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# Integrated Design as a Strategy for Innovating Native Timber Products and Promoting Sustainable Forest Management

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**Abstract:** This study explores how integrating design processes into the native timber industry of southern Chile, specifically in the Araucanía and Los Ríos regions, can improve the value chain and promote sustainability. Chile's native wood sector is constrained by fragmented value chains, underutilised small-diameter logs and limited market confidence. These challenges jeopardise forest sustainability and rural livelihoods, underscoring the imperative to find innovative solutions to reinvigorate the sector. A market gap analysis revealed critical limitations in the current industry, including low supply, limited demand, and weak technological development, especially in producing value-added wood products. The research identified over 417,000 hectares of second-growth roble (*Nothofagus obliqua*)-raulí (*Nothofagus alpina*)-coigüe (*Nothofagus dombeyi*) forests suitable for sustainable management. Interviews with woodworking SMEs showed that 66% already use native timber, yet 46% of the projected volume remains underutilised due to the prevalence of short and thin logs. In response to these challenges, the study developed innovative prototypes such as interior claddings and lattices made from smaller, underutilised logs. These designs were evaluated and validated for use in residential and public buildings, demonstrating their potential to meet new market demands while promoting resource efficiency. The results show that, whilst there is a clear need for better infrastructure, workforce training, and commercial planning to support product adoption, design-driven innovation offers a promising path forward enhancing the industry's competitiveness. Demonstrating how design-led integration can transform under-used native timber into high-value products, simultaneously driving sustainable forest stewardship and local economic growth.

**Keywords:** integrated design process; native timber; sustainable forest management; design innovation; architectural prototypes

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Academic Editor: Thomas Tannert

Received: 31 March 2025
Revised: 25 April 2025
Accepted: 13 May 2025
Published: 29 May 2025

**Citation:** Schueftan, A.; Martin, M.; Buchner, C.; García, S.; Reyes, M.; Arnett, M. Integrated Design as a Strategy for Innovating Native Timber Products and Promoting Sustainable Forest Management. *Buildings* **2025**, *15*, 1886. https://doi.org/10.3390/buildings15111886

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## 1. Introduction

The growing recognition of forests as strategic natural resources in Latin America has underscored the need to enhance the performance of the native timber industry, particularly

in southern Chile, where increasing local demand is currently met through imports of furniture and decorative items [1]. Furthermore, with a growing need globally to improve biodiversity and move towards more sustainable forms of forestry management, it is necessary to identify forms to add value to native forests that embody these practices [2,3]. Despite Chile's abundance of native forests, the sector remains underdeveloped, lacking technological innovation and the production of value-added goods [4–6]. While existing studies have explored sustainable forestry, management practices, and timber construction systems, a significant gap remains in the systematic application of design methodologies to revitalise and transform the native timber sector [7,8].

This study addresses that gap through the application of the Integrated Design Process (IDP), a collaborative, iterative framework that brings together disciplines such as de-sign, forestry, architecture, and engineering throughout the project lifecycle. IDP promotes early-stage coordination, continuous feedback, and holistic problem-solving, making it particularly effective in addressing complex and systemic challenges [9,10]. The primary objective is to demonstrate how IDPs can create value within the native timber industry by supporting the development of new products, improving supply chain performance, and fostering sustainability.

Focusing on the Araucanía and Los Ríos regions, areas marked by limited supply and demand and technological stagnation, the study employed a structured process involving stakeholder interviews, fieldwork, design workshops, and prototype development. This approach identified key challenges and opportunities, leading to the creation of prototypes such as modular claddings and wood lattices, developed using lesser-valued species and short logs and validated for application in an architectural context. The Integrated Design Process (IDP) was selected for this project due to its capacity to foster cross-sector collaboration and align product development with market needs, environmental objectives, and local resource constraints. Unlike traditional linear design models, IDP integrates social, environmental, and technical criteria from the outset, producing scalable and context-sensitive solutions. This systemic approach responds directly to the fragmented and multidisciplinary supply chains in Chile's forestry and construction sectors. Early outcomes indicate that the prototypes developed—such as modular claddings and wood lattices—meet the demands of both residential and public construction while offering strategic uses for underutilised wood resources [11,12].

Beyond addressing supply chain inefficiencies, IDP supports a shift toward holistic and interdisciplinary collaboration across the entire value chain. It facilitates early and continuous engagement among stakeholders—including raw material suppliers, designers, and managers—enhancing coordination, reducing redundancy, and mitigating environmental impact. In regions such as Los Ríos, where native timber faces public scepticism regarding durability, fire resistance, and perceived links to deforestation, IDP provides a structure for building trust through evidence-based, user-centred narratives [13]. A critical enabler of this transformation is educational reform on multiple fronts, which fosters a shared interdisciplinary language and mindset, equipping professionals to navigate paradigm shifts and drive innovation across the design and construction chain [14,15].

In practice, IDP unfolds in iterative phases: a pre-design stage establishes shared goals among stakeholders; design development involves cycles of technical analysis and feedback; and implementation planning ensures coherence through integrated scheduling, procurement, and documentation [16]. Although not mandated by Chilean regulation, IDP is currently encouraged through voluntary sustainability certifications. LEED promotes early collaboration via its "Integrative Process" credit, whilst national frameworks such as CES require IDP explicitly, and EDGE and CVS support it through coordinated efficiency criteria. International case studies further validate IDP's relevance. In Canada,

challenges to IDP integration such as institutional fragmentation highlight the need for contextual adaptation [17], whereas in Sweden, quality assurance practices led by IDPs have successfully improved designer-analyst coordination [18]. These experiences underscore IDP's potential to promote innovation and systemic alignment within Chile's native forestry sector through careful consideration of local factors.

The study applies an Integrated Design Process to the fragmented native wood value chain in southern Chile, uniting forest owners, manufacturers and designers to develop nine architectural prototypes that use small diameter roble (*Nothofagus obliqua*)-raulí (*Nothofagus alpina*)-coigüe (*Nothofagus dombeyi*) logs normally relegated to low-value uses. The results demonstrate that design-led collaboration can convert up to 46% of presently underutilised second-growth standing timber into competitively priced, high-value components, improving supply chain efficiency while strengthening the business case for sustainable forest management and regional economic development [19].

In summary, this study contributes to both academic literature and the practical development of the native timber industry by presenting a replicable model of design-led innovation. It illustrates how IDP can bridge the gap between forestry resources and value-added production, offering a strategic pathway to enhance economic competitiveness, support rural development, and promote the adoption of sustainable practices in the forestry industry of southern Chile [20–22].

## 2. Literature Review

### *2.1. Forestry Practices in Southern Chile*

In southern Chile, native timber has historically been an essential component of architecture and the cultural landscape, particularly in the regions of Los Ríos and La Araucanía. Since pre-Hispanic times, Indigenous Peoples sustainably used the native forest, employing various species such as roble, coigüe, mañío (*Podocarpus saligna*), and raulí for construction, boats, and utensils, whilst also obtaining non-timber forest products essential for their subsistence [23,24]. With the arrival of European settlers, and particularly during the agricultural colonisation processes of the 19th century, the intensive use of native timber became consolidated as a driving force for urban and industrial development, with Valdivia (a city in the Los Ríos region) standing out as a centre of forestry and carpentry activity, driven by the availability of forests and local knowledge of the craft [25,26]. This trajectory solidified a strong connection between native timber and the way of life in the south, reflected in both urban and rural heritage architecture, whose material and symbolic expression is deeply linked to the territory [27,28].

The Los Ríos region, in particular, has maintained a closer connection to the native forest than other areas of the country, not only due to its high proportion of native forest cover but also because of the persistence of small-scale industry actors associated with the management and processing of these species [20]. Unlike regions such as the Biobío or Ñuble, dominated by monocultures of exotic species like radiata pine or eucalyptus, in Los Ríos and parts of La Araucanía, smaller-scale productive dynamics linked to the traditional use of native timber persists, providing a fertile ground for sustainable innovation strategies. Although La Araucanía has a greater presence of exotic plantations, its inclusion as a case study allows for the comparison of different production models within the same territorial and ecological framework [29].

Despite its richness and cultural roots, native timber has been displaced from the formal market primarily because it cannot compete in volume and cost with pine and eucalyptus, species that are easier to dry and have greater homogeneity [30]. Moreover, the indiscriminate logging that occurred between the 16th and 20th centuries, without sustainability criteria, created a negative stigma around its use, a perception that persists despite the

current implementation of sustainable management practices that actively require care and human intervention to prevent forest degradation [31].

At a global level, the replacement of native forests with exotic plantations significantly reduces the structural and functional diversity of the wood available in ecosystems, which negatively affects not only biodiversity but also key processes such as fluvial dynamics and water regulation [32]. This transformation also leads to the loss of native species, impacting genetic diversity and compromising long-term ecological stability, potentially resulting in an irreversible decline in the ecosystem services provided by native forests.

From a territorial perspective, the sustainable use of native timber enables the revaluation of lesser-known local species, where the lack of knowledge and appreciation of native species often limits their local use, promoting their substitution by non-native species and encouraging unsustainable practices [33]. Added to this is the cultural dimension: in many territories, native timber—particularly from long-lived species—is an essential input for traditional, ceremonial, and educational practices of Indigenous peoples, who depend on centuries-old trees not only for their material properties but also for their symbolic and spiritual value [34]. In this context, restoring the link between architecture and native timber through architectural design and sustainable management not only promotes the sustainable use of the resource but also strengthens the territorial identity and cultural landscape of southern Chile, valuing technical and material knowledge deeply rooted in the local communities.

### 2.2. State and Pressure on Native Forests

In Chile, native forests cover an area of 14.7 million hectares [35], of which approximately 5.8 million hectares are considered potentially productive forests. It is important to note that 70% of these forests are owned by private landowners, whose management is influenced by various factors such as market dynamics, public policy, and socioeconomic context [36–38].

Decisions regarding the use and management of native forests are largely dependent on their ability to generate income for both landowners and users. It has been observed that small and medium-sized landowners, being subject to market conditions, are often unqualified to make forestry management decisions. Small landowners tend to leave their forests unmanaged, which leads to degradation and reduces the generated income [9]. The lack of awareness and proper incentives for sustainable forest management by landowners is one of the main causes of forest degradation, as shown in Figure 1. In many cases, landowners adopt a utilitarian view of the forest, considering it an exclusively private resource and perceiving its degradation as an isolated problem, without recognising its impact on a shared ecosystem.

Forest degradation refers to the decline in a forest's ability to provide essential ecosystem services, such as carbon sequestration and wood production, due to various pressures. This phenomenon, present globally, has gained significant attention in international policies related to biodiversity, climate change, and forest management [39]. In Chile, native forest degradation is driven by multiple factors, including livestock activity, which hampers natural regeneration due to overgrazing. Additionally, unsustainable wood extraction is another key factor in this process [40,41]. Whilst both causes are present, in southern Chile, forest degradation is primarily attributed to qualitative factors. This presents an opportunity to implement management methods that contributes to the sustainable conservation and restoration of these ecosystems [42].

In this region, native forest degradation is further exacerbated by the use of inappropriate intervention methods and poor planning of forestry activities. The forest is a constantly evolving ecosystem, where the death of certain trees releases resources for the growth of others. In this natural cycle, regeneration is maintained through a dynamic balance between the death and development of trees and other species. Therefore, when logs are extracted using

the proper techniques, this natural dynamic can be replicated, allowing for the sustainable use of the resource [42]. To prevent degradation and ensure the long-term survival of forests, it is essential to apply a sustainable forest management approach [43]. To achieve this, it is crucial to explore how innovation in the design process of native timber products can enhance the sustainable management of native forests, adding value to their products and improving market profitability, particularly to create opportunities for small landowners.

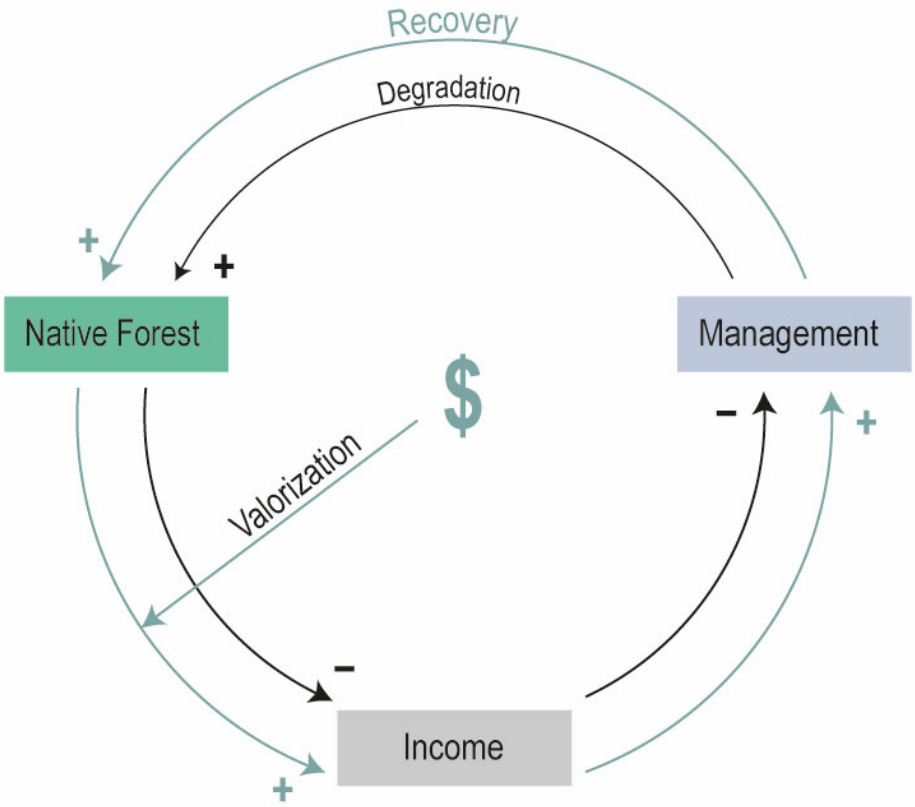



**Figure 1.** Diagram of the valuation of the native forest. Adapted from [9].

Since the mid-20th century, the vast majority of native forests in southern Chile have been subject to various degrees of industrial intervention, often carried out without adequate planning or consideration for the long-term continuity of the resource. These interventions, largely extractive in nature, contributed to the degradation of forest ecosystems and weakened their productive and ecological functions. However, in many cases, native forests have demonstrated a capacity for natural regeneration, with new growth emerging even after periods of intensive exploitation.

Building on this regenerative potential, sustainable forest management strategies propose a proactive approach that focuses on guiding forest dynamics rather than simply extracting resources. Specifically, management interventions aim to concentrate growth in trees that exhibit the most favourable characteristics for timber production—those that are straight, healthy, and possess a well-balanced and homogeneous crown structure. These practices seek to anticipate natural mortality and optimise site productivity by conducting early thinnings that remove less vigorous individuals and thereby allocate more resources to the development of high-quality trees. This silvicultural approach allows for the sustainable use of the forest while maintaining its ecological functions and long-term viability.

In this context, this study focuses on the regions of La Araucanía and Los Ríos in the south of the country, due to their significant area of second-growth forest composed of roble-raulí-coigüe and the presence of industries and producers that work with native

timber. In Chile, forests are classified according to their dominant species, and in particular, roble-raulí-coigüe second-growth forests stand out in the central-southern area for their high productivity, rapid growth, and uniformity in diameter and wood quality [21,44,45]. In addition to their timber value, these forests play a key role in carbon sequestration, tourism, the provision of non-timber products, and regulating the hydrological cycle [46]. The total area of both regions reaches 5 million hectares, with 3.2 million in La Araucanía and 1.8 million in Los Ríos. In La Araucanía, native forests cover 964,153 hectares, with the dominant forest types being roble-raulí-coigüe (49%), araucaria (21%), coigüe-raulí-tepa (12%), and lenga (11%). In Los Ríos, native forests cover 908,531 hectares, with a higher presence of coigüe-raulí-tepa (31%), roble-raulí-coigüe (28%), and evergreen (23%) [35].

Since the implementation of protection, recovery, and sustainable management laws for Chile's native forests in 2008 32,180 hectares of management plans have been approved in La Araucanía and 23,463 hectares in Los Ríos. These plans outline strategies and actions for the conservation, utilisation, and restoration of forest resources under management schemes. Another important factor is the potential wood volume supply in native forests. INFOR (Forestry Institute, Santiago, Chile) studies on roble-raulí-coigüe second-growth forests indicate a potential productive area of 823,899 hectares in the regions from Ñuble to Los Ríos, not including areas with restrictions on intervention [20]. The largest proportion of this area is located in La Araucanía (40%), followed by Biobío (29%), Los Ríos (18%), and Ñuble (12.5%). In La Araucanía and Los Ríos, the potential productive area reaches 481,890 hectares, emphasising the need for sustainability strategies to optimise their utilisation and conservation. Additionally, these regions host various timber companies that process and develop products based on native timber, accounting for 41.7% of the total national consumption of native timber logs [47].

### 2.3. Native Timber Market

The use of wood in general, and specifically native timber, in construction and design has experienced global growth, driven by the increasing demand for sustainable materials. Its renewable origin, biodegradability, and lower environmental impact compared to alternative materials have positioned it as a preferred option across various sectors. Its production requires less energy and generates less pollution, aligning with trends in environmentally responsible construction and manufacturing [48]. Locally, the trend is moving toward end uses in segments such as construction, furniture, door and component manufacturing, as well as design applications, such as cladding, flooring and other architectural components [49,50].

Although there is growing interest in incorporating native timber in the construction sector, the use of exotic species like radiata pine (*Pinus radiata*) and eucalyptus (*Eucalyptus globulus*/*E. nitens*/*E. gloni*) still dominates. Despite this, native timber has significant potential for high-value-added applications [51]. Products such as native timber boards, where the wood is used for both structural and decorative purposes, have emerged [52]. Regarding the furniture and design segment in Chile, a market study conducted by INFOR observed high-quality products in major city markets, particularly in Santiago. These products feature a high quality of execution and finish, and a variety of designs, often using traditional techniques and skills. The supply of native timber in various degrees of processing generally comes from the southern regions of Chile, with wood purchases mainly from intermediaries who dry the wood (air drying followed by chamber drying). The manufacturing of the products takes place in external workshops or in-house facilities of the companies operating in this segment [49]. However, despite the significant potential of native forests, especially roble-raulí-coigüe second-growth forests, their timber products have lost importance in traditional markets at the national level. As evidence of this

trend, Figure 2 shows that the share of native species in the industrial consumption of logs has decreased to less than 1% in recent years [21].

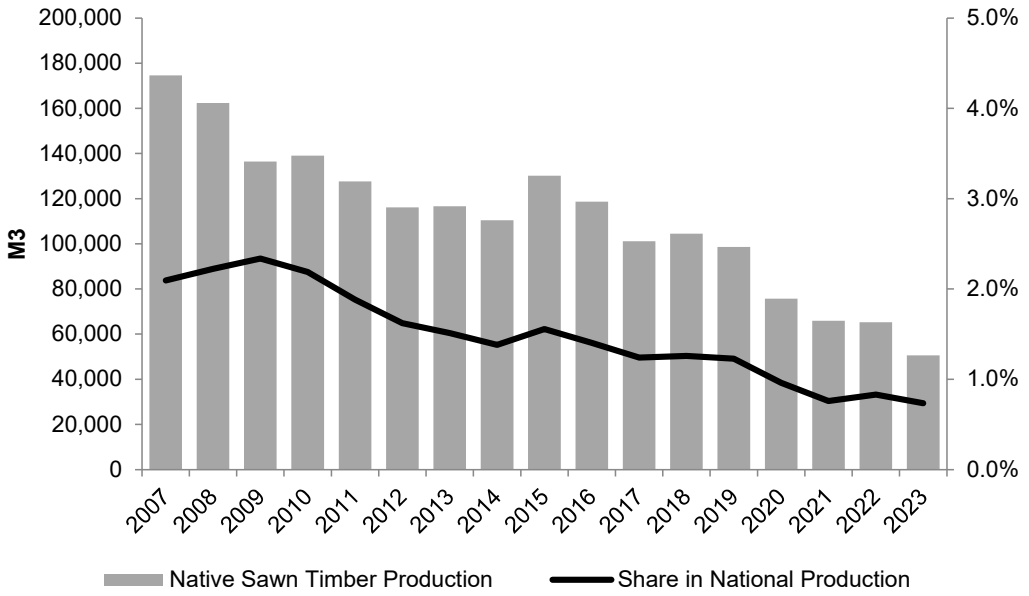



**Figure 2.** Evolution of sawn timber production from native species from 2013 to 2023. Own elaboration.

In 2023, the production of sawn timber from native species in Chile accounted for 0.7% of the national total, showing a year-on-year decrease of 18.6% compared to 2022. A substantial portion of this consumption is directed to the sawmilling industry, accounting for 87% (97,603 $m^3$ssc in 2023), followed by the panel and veneer sector with 13% (13,998 $m^3$ssc), while the remainder is exported as logs. Amongst the most commonly used species in sawn timber production are lenga (*Nothofagus pumilio*), with a share of 0.28% (19,331 $m^3$), roble with 0.15% (10,107 $m^3$), and coigüe with 0.1% (6743 $m^3$) of the sawn timber volume [53]. The exploitation of these forest species is concentrated in regions such as La Araucanía, Los Ríos, and Los Lagos, which represented 60% of the native species consumption in 2023 (66,652 $m^3$ssc) [47]. Furthermore, native timber exports have maintained a steady trend, with species like lenga, roble, and raulí being the most demanded in both national and international markets [54].

Various factors can explain these changes in consumption, including the limited understanding and application of regulations related to the domestic market for native timber, often due to a lack of collaboration among stakeholders. Another contributing factor is the lack of innovation in product diversification at the log level, uncertainty in supply for primary and secondary transformation, and a lack of incentives to adopt sustainable practices. A key issue is that as native sawn wood does not undergo secondary transformation processes, it has a very low economic value, similar to that of firewood. Additionally, there is insufficient adoption of new technologies in cutting and drying, which affects its competitiveness, and facilitates the consolidation of wood from exotic plantations as a more accessible option due to its lower cost and greater availability. In this context, sustainable management of native forests presents an opportunity to integrate landowners into a more inclusive and sustainable economic development of the forestry sector [47].

On the other hand, a significant volume of native timber is used to meet the energy demand of both urban and rural residential sectors, particularly for heating and cooking (firewood and charcoal). Although there are no updated official figures for all the regions of the country, between 2014 and 2019, national consumption of firewood from native timber increased from 5.5 to 6 million solid cubic metres, accounting for between 45% and 50%

of total firewood consumption, with the remainder coming from plantations of exotic species [55]. Despite their high consumption, firewood and charcoal are low-value-added products, as their commercialization generally does not involve industrial processes that could increase profitability. This situation limits the development of a more sophisticated production chain and reduces economic opportunities for native forest owners. Additionally, in the sawmilling sector, rigid criteria for classifying logs based on diameter and length persist, making it difficult to utilise smaller trees, those with poor straightness, or those in poor health. This problem is exacerbated by the lack of technology in small and medium-sized industries to process these logs, leading many to be primarily used for biomass energy. As a result, many high-quality logs remain unused in forests, negatively impacting sector productivity and causing significant losses in the value of the forest resource [21].

### *2.4. Public Policies for the Promotion of Wood*

Wood construction has emerged as an area of priority to promote the sustainable use of native forests and stimulate local economies. At the national level, the Chilean government has implemented the 2015–2035 Forestry Policy, aimed at increasing productivity and the sustainable use of forest resources, including improvements in the management of native forests and plantations. This policy promotes the use of timber in construction and biomass, seeks to reduce technological gaps in the industry, and encourages the sustainable development of high-value non-timber forest products for the market [56]. However, its implementation faces challenges, such as resistance from small landowners and the risk of overexploitation if responsible management is not ensured [57].

In addition to national forestry policies, there are key territorial initiatives driving the development of native timber construction in southern Chile at the local level. In this regard, the regions of Los Ríos and Araucanía have adopted differentiated approaches in their development strategies related to the forestry industry and wood usage, reflecting their territorial and productive particularities.

The Los Ríos region has incorporated the valorisation of native timber as an essential component of its strategic planning. The 2023–2037 Regional Development Strategy aims to enhance the forestry industry with an emphasis on the sustainable use of native forests, promoting product diversification and technological innovation [58]. This is framed by the Forest Industry Promotion Table—comprising public institutions such as the National Forest Corporation (CONAF), the Forestry Institute (INFOR), the Corporation for the Promotion of Production (CORFO), the Regional Government (GORE), and various trade associations—which serves as a strategic and collaborative governance space aimed at increasing the value of native timber and promoting its sustainable use in the regional industry. This table promotes the coordination of financing instruments, productive innovation, and the creation of local value chains to stimulate the sustainable forestry economy [59]. However, as with many territorial governance initiatives, the effective implementation of the proposals agreed upon in these platforms faces significant challenges. Coordination amongst multiple stakeholders, continuity of processes, and monitoring of agreements are critical factors that determine their tangible impact on the territory, which are still unmet.

In the Araucanía region, the regional development strategy has prioritised product diversification. Although the forestry industry remains significant, the focus has shifted toward industrialisation and sustainable construction as key drivers for adding value to the industry. One example of this is the "Desafío Construye Araucanía" initiative, promoted by the Technological Center for Innovation in Construction (CTEC) [60], which seeks to foster innovation in industrialised and sustainable construction through the creation of a consortia that integrates architecture firms, real estate developers, and construction companies, with at least one entity operating in the region. Similarly, other initiatives,

promoted by the Regional Government of La Araucanía and CORFO [61], aim to align regional interests and strengthen collaboration with local stakeholders, fostering sustainable practices in the sector, such as efficient waste management. In this context, sustainability and industrialisation emerge as concrete opportunities to promote wood usage, integrating innovation, efficiency, and territorial relevance.

These local initiatives represent a territorial implementation of national public policies and demonstrate that the push for timber construction is also being actively developed within the territories. In both regions, these actions not only complement national strategies but also allow for their adaptation to the cultural, ecological, and productive specificities of the territory. Coordination between public and private actors at the regional level is a key foundation for advancing a sustainable, competitive timber industry that is rooted in the identities and resources of southern Chile. Additionally, the coordination between different levels of public policy—national, regional, and local—is crucial for ensuring the harmonious development of a sustainable forestry industry based on native forests [41].

## 3. Methodology

The methodology of this research was grounded in the Integrated Design Process (IDP), applied as a strategic framework to structure collaboration across the value chain of native timber products. This approach was particularly suited to the fragmented and resource-constrained context of southern Chile's forestry and construction industries. Rather than revisiting the motivations for adopting IDP already outlined in the introduction, this section details how the methodology was practically implemented to address specific challenges in the regions of Araucanía and Los Ríos, especially regarding the use of roble-raulí-coigüe timber from smaller-diameter logs.

The research focused on the design and development of architectural components that could increase the utilisation and perceived value of lesser-used resources from native forests. The methodology was structured to activate interdisciplinary collaboration at every stage of product development, encouraging early and ongoing input from forestry professionals, designers, manufacturers, and end users. Design was positioned not as a standalone phase but as an integrative mechanism, linking technical, environmental, and social considerations from concept to final product. Multiple modes of engagement were employed to support this integrative approach. These included stakeholder interviews, technical meetings, focus groups, training workshops, and participatory design sessions. The iterative nature of IDP allowed feedback to flow continuously between participants, enhancing responsiveness to emerging insights and reinforcing shared objectives. Outputs from these interactions included timber species data sheets, prototype fabrication guides, marketing materials for design professionals, and a native timber educational book for broader audiences. All materials were developed collaboratively and disseminated openly, contributing to transparency and stakeholder empowerment.

Importantly, in this application, the process deviated from conventional, linear models by adopting a cyclical structure in which the design acted as both catalyst and connector (see Figure 3). This methodological shift enabled real-time adjustments to address material constraints, production feasibility, and user needs, whilst also enhancing coordination between sectors that typically operate in isolation. By emphasising information flow and co-decision-making, the methodology aimed to reinforce the systemic relationships necessary for long-term innovation and sustainability in the native timber sector.

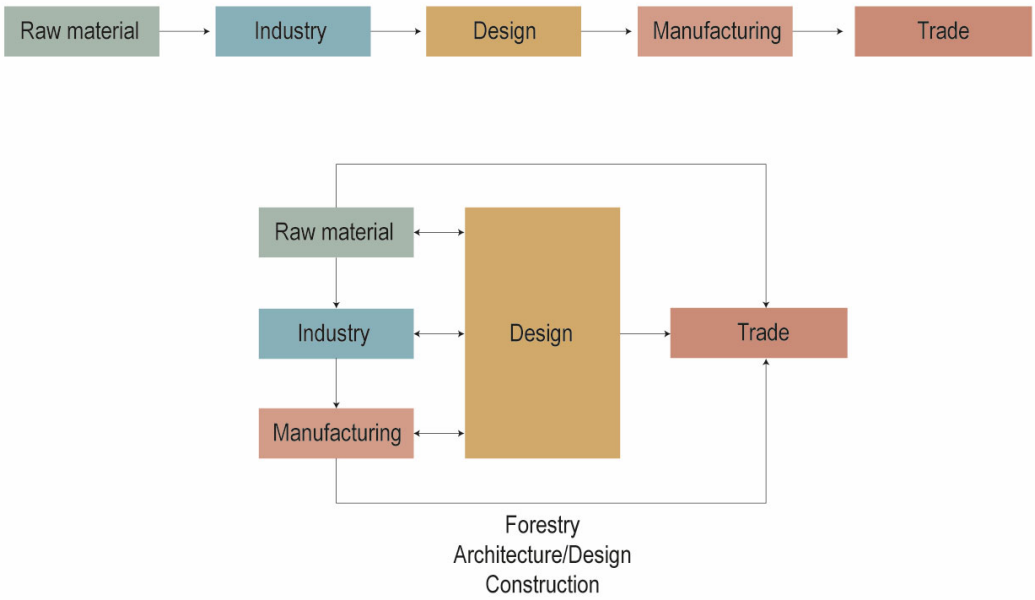



**Figure 3.** Linear design process and integrated design process diagram. Own elaboration.

### *3.1. Characterisation of the Natural Resource, Local Industry, and Market*

The initial stage of development, which focused on characterisation, was crucial, as the information gathered formed the foundation for the design of the architectural prototypes. Firstly, a comprehensive literature review was conducted for the forestry resources, utilising both primary and secondary sources, including previous studies on the use and exploitation of native forests. To understand the species composition in the regeneration areas of the selected regions, data from the National Forest Inventory (IFN) was analysed. This inventory uses a cluster sampling method with three concentric circular plots, following a systematic grid of points. This statistical-mathematical tool provides detailed information on the condition and status of native forest ecosystems.

The analysis of forest ownership was based on data from the Natural Resources Information Centre (CIREN), identifying four ownership classes based on land area: small owner ($\leq$50 hectares), medium owner (>50 and $\leq$200 hectares), large owner (>200 and $\leq$1000 hectares), and very large owner (>1000 hectares). The projected future timber supply from regenerated areas was based on Martin et al., 2020 [20], which considered manageable areas excluding protection zones such as watercourses, steep slopes, protected areas (both public and private), and forests with low occupancy not suitable for intervention. To estimate timber supply projections, an interpolation method was employed using IFN data, applying management schemes that included thinning, harvesting and regeneration cuts. Three density categories and three basal area levels were defined, resulting in nine general conditions to classify the stands. The NOTHOPACK model was used to estimate yields for each intervention and optimise timber supply, determining the appropriate timing for thinning or harvests based on basal area, density, and stand age, setting a target diameter of 40 cm to begin harvest and regeneration cuts. It is a growth simulator designed for second-growth forests of the roble-raulí-coigüe (*Nothofagus*) forest type. This tool allows for projecting stand growth, incorporating the possibility of applying thinning and obtaining user-defined timber products, thus facilitating the planning and evaluation of different forestry management scenarios.

The industry analysis was conducted through interviews with small and medium-sized timber companies in the studied regions, aimed at understanding their current production processes and identifying opportunities for developing products based on native timber. The selection of participating companies was based on the Forest Institute (INFOR) database, which compiles information on the primary forest industry in

Chile. In 2021, 107 production units using native timber were identified. From this group, 40 companies were chosen through a directed sampling process, considering their level of processing (29% with secondary processes and 71% with primary processes). This distribution aligns with national trends, where mobile sawmills—typically associated with primary, low-volume operations—represented 74.7% of native timber processors in 2023. The sample, therefore, reflects the technological and operational diversity of the sector.

To ensure methodological rigour, the selected companies were predominantly small and medium-sized enterprises (SMEs), consistent with the structure of the existing national native timber industry. In 2023, this sector employed 774 workers, 78% of whom were involved in operations producing less than 1000 $m^3$ of sawn wood annually. The companies included in the study exhibited comparable characteristics, with most reporting annual outputs below 500 $m^3$. These attributes confirm both the territorial and operational representativeness of the sample.

Data collection was carried out on-site through direct interviews with company representatives. A total of 38 valid responses were obtained, yielding a 95% response rate and covering 35.5% of the national population of native timber processors identified by INFOR. Assuming a simple random sampling model, this corresponds to a margin of error of approximately $\pm$12.8% at a 95% confidence level, providing robust exploratory value to the analysis.

The questionnaire was structured in two parts: the first covered basic company information, including production scale, infrastructure, and employment; the second focused on the use and potential of native timber. Topics included sawmill type, species used, processing technologies, commercialisation strategies, barriers to timber utilisation, access to financing, supplier networks, and diversification opportunities. The information was analysed using descriptive statistics, and the results were subsequently shared in working groups, forums, and stakeholder meetings with actors from the forestry, design, architecture, and construction sectors. This participatory dissemination strategy helped to reinforce the systemic understanding of the industry, linking natural resource characteristics with regional production dynamics.

In parallel, market potential was assessed through an online questionnaire aimed at construction professionals, architects, and designers. The goal was to identify perceived barriers and explore opportunities for incorporating native timber products in sustainable construction projects. Participants were selected based on experience with eco-friendly materials, and a total of 47 responses were collected. The data were processed using descriptive methods to identify emerging trends, ensuring comparability with previous research in the field.

### *3.2. Material Selection and Classification*

Based on the classification of the forestry sector, and the structure of the existing Chilean forestry chain as well as incorporating feedback from the industry partners, the available timber groups were identified and classified for selection. Within the various classifications, there was a focus on avoiding pressure on native forests by creating over demand for native timber through the introduction of new products. However, it was also necessary to consider how industry partners could begin to innovate without drastic changes to their supply chain or infrastructure. Thus, it was chosen to focus on air-dried wood sourced from saw logs (see Figure 4) that would normally go towards low-value products such as the construction of pallets. Considering the possible requirements of SMEs there was also a focus on short-length logs that are often sourced from native forests and are less desirable due to their limited length at around 1200–1500 mm. Furthermore, this approach allowed for the research to

simultaneously incorporate manufacturing methodologies that could be applied to offcuts from processes resulting from premium products such as timber for construction and flooring.

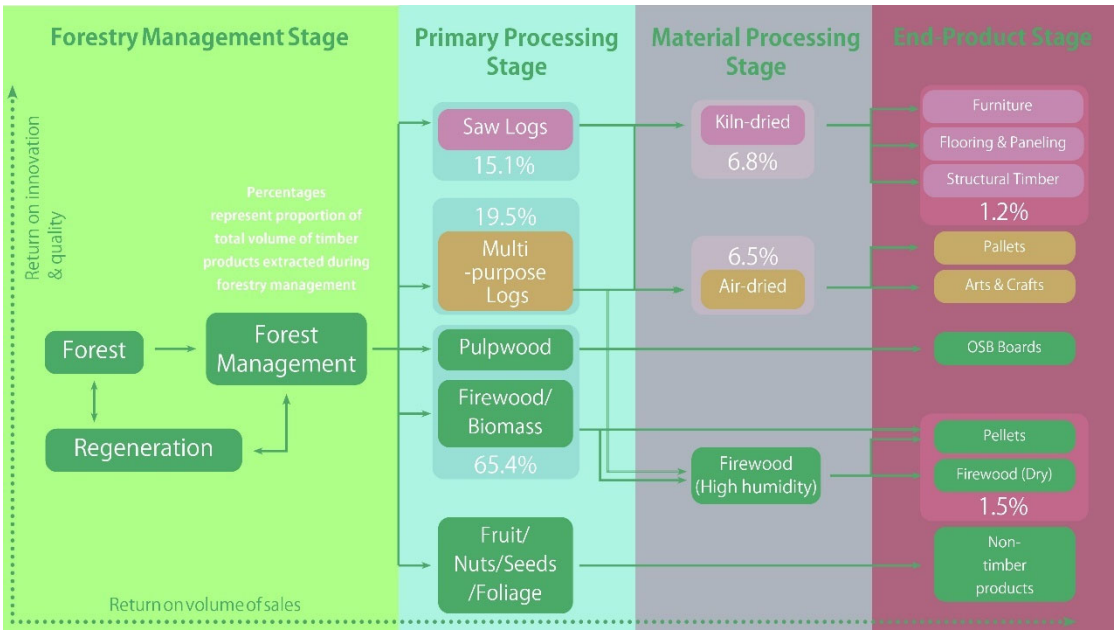



**Figure 4.** Native forest supply chain in Chile. Adapted from [57,62].

These saw logs are often classified as multipurpose saw logs, as they are used for a variety of applications from biomass and pellets to artisan crafts and pallets. These are, however, low-value products and considering that these logs are yielded in greater volume than sawlogs for more desirable products such as furniture and construction timber (Figure 4), this shows there is a largely untapped resource where native timber could be transformed into higher value products without great environmental impact or over demand on the existing forestry chain. Reinforced by the fact that 46% of the projected volume suitable for sawn timber in second-growth native forests is already under-utilised, whilst the methodologies for fabrication that will be developed for small sections of timber will allow for a larger proportion of standing timber and offcuts from other processes to be used [20,21,57].

### *3.3. Design and Manufacturing of Prototypes*

During the design and validation process, meetings and workshops were held with key stakeholders involved in the end-of-chain use of native timber. These sessions addressed the types of products with the greatest potential, their opportunities and challenges, and collaboratively defined the prototypes to be developed. Surveys were conducted with the same stakeholders, providing additional insights into barriers, material perceptions, and feasibility of use. The process involved active participation from organisations such as the Chilean Chamber of Construction (CCHC), public service representatives from the Ministry of Public Works (MOP) and the Housing and Urbanization Service (SERVIU), as well as real estate companies and professionals in design, architecture, and construction. This diverse group of participants allowed for the integration of different perspectives in the development of solutions, ensuring the technical and commercial relevance of the products to be defined.

Next, a design exploration phase was initiated in collaboration with the School of Architecture at the Universidad Austral de Chile, through an elective course focused on the design of innovative construction elements and components using native timber. This course, held during the second semester of 2022, was vertically integrated with

students from first to fourth year, representing an innovation in the integrated design process. The students designed elements and components based on the characteristics of the raw material and available technology in the local industry, linking the decision-making process with the local production chain and the characteristics and potential of the natural resource. This experience led to the first prototype proposals for interior claddings and lattice screens that would be sourced from short and thin native logs.

Subsequently, the design process continued with the MADlab team from the Universidad Autónoma de Chile to develop the designs intended for the prototyping phase. Timber species and properties were reviewed for their possible applications and required processing and manufacturing stages. Products with potential for innovation were then analysed in terms of design, formats, dimensions, and anchoring systems, considering various manufacturing processes appropriate for the classified timbers, from manual methods to mechanised and hybrid techniques. During this stage, meetings and discussions were held with previously interviewed stakeholders to validate the design developments. Establishing design criteria based on the raw material that would be supplied and the technology available and feasible for the partners involved. Prototypes were then developed and optimised based on these discussions to ensure their feasibility and performance. A detailed breakdown of parts, components, jigs and fabrication methodologies was created, specifying the necessary information for fabrication based on the requirements of industry partners. This information was then translated into technical sheets (see Figure 5) to permit the continued production of the prototypes by interested parties, including recommendations for appropriate timber species or combinations of species, humidity, minimum length and quality and the infrastructure necessary for fabrication. Thus, enabling the collection of key data on production feasibility and optimising manufacturing strategies based on the feedback from other members of the IDP.

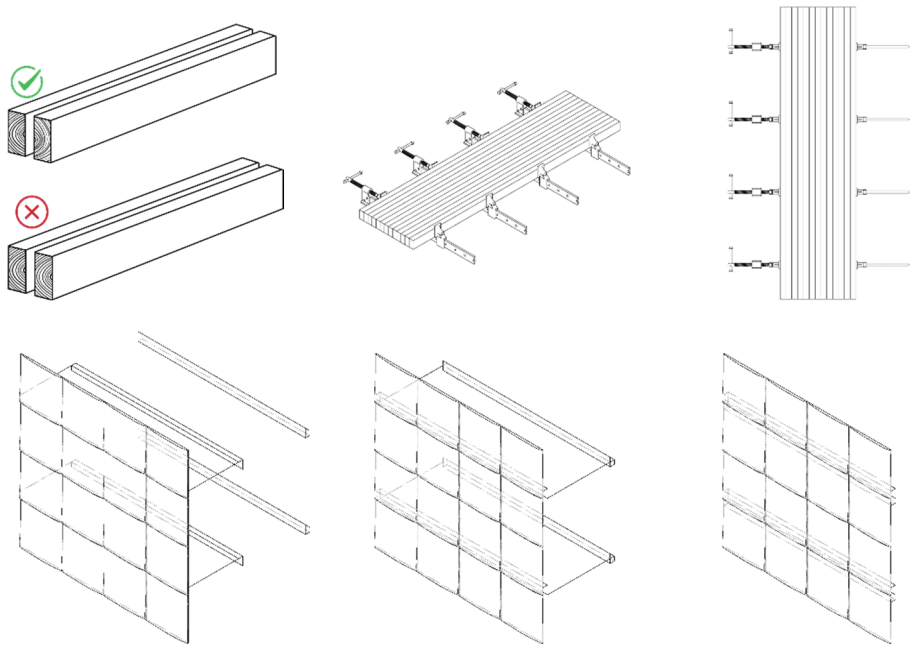


**Figure 5.** Images from instructional documents elaborated by MADlab illustrating fabrication methodologies and jigs for manufacture.

### *3.4. Evaluation of the Value Chain Through the Integrated Design Process*

As part of the integrated design process, a new round of surveys was conducted to validate the prototypes once they were fabricated. This evaluation allowed for the analysis of their adoption feasibility, ensuring that the design met the sector's needs in terms of machinery and manufacturing processes. This iterative process facilitated

continuous optimisation, avoiding a linear development approach and promoting feedback and participation from all stakeholders at every stage of the design process.

The application of these surveys also allowed for the identification of gaps in the value chain and the assessment of opportunities to strengthen the industry through the use of native timber. Within the native timber industry chain in the country, three main links were identified: the raw material producers, timber processors, and manufacturers and marketers. The surveys were distributed through digital platforms and in-person interviews at different locations within the regions under study. The survey structure was based on five key aspects: Products and/or services, customer and sales definition, supply, production processes, and external logistics. For the sample selection, a representativeness criterion was established based on active participation in the industry and experience in using native timber. The sample was proportionally distributed across the different links in the production chain, designed to ensure a balanced representation of the involved stakeholders and to allow the identification of common patterns in the perception of sector gaps and opportunities.

Finally, based on the combined analysis of the qualitative and quantitative data collected, intervention strategies were defined to improve the competitiveness of the various stakeholders in the timber industry, strengthen their management capacities, and establish native timber as a viable and sustainable alternative in both national and international markets.

## 4. Results

### *4.1. Characterisation of the Resource, Industry, and Local Market*

The resources, the industry, and the local market are fundamental concepts in the integrated design process, as the articulation between them is key to ensuring efficient, sustainable, and viable solutions at every stage of the process. The following section presents the characterisation of native timber, considering its availability, species diversity types of forest ownership, and properties. It also analyses the timber industry in the regions of Araucanía and Los Ríos, evaluating the feasibility of commercialising native timber products in the Chilean market.

The roble-raulí-coigüe forests cover 417,560 hectares in these regions, with no legal or environmental restrictions on management, and are in a condition that would allow for management interventions (Figure 6). Of this area, 68% is located in the Araucanía region (Figure 5). Due to their abundance, these forests present a high potential for management to improve their growth and economic valuation.

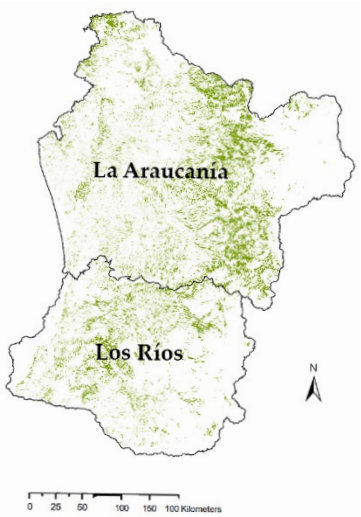



**Figure 6.** Map of roble-raulí-coigüe forest areas in the regions of Araucanía and Los Ríos. Own elaboration.

The harvesting methods considered in this study involve two intermediate thinnings and a final harvest, ensuring regeneration over periods of at least 10 to 15 years. Most interventions correspond to thinning operations until a minimum average diameter is reached. Furthermore, legal provisions require regeneration—either natural or supplemented with planting—to be established within two years after harvesting. These safeguards ensure the ecological continuity of forest ecosystems. Additionally, it is important to consider that the current level of native forest management remains relatively low: as of 2023, only 23% of the national goal of 200,000 hectares sustainably managed by 2030 had been achieved [8]. This low intervention rate supports the conservative approach adopted in the study and underscores the importance of advancing sustainable management practices that balance ecological resilience and productive use.

Using data from the National Forest Inventory (IFN), the species composition was determined in terms of basal area, volume, and tree count. In the Araucanía region, roble, coigüe, and raulí dominate, while in Los Ríos region, roble and olivillo (*Aextoxicum puntactum*) are prominent, followed by coigüe and Ulmo (*Eucryphia cordifolia*).

According to CIREN property data, forest ownership was classified into four categories based on surface area. It was found that small property owners generally produce firewood for self-consumption and require professional support to develop management plans. In contrast, medium and large property owners not only produce firewood but also generate sawn wood and railway sleepers.

The area considered in the projection model amounted to 286,124 hectares in the Araucanía region and 131,436 hectares in Los Ríos (Table 1).

**Table 1.** Area of roble-raulí-coigüe forest by property size (ha). Own elaboration.

| | **Property Size (ha)** | | | | |
|---|---|---|---|---|---|
| **Region** | **≤50** | **50–200** | **200–100** | **>1000** | **Total** |
| La Araucanía | 63,659 | 62,582 | 65,846 | 94,037 | 286,124 |
| Los Ríos | 15,642 | 29,811 | 42,241 | 43,742 | 131,436 |
| Total | 79,301 | 92,393 | 108,087 | 137,779 | 41,756 |
| % | 19% | 22% | 26% | 33% | 100% |

The overall results obtained in this study refer to two contrasting scenarios. The first, referred to as the "Potential" scenario, maximising the supply without imposing any management criteria or the need to meet a specific demand. In this case, the optimisation was solely focused on maximising the possible supply based on the applied management schemes and the estimated growth or yield rates. In contrast, the second scenario, referred to as the "Conservative" scenario, restricted interventions to only 30% of the available area. This limitation was based on a cautious assumption stemming from the current low level of effectively managed land (Table 2). While this proportion may appear modest in relation to the total available area, it aligns with Chile's national climate commitments. Under its Nationally Determined Contributions (NDCs) and the National Strategy on Climate Change and Plant Resources (ENCCRV), Chile has pledged to sustainably manage and restore 200,000 hectares of native forest by 2035. However, recent progress has been slow: data from the 2024 National Climate Action Report indicate that only 23% of this target has been achieved by 2023, with greenhouse gas capture at just 7.7% of the expected level [8]. At the current pace, less than 30,000 hectares would be sustainably managed through incentives under Law 20.283, representing only 15% of the national goal. This conservative intervention level also reflects the need for realism in scaling up native forest management, despite the significant funding received—over USD 89 million from the Green Climate Fund

and the World Bank's Carbon Fund—allocated to reforestation, restoration, and sustainable forestry across the country.

**Table 2.** Area of roble-raulí-coigüe regeneration suitable for management, excluding environmental and protection restrictions. Own elaboration.

| Region | Total Area (ha) | Area Excluding Restrictions (ha) |
|---|---|---|
| La Araucanía | 417,023.98 | 330,397.00 |
| Los Ríos | 197,719.71 | 151,493.00 |
| Total | 614,743.63 | 418,890.00 |

In the "Potential" scenario, the supply could double or even triple the current demand. In the "Conservative" scenario, the Araucanía region would not meet the projected consumption in the first period but would reach adequate levels in the second period. Los Ríos region would achieve this balance by the third period.

The literature review emphasises the importance of sustainable management. If the potential is utilised with technical criteria, the production would be sufficient. However, excessive restrictions would limit the supply. During the first nine years, extraction will be limited to thinning, with no harvests or regeneration cuts, which will begin after the tenth year and gradually increase. Between 2029 and 2031, the contribution of wood from harvest cuts will range from 1% to 4%, increasing to up to 50% by 2044–2046. The definition of log products is provided in Table 3. The types of products to be obtained were defined based on the characteristics of products currently traded in the market, according to information gathered from sawmills and forestry companies.

**Table 3.** Definition of wood product types in logs. Own elaboration.

| Products | Type of Products (Logs) | | | | Characteristics |
|---|---|---|---|---|---|
| | Roble-Raulí-Others | | Coihue | | |
| | Diameter (cm) | Length (m) | Diameter (cm) | Length (m) | |
| P1 | >34 | 3.6 | >50 | 3.6 | High-value sawlogs |
| P2 | >34 | 2.6 | >34 | 3.6 | Peeler logs |
| P3 | >20 | 2.44 | >30 | 2.44 | short sawlogs |
| P4 | >10 | 2.44 | >10 | 2.44 | pulp logs |
| P5 | >5 | 1 | >5 | 1 | firewood |

In the "Potential" scenario, the majority of the supply will come from thin pulpwood and sawlogs, highlighting the need to create higher value-added products. In the "Conservative" scenario, although the supply is lower, there remains a significant yield of usable timber (Tables 4 and 5).

Regarding the timber industry, 66% of the surveyed SMEs use native wood to produce sawn timber, with roble (40%) being the most demanded species, followed by raulí (16%) and laurel (Laurelia sempervirens) (15%). Coigüe and mañío are used to a lesser extent, with preferences of 10% and 5%, respectively. The main clients are individuals (42%), construction companies (20%), and the retail sector (18%). However, sourcing timber remains a challenge: 49% of companies purchase timber from intermediaries, and only 7% have their own supply. Furthermore, 69% lack drying or impregnation equipment, limiting product diversification.

Regarding new products made from native timber, the most promising include doors and accessories (50%), interior and exterior lattices (39%), and interior cladding (36%). However, 63% of SMEs are unaware of their potential market, reflecting a disconnection

in the production chain and the need for strategies to improve information flow and connections between producers and consumers.

**Table 4.** Supply by product type in conservative scenario for Araucanía region (ha). Own elaboration.

| Conservative Scenario—La Araucanía | | | | | | |
|---|---|---|---|---|---|---|
| **Three-Year Periods** | **High Value ($m^3$)** | **Sawlog ($m^3$)** | **Small-Diameter Sawlog ($m^3$)** | **Pulpwood ($m^3$)** | **Firewood ($m^3$)** | **Total ($m^3$)** |
| 2020–2022 | 11,419 | 74,826 | 56,721 | 167,588 | 12,769 | 323,323 |
| 2023–2025 | 41,365 | 201,032 | 160,519 | 386,330 | 26,387 | 815,634 |
| 2026–2028 | 47,018 | 220,419 | 172,986 | 401,038 | 26,388 | 867,849 |
| 2029–2031 | 48,686 | 213,654 | 164,706 | 360,398 | 24,192 | 811,635 |
| 2032–2034 | 67,965 | 305,859 | 237,742 | 487,373 | 33,833 | 1,132,773 |
| 2035–2037 | 50,161 | 232,269 | 176,452 | 358,002 | 19,124 | 836,009 |
| 2038–2040 | 62,510 | 295,744 | 225,130 | 437,540 | 20,905 | 1,041,830 |
| 2041–2043 | 84,459 | 407,965 | 312,501 | 574,505 | 28,152 | 1,407,581 |
| 2044–2046 | 68,469 | 325,834 | 255,249 | 445,122 | 29,249 | 1,123,922 |
| 2047–2049 | 92,813 | 421,516 | 322,153 | 550,105 | 61,539 | 1,448,125 |

**Table 5.** Supply by product type in conservative scenario for Los Ríos region (ha). Own elaboration.

| Conservative Scenario—Los Ríos | | | | | | |
|---|---|---|---|---|---|---|
| **Three-Year Periods** | **High Value ($m^3$)** | **Sawlog ($m^3$)** | **Small-Diameter Sawlog ($m^3$)** | **Pulpwood ($m^3$)** | **Firewood ($m^3$)** | **Total ($m^3$)** |
| 2020–2022 | 4503 | 29,914 | 22,683 | 67,597 | 5163 | 129,858 |
| 2023–2025 | 10,726 | 51,169 | 40,874 | 99,694 | 7088 | 209,551 |
| 2026–2028 | 27,951 | 131,631 | 103,467 | 239,263 | 15,662 | 517,975 |
| 2029–2031 | 18,691 | 82,269 | 63,431 | 138,031 | 9237 | 311,658 |
| 2032–2034 | 36,669 | 165,056 | 128,270 | 262,939 | 18,216 | 611,150 |
| 2035–2037 | 34,048 | 158,195 | 119,560 | 243,367 | 12,294 | 567,465 |
| 2038–2040 | 37,952 | 179,219 | 135,967 | 266,712 | 12,680 | 632,530 |
| 2041–2043 | 40,477 | 195,435 | 149,498 | 275,212 | 13,481 | 674,073 |
| 2044–2046 | 32,570 | 154,650 | 120,883 | 211,172 | 14,262 | 533,537 |
| 2047–2049 | 44,905 | 192,713 | 151,350 | 246,567 | 42,469 | 678,004 |

The survey conducted with architects and consultants in the construction sector revealed that 85% view native timber as an advantage, provided it is sourced sustainably. Additionally, 83% believe it is suitable for use in residential and public projects, particularly for architectural finishes and furniture, rather than for structural purposes. Furthermore, 82% of respondents recognise a growing interest in native timber. However, 65% identify high costs, limited supply, and misinformation as major barriers to its broader adoption.

### *4.2. Prototype Design Validation*

During meetings with experts from the timber sector, such as architects and construction firms, significant market interest in native timber products was evident, particularly for building finishes. Based on these discussions, proposals for prototypes were defined and validated.

The need for standardisation was emphasised, and the potential to develop pieces or components that offer greater flexibility in design was recognised. Demand was identified for elements such as door and window pieces, trims, cornices, and other components. Furthermore, it was noted that there is considerable potential for using native timber in public buildings, where the design of modules and components could accelerate project development whilst also connecting them to local cultural aspects. In this context, it is crucial to consider the labour required to transform these components into final products.

It was highlighted that sustainable forest management could serve as a strategic advantage, adding value both environmentally and socially. This is especially relevant when positioning these products in markets sensitive to the origin and traceability of materials. In line with the goal of strengthening the use of native timber and promoting an integrated design approach within the industry, nine architectural prototypes were developed, which can be applied in both residential and public buildings. These designs are intended to maximise the value of the forest resource and optimise its use in construction (Table 6).

**Table 6.** Architectural product prototypes.

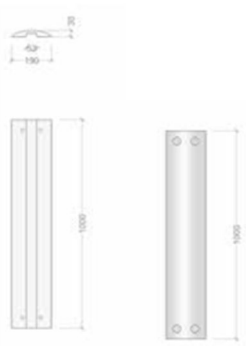
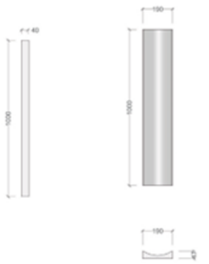
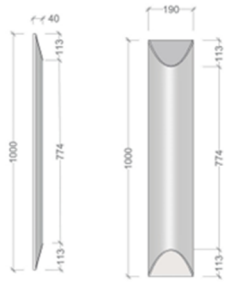
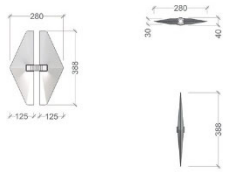
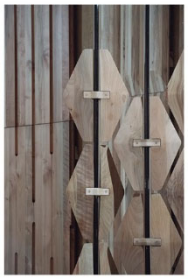
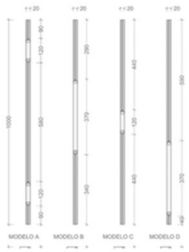
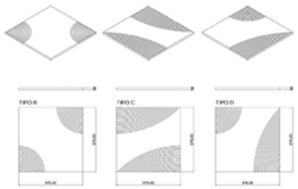
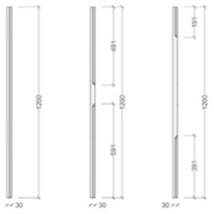
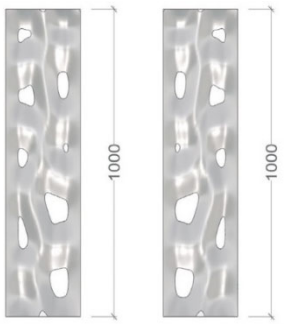
| Name | Module | Image | Description |
| --- | --- | --- | --- |
| Louvre |  | | Modular exterior louvre system. Each panel is machined in two halves and assembled onto a 50×30 mm steel structural core, permitting easy site assembly and flat packing of components for logistics. Also facilitates the removal and replacement of damaged components.<br><br>Manufactured in roble with exterior grade adhesive and finished with Osmo oil exterior finish to ensure the louvres weather correctly. Requires periodic application of finish to ensure durability. |
| Wavy Tile | | | Designed to create a pleasing aesthetic that casts light and shade across the interior wall of a room. Lightweight at under 5 kg per panel permitting easy installation.<br><br>Can be manufactured from a range of timber species for interior use. In this case a panel fabricated from a mixture of coigüe, roble and raulí was used. With the promise of further investigation to confirm possible façade shading properties. |
| Concave |  | | Modular system design to create a continuous undulating surface. Using french cleats to facilitate an easy and economic form to mount continuous units over large wall spans.<br><br>Manufactured in both roble and mixed species panels to demonstrate how different species can be used to achieve different aesthetics. |
| Convex |  | | Modular system design to create a continuous undulating surface. Using french cleats to facilitate an easy and economic form to mount continuous units over large wall spans.<br><br>Manufactured in both roble and mixed species panels to demonstrate how different species can be used to achieve different aesthetics. |

**Table 6.** *Cont.*

| Name | Module | Image | Description |
| --- | --- | --- | --- |
| Petal |  |  | Multi component interior divider system. Each petal is individually machined using a CNC router or pantograph router. The petals are then assembled onto a central axis which includes a hidden bearing allowing each composed unit to spin around its central axis allowing for a customisable experience.<br><br>20 mm anodised steel tubes form the central axis allowing for ease of mounting in a variety of spaces. |
| Profile |  | | Each profile is a variation of the same cut which use the natural form of the router cutter to generate its geometry when combined with diagonal cuts on a table saw. Thus allowing a variety of possible assemblies Using different lengths of positions of cut.<br><br>Designed for ease of manufacture with basic timber processing machinery and limited skill levels. |
| Radial Groove |  | | Modular system that uses a repeated arc cut using a hand router. The position of the arc allows for several panels to be machined separately and joined together to achieve large continuous designs for large wall spans.<br><br>Fabricated from mixed species panels Using a variety of grades of timber to demonstrate the capacity to create larger components where necessary. |
| Vertical Slot |  | | Simple design that uses a variety of basic cuts to the edges of a board to create a repeating pattern.<br><br>Made using boards of roble to show even with very basic equipment, such as a hand router in this case, it is possible to make simple designs that can add value to short boards cut from large lengths of timber for construction that have limited value. |
| Topography |  | | The most geometrically complex design, designed using parametric design and fabricated using a CNC router. It was designed to show SMEs the possibilities made available by incorporating even basic digital design tools into their infrastructure.<br><br>The geometry is completely customisable to create a variation of perforations for back-lighting or complementary material backdrops. With the promise of further investigation to confirm possible acoustic baffling properties. |

While this study did not include laboratory performance testing (e.g., durability or acoustic resistance), the design stage considered the typical environmental conditions to which interior architectural components are exposed. These include fluctuations in humidity, which were addressed by designing panelised systems with precise joints and

separation between elements to accommodate dimensional changes. Furthermore, the feasibility assessment incorporated stakeholder feedback, and market comparisons were conducted to evaluate adoption potential. Although empirical testing remains a future step, the prototypes were conceptually validated in terms of manufacturing feasibility, architectural compatibility, and market relevance through iterative engagement with industry professionals and end users.

### 4.3. Gaps in the Production Process and Strengthening Proposal

After developing the prototypes, the feasibility of production by local companies was assessed. A gap analysis of the industry was conducted to identify the differences between the sector's current capabilities and the requirements necessary for product development. This analysis helped determine the technical, economic, and operational challenges that companies might face when scaling up production. The feasibility of development was based on identifying these gaps and the potential to close them through investments, training, or improvements in production processes. It is important to note that the gap analysis in this stage specifically focused on the production phase within the value chain, without delving deeply into the forest management or final commercialisation stages. This focus was driven by the main objective of the study, which was to assess the technical and productive feasibility of developing new products made from native timber, considering the local industry's capabilities and challenges for large-scale manufacturing. Whilst issues affecting the entire value chain were identified, focusing on the production phase provided precise information on technical, technological, and operational aspects that directly affect the feasibility of designing and manufacturing the developed prototypes.

The main gaps across the production chain included insufficient log supply, rising production costs, and limited demand for native timber. Additionally, the shortage of labour and working capital restricts sector growth. Only 29% of the production units carry out secondary-level processing, which is hindered by the lack of equipment for wood drying, and impregnation. The Business Management Maturity Index highlighted significant gaps in commercial management, productivity, and product certification within the timber sector. Whilst some forestry companies have more solid financial and strategic management plans, sawmills and timber traders need to strengthen their planning, digitalisation, and access to new markets to enhance their competitiveness.

Table 7 outlines the identified gaps for various actors within the production chain, including forest owners, sawmill owners, timber processors, and traders (construction companies, carpenters, hardware stores, etc.), along with proposed strengthening actions. Additionally, the previous sections have identified challenges that affect end users, such as architects, designers, and construction companies. This comprehensive perspective is key to strategically addressing sector issues and ensuring an approach that encompasses the entire production process, from raw materials to their market application.

These gaps highlight the need to develop integrated strategies that strengthen forest management, optimise production costs, and improve the quality of the final product, while also consolidating a more efficient and sustainable supply chain. In this regard, the Integrated Design Process (IDP) applied during the project facilitated the involvement of key stakeholders in the production sector, identified the obstacles present in the production phase through a participatory approach, and, as a result, proposed solutions aligned with the system's capabilities and challenges. Therefore, the proposed strengthening actions aim not only to address specific issues but also to make collaborative design processes, such as the IDP, feasible and scalable. In this approach, the design of value-added products is not an isolated outcome, but part of a broader strategy that contributes to

enhancing the sustainable management of native forests, promoting territorial coordination, and strengthening the competitiveness of the local industry.

**Table 7.** Gaps and strengthening proposals in the production chain. Own elaboration.

| Links | Gaps | Strengthening Proposals |
| --- | --- | --- |
| ***Forest Owners*** | Lack of market information hinders positioning and strategic decision-making, limiting the sector's ability to identify opportunities and adapt to demand. | Optimization of the value chain from production to commercialization, through comprehensive management covering production, commercialization, finance, operations, communication, and client relations. |
| | Economic fluctuations and a shortage of specialized labor negatively impact operations, while high production costs reduce profitability and competitiveness compared to exotic species. | Business segmentation to apply tailored strategies, along with a systemic approach that aligns operations with market demands, resource optimization, and product development. |
| | Uncertainty caused by territorial conflicts and forest fires affects long-term planning and increases operational risks across the sector. | Promotion of stakeholder collaboration, continuous iteration, and capacity building through training and financial advisory, supporting strategic planning and sustainable forest management in line with the PDI's objectives. |
| ***Sawmill Owners*** | Lack of structured management, sectoral coordination, and strategic planning limits market alignment, integration into the value chain, and overall sector consolidation. | Enhancing sector efficiency through continuous improvement, integrated design, and the optimization of internal management and the supply chain, fostering innovation, responsiveness, and financial planning. |
| | Economic dependence, low diversification, and commercial informality increase financial risks, reduce competitiveness, and hinder market differentiation. | Promoting collaborative strategies and stakeholder coordination to strengthen integration, increase bargaining power, and consolidate stable markets through economic diversification and higher value-added exports. |
| | | Advancing quality through the implementation of standards, certifications, and technology adoption, ensuring product reliability, competitiveness, and value addition in native wood markets. |

**Table 7.** *Cont.*

| Links | Gaps | Strengthening Proposals |
| --- | --- | --- |
| ***Wood Processors and Marketers*** | Financial instability, limited availability and high cost of native wood, and logistical difficulties restrict production capacity and hinder control over the supply chain. | Improving customer experience and service through proactive sales strategies, market segmentation, and enhanced logistical efficiency to boost productivity and expand market reach. |
| | Lack of quality protocols and dependence on vertically integrated sawmills reduce scalability, exclude other stakeholders, and lead to inconsistent products and economic losses. | Strengthening financial planning and resource management to reduce economic vulnerability, while fostering strategic alliances that open access to new markets and enhance competitiveness in line with PDI's innovation and sustainability goals. |

## 5. Discussion

In Chile, the native timber value chain remains highly fragmented, with limited interaction among forest owners, sawmills, manufacturers, and distributors. This disconnection weakens traceability, hinders innovation, and restricts value creation within the regions of origin. The IDP offers a clear pathway to address these systemic inefficiencies by promoting iterative development and early coordination amongst actors, from raw material suppliers to designers and managers. This model not only aligns product development with environmental goals but also tackles social concerns, such as user scepticism regarding native timber's durability and fire resistance, particularly in the Los Ríos region [12,13].

The global transition toward more collaborative production models highlights the necessity of adapting these frameworks to local contexts, regulations, and cultural practices. This adaptation demands not only technical shifts but also systemic changes in structure and mindset—moving beyond fragmented models to more integrated approaches that enhance efficiency, sustainability, and innovation [63,64]. In this regard, the Integrated Design Process (IDP) has emerged as a promising strategy for Chile's native timber sector. The findings of this study indicate that IDP improves coordination across the value chain, fosters ecological, economic, and social sustainability, and enhances the competitiveness of native timber products in both national and international markets. It encourages the use of lesser-known species and small-diameter logs, supports traceability, reduces waste through design customisation, and promotes territorial innovation through stakeholder collaboration.

Notably, the project demonstrated that transitioning to a more integrated design model is feasible, even in contexts with outdated equipment and regulatory constraints. Nine prototypes were developed using short-length logs (1.2–2 m) and small diameters (14–30 cm), which are typically underutilised in traditional industries. Survey results showed that 83% of respondents considered these products viable for residential and public applications.

The IDP also plays a crucial role in this case by pairing specialists in timber fabrication in the South of Chile with timber suppliers during the development of products allowing both parties to understand the limitations and opportunities provided by their respective fields. Although this was realised in this study by incorporating the project team into discussions with timber suppliers, this was a short-term solution. To have a further impact on the industry this initial exercise will need to be complimented by training, education, and infrastructure investment to bridge the gap between the existing products traditionally elaborated by SMEs in comparison to the prototypes presented.

Currently, the majority of IDPs concerning architectural timber products or components are conducted at high levels of technological application. Processes such as Design for Manufacture and Assembly are incorporated through parametric and generative design to increase efficiency

and to respond to new materials based directly on their physical properties. Or at a more macro scale, looking to increase logistical efficiency and customisability through modular assembly and algorithmic design of large-scale buildings. Ultimately these cases seek to improve sustainability in the industry as is the case with the research conducted [65–68]. However, the process developed here diverges from international cases by responding to Chile's unique institutional and industrial conditions, namely, the lack of regulatory mandates for IDP, structural constraints in SMEs, and limited market integration of native timber products. Whilst IDP, in high-income contexts, is often supported by established standards and incentives, in Chile it must be adapted to fragmented value chains, underutilised resources, and decentralised governance structures. Thus, the research contributes new insights by showing how a collaborative design methodology can be contextually tailored to promote sustainable forest management, product innovation, and regional development under these specific local constraints [51,69,70]. To synthesise the main insights discussed, Table 8 outlines three key dimensions: structural barriers in the native timber value chain, the strategic contribution of the Integrated Design Process (IDP), and the main challenges for its implementation in the Chilean context.

**Table 8.** Summary of key barriers in the native wood value chain, the potential of the Integrated Design Process (IDP), and implementation challenges in the Chilean context.

| Key Barriers in the Native Wood Value Chain | Integrated Model (IDP): Potential | Challenges for Implementation |
| --- | --- | --- |
| Disarticulated value chain<br>Structural isolation among forestry, design, and construction actors hinders integrated development. | Enables cross-sector alignment<br>From forest to final product. | Scalability<br>Requires adaptation to limited local infrastructure. |
| Limited resource utilization<br>Conventional production standards exclude alternative wood types and formats. | Redefines design constraints as opportunities<br>IDP allows rethinking material selection criteria and encourages innovative uses of non-conforming resources. | Standards and certification<br>Lack of standardization and regulation for non-traditional products. |
| Technological gap in processing capacity<br>Technical limitations restrict the feasibility of advanced or value-added product lines. | Supports incremental innovation<br>IDP encourages design solutions calibrated to existing tools and workflows, fostering feasible innovation pathways. | Investment in technology<br>Needs for drying, impregnation, and manufacturing processes. |
| Information asymmetries and weak demand articulation<br>Producers operate with limited insight into architectural trends and user preferences. | Facilitates demand-driven innovation<br>IDP links producers with specifiers (architects, designers), enabling product development based on real use cases. | Professional training and culture<br>Shift toward interdisciplinary collaboration. |
| Perception of low market value<br>Native wood is not generally perceived as a premium or high-performance option. | Builds cultural and symbolic value<br>Through participatory narratives and emphasis on origin, IDP helps reposition native wood as a meaningful material. | Coordinated governance<br>Overcoming institutional duplication and isolated platforms. |

The adoption of new technologies and technical education in Southern Chile also poses a contextual limitation in the ability to propose economically sustainable designs. Technologies such as CNC manufacture, 3D scanning, Mixed reality and Big Data would allow for the efficient and rapid digitisation of small pieces which can then be traced, assembled, and machined with more precision and less waste, thus greatly reducing production costs and technical ability of the workforce. However, there is traditionally a low uptake of these technologies due to their high investment for start-up, a lack of technical ability in the workforce to maintain and operate machinery once installed, and general scepticism concerning their complexity and return on investment. Designers are also limited in their experience in fabrication processes utilising native timbers and struggle to provide designs that do not require technical intervention to prepare 3D CAD files and translate their designs into feasible products. As a result, the prototypes presented were forced to focus on more traditional manufacturing methods for the most part, thus limiting their cost effectiveness, efficiency, and scalability [13,71,72].

Policy and regulatory frameworks play a vital role in scaling these strategies. Currently, IDP is not mandatory in Chile but is promoted through voluntary certifications such as LEED, CES, EDGE, and CVS, which encourage early-stage coordination and sustainability-focused design decisions. However, broader adoption requires robust governance and incentive structures. Participatory strategic forest management has been recognised as an effective model for aligning governance, sustainability, and industrial development goals [19,22,73]. Yet existing initiatives often operate in isolation, leading to duplicated efforts and reduced impact. A centralised coordination body could strengthen current programmes, link them with the Sustainable Construction Strategy of the Ministry of Housing and Urbanism (MINVU), and foster integrated development through incentive mechanisms that highlight the sustainable attributes of timber products.

Beyond operational improvements, unlocking the sector's full potential requires public policies that promote integrated forest resource management. This includes enhancing transparency and data availability across the value chain, supporting investment in advanced technologies, and expanding access to new markets and certification systems.

## 6. Conclusions

The results indicate that Chile's native wood sector faces significant challenges, including fragmented value chains, underutilisation of small-diameter logs, and limited market confidence. These issues threaten both forest sustainability and rural livelihoods, highlighting the urgent need for innovative strategies to revitalise the sector. A market gap analysis further identified key constraints within the current industry structure, such as low supply, limited demand, and insufficient technological development—particularly in the production of value-added wood products.

The study has also demonstrated the relevance and effectiveness of the Integrated Design Process (IDP) as a systemic and collaborative methodology for addressing long-standing challenges in the native timber industry of southern Chile. Through its application, the research bridged critical gaps between raw material availability, underutilised forestry resources, and the development of context-sensitive, value-added products. The interdisciplinary and iterative nature of IDP enabled the coordination of fragmented actors in the forestry and construction sectors, fostering early-stage collaboration and aligning design objectives with local resource constraints, user needs, and sustainability goals. In addition, the integrated approach enabled the exploration of a more sustainable production model, illustrating to the various partners involved, how through innovative processes such as IDP, value can be added to the short lengths of timber often yielded from sustainably managed native forests.

From an environmental and resource management perspective, the IDP approach contributes to more sustainable forestry practices by promoting the inclusion of underutilised species and enhancing the long-term viability of sustainably managed forests through improved market access. The study confirmed the potential of this strategy, revealing that second-growth roble-raulí-coigüe forests in the Araucanía and Los Ríos regions span over 417,000 hectares without legal restrictions on management. Sustainable harvesting could be applied annually to between 15,000 and 43,000 hectares in Araucanía and 6000–19,000 hectares in Los Ríos, with 46% of the projected harvested volume suitable for sawn timber—most of which currently remains underutilised. In addition, interviews with woodworking SMEs revealed that 66% already use native timber; however, utilisation remains limited due to the prevalence of short and thin logs, which reduces the potential for higher-value applications.

The development of nine prototypes, including modular interior claddings and lattices made from lesser-valued species and small-diameter logs, not only validated the technical viability of native timber in architectural contexts but also highlighted the potential for innovation and added value across the supply chain. By structuring the design process around a user-centred and environmentally conscious framework, the study has shown how design can be a transformative tool in shifting perceptions of native timber, particularly in regions such as Valdivia, where concerns around fire resistance, durability, and environmental impact persist.

Although the results of this study are promising, it is important to acknowledge its limitations. The geographic focus on the Los Ríos and Araucanía regions, while appropriate for a context-specific analysis, limits the broader applicability of the findings at the national or international level. Additionally, the scope of the research was centred on design and pre-commercial validation; therefore, aspects such as long-term durability, user behaviour in real-life settings, and full market deployment were not assessed. The technical feasibility of large-scale manufacturing and the adaptation of local industry infrastructure remain areas also requiring deeper examination. These limitations may affect the scalability of the proposed solutions and should be addressed in future applied research. Beyond operational improvements, unlocking the sector's full potential requires public policies that promote integrated forest resource management. This includes enhancing transparency and data availability across the value chain, supporting investment in advanced technologies, and expanding access to new markets and certification systems. Finally, although stakeholder engagement was a core part of the methodology, the degree of industry-wide adoption remains to be evaluated.

Future research should expand the application of IDP to other regions and explore its scalability across diverse forest ecosystems and market contexts. Complimentary studies should focus on examining the environmental performance, market acceptance, and economic feasibility of the developed prototypes by integrating policy analysis, life-cycle assessments, and more advanced testing of acoustic and aesthetic properties. Particularly their performance under varying humidity conditions and the effectiveness of maintenance and protection treatments. Additionally, the design format could be re-evaluated, potentially at a smaller scale, to reduce weight and facilitate installation. A deeper examination of appropriate fastening systems is also recommended. However, the most critical next step lies in conducting operational-scale testing, especially considering the positive reception these products have received from stakeholders who evaluated the prototypes firsthand. This research could also continue to improve on the IDP methodology used by more actively incorporating industry partners into the design-to-manufacture process undertaken. Thereby addressing the challenges of incorporating new technologies by pairing interested industrial partners with academics who can aid in the development of fabrication lines for new products made from low-value native timbers.

Despite the challenges that still need to be addressed and further explored in terms of research and implementation, the results indicate that by continuing to align design

innovation with ecological stewardship and local development, IDP offers a replicable and adaptable model for advancing circular, inclusive, and resilient bioeconomies. In doing so, it helps tackle the significant structural challenges faced by local industries that limit their ability to scale processes and meet market demands.

**Author Contributions:** Conceptualization, A.S., M.M., C.B., M.R. and M.A.; methodology, A.S., M.M., C.B., M.R. and M.A.; validation, A.S., M.M., C.B., M.R. and M.A.; formal analysis, A.S., M.M., C.B., M.R. and M.A.; investigation, A.S., M.M. and C.B.; resources, A.S., M.M., C.B., M.R. and M.A.; data curation, A.S., M.M. and C.B.; writing—original draft preparation, A.S. and S.G.; writing—review and editing, A.S., M.M., C.B., S.G., M.R. and M.A.; visualisation, A.S., M.M., C.B., S.G., M.R. and M.A.; supervision, A.S., M.M. and C.B.; project ad-ministration, A.S. and M.M.; funding acquisition, A.S., M.M. and C.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Native Forest Research Fund (FIBN) of the National Forest Corporation (CONAF) through the FIBN 008/2021 project, "Innovating in the design of products made from native woods of roble-raulí-coigüe in the regions of Araucanía and Los Ríos".

**Data Availability Statement:** The data sets presented in this article are not readily available be-cause they have privacy restrictions.

**Acknowledgments:** This research also received support from Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD), ANID BASAL FB210015, and the Centro de Desarrollo Urbano Sustentable (CEDEUS), ANID FONDAP N○1523A0004. The project team would like to thank the collaboration of the partners: School of Architecture—Universidad Austral de Chile, Material Design Laboratory (MADlab)—Universidad Autónoma de Chile, Cámara Chilena de la Construcción (CChC)—Valdivia, Architecture Department—Ministry of Public Works of Chile (MOP), Housing and Urbanization Service (SERVIU)—Los Ríos Region, Compite S.A. We also acknowledge and appreciate the participation and support of the National Forest Corporation (CONAF), and Aprobosque.

**Conflicts of Interest:** The authors declare no conflicts of interest. The funders had no role in the study's design, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| AIFBN | Agrupación de Ingenieros Forestales por el Bosque Nativo (Association of Forestry Engineers for Native Forests, Chile). |
| CCHC | Cámara Chilena de la Construcción (Chilean Chamber of Construction). |
| CIREN | Centro de Información de Recursos Naturales (Center for Natural Resources Information, Chile). |
| CONAF | Coproración Nacional Forestal (National Forest Corporation, Chile). |
| CORFO | Corporación de Fomento de la Producción (Corporation for the Promotion of Production, Chile). |
| CORMA | Corporación Chilena de la Madera (Chilean Wood Corporation). |
| CTEC | Centro Tecnológico para la Innovación en Productividad y Sustentabilidad en la Construcción (Technology Center for Innovation in Productivity and Sustainability in Construction). |
| GORE | Gobierno Regional (Regional Government. |
| IDP | Integrated Design Process. |
| IFN | Inventario Forestal Nacional (National Forest Inventory, Chile). |
| IMGP | Indice de Madurez de Gestión Empresarial (Business Management Maturity Index). |
| INFOR | Instituto Forestal (Forestry Institute, Chile). |
| MINVU | Ministerio de Vivienda y Urbanismo (Ministry of Housing and Urban Development, Chile). |

| | |
|---|---|
| MOP | Ministerio de Obras Públicas (Ministry of Public Works, Chile). |
| SERVIU | Servicio de Vivienda y Urbanización (Housing and Urbanization Service, Chile). |
| SMEs | Small and Medium-sized Enterprises. |

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