuse of wood species | 0,12 | 0,01 | 0,33 | 0,31 | 0,19 | 0,11 | 0,07 | 0,005 | 0,004 | 0,003 | 0,002 | 0,001 |
| | B_type of assembly | 0,34 | 0,04 | 0,25 | 0,34 | 0,19 | 0,14 | 0,08 | 0,010 | 0,013 | 0,008 | 0,005 | 0,003 |
| | C_surface treatments | 0,54 | 0,06 | 0,27 | 0,34 | 0,19 | 0,12 | 0,08 | 0,016 | 0,021 | 0,012 | 0,007 | 0,005 |
| | WEIGHT Criterion 2 | | 0,11 | | | | | EVALUATION Criterion 2 | 0,031 | 0,039 | 0,022 | 0,014 | 0,009 |
| INTEGRABILITY | A_workability of the species | 0,31 | 0,02 | 0,30 | 0,22 | 0,22 | 0,14 | 0,13 | 0,006 | 0,005 | 0,005 | 0,003 | 0,003 |
| | B_ element's possibility to be equipped | 0,16 | 0,01 | 0,34 | 0,26 | 0,15 | 0,14 | 0,11 | 0,004 | 0,003 | 0,002 | 0,002 | 0,001 |
| | C_connections between elements | 0,53 | 0,04 | 0,30 | 0,26 | 0,19 | 0,13 | 0,13 | 0,011 | 0,010 | 0,007 | 0,005 | 0,005 |
| | WEIGHT Criterion 3 | | 0,07 | | | | | EVALUATION Criterion 3 | 0,021 | 0,017 | 0,013 | 0,009 | 0,009 |
| MAINTAINABILITY | A_durability of the species | 0,42 | 0,07 | 0,29 | 0,25 | 0,22 | 0,17 | 0,08 | 0,020 | 0,017 | 0,015 | 0,012 | 0,006 |
| | B_surface treatments | 0,10 | 0,02 | 0,33 | 0,28 | 0,18 | 0,12 | 0,10 | 0,006 | 0,005 | 0,003 | 0,002 | 0,002 |
| | C_elements geometry | 0,26 | 0,04 | 0,34 | 0,27 | 0,22 | 0,08 | 0,09 | 0,015 | 0,012 | 0,009 | 0,004 | 0,004 |
| | D_service life of the technical element | 0,22 | 0,04 | 0,31 | 0,29 | 0,19 | 0,14 | 0,08 | 0,012 | 0,011 | 0,007 | 0,005 | 0,003 |
| | WEIGHT Criterion 4 | | 0,17 | | | | | EVALUATION Criterion 4 | 0,052 | 0,045 | 0,035 | 0,023 | 0,014 |
| APPEARANCE | A_elements geometry | 0,39 | 0,12 | 0,33 | 0,19 | 0,13 | 0,30 | 0,05 | 0,040 | 0,022 | 0,015 | 0,036 | 0,006 |
| | B_dimensional stability | 0,14 | 0,04 | 0,33 | 0,11 | 0,19 | 0,27 | 0,09 | 0,015 | 0,005 | 0,009 | 0,012 | 0,004 |
| | C_ color change | 0,08 | 0,02 | 0,31 | 0,16 | 0,17 | 0,28 | 0,08 | 0,007 | 0,004 | 0,004 | 0,007 | 0,002 |
| | D_quality of the connections | 0,25 | 0,08 | 0,36 | 0,13 | 0,24 | 0,21 | 0,06 | 0,028 | 0,010 | 0,019 | 0,016 | 0,005 |
| | E_ aesthetical quality of the wood | 0,14 | 0,04 | 0,36 | 0,26 | 0,19 | 0,11 | 0,07 | 0,016 | 0,012 | 0,008 | 0,005 | 0,003 |
| | WEIGHT Criterion 5 | | 0,31 | | | | | EVALUATION Criterion 5 | 0,106 | 0,053 | 0,055 | 0,076 | 0,020 |
| | | | | | | | | TOTAL EVALUATION | 0,32 | 0,22 | 0,21 | 0,17 | 0,08 |

### EXAMPLES OF REALIZATIONS

1. Denning House (California) – Ennead Architects
2. Casa bifamiliare privata Mut zur Lücke, Innsbruck
3. Active House – LP Arckitektur
4. Complesso residenziale (Vienna) - Schluder architektur / Hagmüller Architects
5. Ville del Parco Adriano (Milano) – Studio A


**Figg. 11, 12** | Sample sheets describing compliant technical solutions for external cladding of the external walls (credits: Research Group elaboration, 2020).

Starting from the assumption that a sustainable approach to architectural design cannot disregard the consideration of the production sector present in the construction context, the theme of the use of wood species from a short supply chain necessarily entails many evaluations regarding the feasibility of construction solutions that expose wood as the outermost layer of the stratigraphy of the VPWs. Therefore, a fundamental step to screen the proposed solutions is represented by the analysis of many case studies, which also highlighted a strong heterogeneity in the design approach, in the morphological, constructive and material solutions, and allowed to develop a tool for the promotion of short supply chain products and for the choice of design alternatives based on assessments as objective as possible (AHP) to be transferred to the definition of the solutions of the Directory.

However, this promotion has to deal with forest resource supply issues (complex spatial articulation, high planning and management costs, environmental risks) that currently severely limit the use of wood in many Italian regions. For this reason, numerous experiments with innovative systems (GIS technologies, remote sensing, etc.) for the inventory, planning and monitoring over time of wood resources on a local scale are underway. Furthermore, the dissemination of short supply chain wood products must take into account the difficulties in certifying the origin of wood and certification, with protocols currently being tested and the desired establishment of a database on the origin and quality of wood at species and geographical area level still being defined.

In future developments, the repertoire could be implemented and managed by means of computer-based systems capable of allowing a faster application of AHP to the proposed technical solutions with different local wood species, using the identified criteria. While in its current configuration the repertoire requires the external cladding layer to be compared and evaluated separately from the internal one, a future implementation with computer-based tools could manage the evaluation of both claddings at the same time. A repertory of innovative technical solutions thus structured to guide the design of sustainable buildings using wood from the local forest heritage, intervening in the containment of supply chains in the construction sector for which it favours ecosystemic conversion and new employment.

**Notes**

1) For further information refer to the Report Edilizia in Legno (2021) at: federlegnoarredo.it/ContentsFiles/Presentazione%206%C2%B0%20Rapporto%20Edilizia%20in%20Legno.pdf [Accessed 26 July 2022].

2) It should be noted that in our country, for limited local handicraft production, there are production activities linked to native woods; examples are the stone pine works in the Eastern Alps, the cork production and processing industry in Gallura, the use of chestnut in the Apennines, etc.

3) The Italian woodland heritage presents a wide variety of wood species that hint at a concrete

use in the world of construction (both for structural and non-structural use) that is spreading rapidly; an increase in interest in 'wood architecture' is, therefore, to be expected, also as a result of a greater awareness of the sustainable use of wood and the resolution of issues such as supply, traceability, sustainability and energy efficiency of the processing chain; careful attention to the production process of wood-based technical elements, also as a result of an increasingly precise regulatory framework; widespread technical knowledge about the material, its performance characteristics (technological and expressive) and the criticalities to be compensated for; research into treatments to improve its durability.

**References**

Al-Saggaf, A., Nasir, H. and Hegazy, T. (2020), "An Analytical Hierarchy Process-based system to evaluate the life-cycle performance of buildings at early design stage", in *Journal of Building Engineering*, vol. 31, 101364, pp. 1-16. [Online] Available at: doi.org/10.1016/j.jobe.2020.101364 [Accessed 26 July 2022].

Comitato Capitale Naturale (2021), *Quarto Rapporto sullo Stato del Capitale Naturale in Italia*, MiTE, Roma. [Online] Available at: mite.gov.it/sites/default/files/archivio/allegati/CapitaleNaturale/IV_Rapporto_CN.pdf [Accessed 26 July 2022].

Della Spina, L. (1999), *Procedure di valutazione della qualità abitativa*, Gangemi Editore, Roma.

European Commission (2020), *EU Biodiversity Strategy for 2030 Bringing nature back into our lives*, document 52020DC0380, 380 final. [Online] Available at: eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0380 [Accessed 26 July 2022].

European Commission (2019), *The European Green Deal – Delivering on our targets*. [Online] Available at: op.europa.eu/en/publication-detail/-/publication/762414e8-ee81-11eb-a71c-01aa75ed 71a1 [Accessed 26 July 2022].

European Commission (2012), *Innovating for Sustainable Growth – A Bioeconomy for Europe*, document 52012DC0060, 060 final. [Online] Available at: eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52012DC0060 [Accessed 26 July 2022].

Fares, S., Scarascia-Mugnozza, G., Corona, P. and Palahí, M. (2015), "Sustainability – Five steps for managing Europe's forests", in *Nature*, vol. 519, pp. 407-409. [Online] Available at: doi.org/10.1038/519407a [Accessed 26 July 2022].

Fattinnanzi, E. and Micelli, E. (2019), "Valutare il progetto di Architettura", in *Valori e Valutazioni*, vol. 23, pp. 3-14. [Online] Available at: siev.org/wp-content/uploads/2020/02/23_02-_-FATTINNANZI-MICELLI.pdf [Accessed 26 July 2022].

Ferrante, T. (2008), "Legno – I caratteri dell'innovazione", in Nesi, A. (ed.), *Progettare con l'informazione – Percorsi e gestione delle informazioni tecniche per la promozione e il controllo dell'innovazione nei materiali e nel prodotto di architettura*, Gangemi Editore, Roma, pp. 61-104.

Fioravanti, M., Goli, G. and Togni, M. (2019), "Miglioramento del legno di faggio attraverso la modificazione termica in vapore saturo", in Maetzke, F. G., Sferlazza, S., Badalamenti, E., Da Silveira Bueno, R., Fretto, S., La Mantia, T., La Mela Veca, D. and Bucci, G. (eds), *Proceedings of the XII Congresso Nazionale SISEF – La Scienza Utile per le Foreste – Ricerca e Trasferimento, Palermo, 12-15 Novembre 2019*, p. 77. [Online] Available at: congressi.sisef.org/xii-congresso/materiale/2019_11_02_xii_sisef_abstractbook_orals_final.pdf [Accessed 26 July 2022].

Folke, C., Biggs, R., Norström, A. V., Reyers, B. and Rockström, J. (2016), "Social-ecological resilience and biosphere-based sustainability science", in *Ecology and Society*, vol. 21, issue 3, article 41. [Online] Available at: dx.doi.org/10.5751/ES-08748-210341 [Accessed 26 July 2022].

Hetemäki, L., Hanewinkel, M., Muys, B., Ollikainen, M., Palahi, M. and Trasobares, A. (2017), "Leading the way to a European circular bioeconomy strategy", in *From Science to Policy*, vol. 5, pp. 5-46. [Online] Available at: efi.int/sites/default/files/files/publication-bank/2018/efi_fstp_5_2017.pdf [Accessed 26 July 2022].

MATTM – Ministero dell'Ambiente e della Tutela del Territorio e del Mare (2007), *Piano d'Azione Nazionale per la sostenibilità ambientale dei consumi nel settore della pubblica amministrazione (ovvero Piano Nazionale d'Azione sul Green Public Procurement – PAN GPP).* [Online] Available at: mite.gov.it/sites/default/files/archivio/allegati/GPP/all.to_19_PAN_GPP_definitivo __21_12_2007.pdf [Accessed 26 July 2022].

MIMS – Ministero delle Infrastrutture e della mobilità sostenibile (2021), *Linee guida per la redazione del progetto di fattibilità tecnica ed economica da porre a base dell'affidamento di contratti pubblici di lavori del PNRR e del PNC.* [Online] Available at: mit.gov.it/nfsmitgov/files/media/notizia/2022-01/1.%20Linee_Guida_PFTE.pdf [Accessed 26 July 2022].

Moghtadernejad, S., Chouinard, L. E. and Mirza, M. S. (2018), "Multi-criteria decision-making methods for preliminary design of sustainable facades", in *Journal of Building Engineering*, vol. 19, pp. 181-190. [Online] Available at: doi.org/10.1016/j.jobe.2018.05.006 [Accessed 26 July 2022].

Ogrodnik, K. (2019), "Multi-Criteria Analysis of Design Solutions in Architecture and Engineering – Review of Applications and a Case Study", in *Buildings*, vol. 9, issue 12, article 244, pp. 2-17. [Online] Available at: doi.org/10.3390/buildings9120244 [Accessed 26 July 2022].

Osservatorio per il Capitale Naturale – Ufficio aree protette per la biodiversità (2020), *La bioeconomia delle foreste – Conservare, ricostruire, rigenerare – Terzo Forum sulla Gestione Forestale Sostenibile, Roma, 19 Novembre 2020*. [Online] Available at: legambiente.it/wp-content/uploads/2020/11/Bioeconomia-delle-foreste-report-2020.pdf [Accessed 26 July 2022].

Paoloni, F., Ferrante, T. and Villani, T. (2018), "Maintenance systems and cost for wooden façades", in *Proceeding Word Conference on Timber Engineering (WCTE 2018) – August 20-23, 2018, Seul, Republic of Korea*, pp. 1-9. [Online] Available at: researchgate.net/publication/ 327690084_MAINTENANCE_SYSTEMS_AND_COSTS_FOR_ WOODEN_FACADES [Accessed 26 July 2022].

Scarascia Mugnozza, G., Brunetti, M., Cremonini, C., De Dato, G. B., Ferrante, T., Fioravanti, M., Fragiacomo, M., Lasserre, B., Lelli, M., Marchetti, M., Nocetti, M., Piazza, M., Todaro, L., Togni, M., Villani, T., Zanuttini, R. and Romagnoli, M. (2019), "PRIN 2015 –La filiera corta nel settore biomasse legno – Innovazione per la bioedilizia e l'efficienza energetica", in Maetzke, F. G., Sferlazza, S., Badalamenti, E., da Silveira Buento, R., Fretto, S., La Mantia, T., La Mela Veca, D. S. and Bucci, G. (eds), *La scienza utile per le foreste – Ricerca e trasferimento – XII Congresso Nazionale SISEF, Palermo, 12-15 Novembre 2019*, p. 10. [Online] Available at congressi.sisef.org/xii-congresso/materiale/2019_11_02_xii_sisef_abstractbook_orals_final.pdf [Accessed 26 July 2022].

Sciomenta, M., Spera, L., Bedon, C., Rinaldi, V., Fragiacomo, M. and Romagnoli, M. (2021), "Mechanical characterization of novel Homogeneous Beech and hybrid Beech-Corsican Pine thin Cross-Laminated timber panels", in *Construction and Building Materials*, vol. 271, 121589, pp. 1-11. [Online] Available at: doi.org/10.1016/j.conbuildmat.2020.121589 [Accessed 26 July 2022].

UN – United Nations (2015), *Transforming our world – The 2030 Agenda for Sustainable Development.* [Online] Available at: sustainabledevelopment.un.org/content/documents/21252030%20Agenda% 20for%20Sustainable%20Development%20web.pdf [Accessed 26 July 2022].

WWF (2020), *Living Planet Report 2020 – Bending the curve of biodiversity loss.* [Online] Available at: f.hubspotusercontent20.net/hubfs/4783129/LPR/PDFs/ENGLISH-FULL.pdf [Accessed 26 July 2022].