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DEVELOPMENT OF AN INTEGRATED SUSTAINABILITY AND STRUCTURAL SAFETY INDICATOR, APPLIED TO CENTRAL CHILE FOR THE WOODEN HOUSING MARKET[1]

DESARROLLO DE UN INDICADOR INTEGRADO DE SUSTENTABILIDAD Y SEGURIDAD ESTRUCTURAL PARA EL MERCADO DE VIVIENDAS DE MADERA APLICADO A CHILE CENTRAL

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RESUMEN

El mercado de viviendas en Chile, basado en madera, requiere una revisión complementaria en función de las ventajas competitivas que posee este material respecto a sus prestaciones técnicas y propiedades estructurales, para fortalecer el cumplimiento de la Ordenanza General de Urbanismo y Construcción [OGUC] chileno y los Códigos de Construcción Sustentables. En ese marco, el objetivo central de la presente investigación fue desarrollar un Indicador Integrado de Seguridad y Sustentabilidad (IISS) capaz de integrar aspectos normativos, sociales, territoriales y ambientales, conforme a las variables: (1) presentación, (2) sustentabilidad y (3) seguridad de una vivienda. Para esto, se recopiló información de 230 empresas constructoras en madera localizadas entre las regiones de Valparaíso y Los Ríos, en Chile Central; proceso en el que destacó la presentación del producto y la seguridad como insumos para aplicar la metodología de cálculo del IISS. Esta integración dio como resultado una clasificación de indicadores técnicos útiles para fomentar la utilización del material madera como opción constructiva que prevalezca o se complemente con otro tipo de materias primas.

Palabras clave
viviendas de madera, seguridad, sustentabilidad.

ABSTRACT

The wood-based housing market in Chile requires a complementary review that considers the competitive advantages of this material regarding its technical features and structural properties, to strengthen compliance with the Chilean General Urban Planning and Construction Ordinance (OGUC, in Spanish) and the Sustainable Building Codes. The purpose of this research was to develop an Integrated Sustainability and Safety Indicator (IISS, in Spanish), which integrates regulatory, social, territorial, and environmental aspects, considering (1) presentation, (2) sustainability, and (3) safety variables for wooden houses. For this, information was collected from 230 wood construction companies located between the regions of Valparaíso and Los Ríos, in Central Chile, where product presentation and safety were highlighted as inputs to calculate the IISS. This integration resulted in a classification of useful technical indicators to promote wood use as a construction option that prevails over or complements other building options.

Keywords
Wooden houses, Safety, Sustainability

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INTRODUCTION

Several studies (Domljan & Janković 2022, Soust-Verdague, Moya & Llatas, 2022, Harju, 2022; Luhas *et al.*, 2021; Andac, 2020; Toppinen, D'amato & Stern, 2020; Bugge, Hansen & Klitkou, 2016; Ollikainen, 2014; Cai & Aguilar, 2013; Cai & Aguilar, 2014) have emphasized that the consumption of forestry products is essential to improve and promote the quality of people's lives, sustainable development, and a transition towards biological-based circular economies. In this context, wood as a building material stands out with its sustainable properties (Viholainen *et al.*, 2021; Brusselaers, Verbeke, Mettepenningen & Buyesse, 2020), longevity in use (Luo, Mineo, Matsushita & Kanzaki, 2018), positive impact on the living environment (Harju, 2022; Rhee, 2018; De Morais & Pereira, 2015), aesthetic perception (Lähtinen *et al.*, 2021; Bhatta, Tiippana, Vahtikari, Hughes & Kyttä, 2017), carbon storage properties, and the reduction of greenhouse gas emissions (Lippke *et al.*, 2011; Petersen & Solberg, 2005).

From this approach, instruments are needed in Chile to objectively evaluate the wooden houses available on the market, and identify the advantages and disadvantages involved in building with this material, in compliance with mandatory and voluntary technical criteria. The problem identified in Chile is that the coherence of public and private bodies responsible for monitoring what is sold, and how offered wooden houses are installed, is unresolved since there are no tools for consumers to know what to look for when buying. This situation is related to factors such as the housing deficit (Fundación Vivienda, 2019; Vergara & Reyes, 2019), the shortage of supply, the applicability of subsidies linked to rising prices, and also the migratory effect. The purchase decision is mainly based on accessible prices and aesthetic visual attributes. In fact, there is a significant number of homes that are not being registered and revised. Added to this, there is a lack of information that consumers have access to before buying homes, regarding the technical benefits of wood.

In the Chilean regulatory area, according to the urban planning and construction law D.F.L. N°458 of 1976, wooden buildings, as well as those made of other materials, are obliged to build with systems registered and recognized by the Chilean Ministry of Housing and Urbanism. Compliance with these standards, as well as other voluntary ones found in sustainable building codes, including life-cycle analysis and carbon footprint measurements, is key to leading the productive sector towards higher habitability standards, where, until now, no background information quantifies the compliance of these provisions in the wood construction market (Castle, Garay, Tapia, Garfias & Orell, 2020).

The lack of standardization and availability of technical information is also supported by the shortage of products marketed under the Chilean Norm NCh1207 for the visual classification of radiata pine, a situation that was revised and ratified in the Chilean Scientific and Technological Development Fund (FONDEF, in Spanish) project, (IT16i10003), referring to critical infrastructure standards for homes located in urban-forest interface areas. There, the technical terms and conditions for the first design of an integrated system of safety and quality indicators for wood-based infrastructure were formulated, comparing Chilean and foreign standards based on the premise of establishing comparable conditions between one country and another (Castle *et al.*, 2020). From this experience, Garay, Pfenniger, Castle, and Fritz (2021a) submitted an IISS proposal to highlight the competitive advantages of wood construction elements and components, that is to say, emphasizing these on facing the demands the buyer market has so that they might be included by the supplier market to position wood as a reliable and standardized product.

In particular, the integrated safety and sustainability indicator (IISS) constitutes a value that is obtained by an analytical evaluation model applied to a product, considering the criteria that describe the competitive advantages of different construction typologies. As mentioned above, the IISS has been created for other wood products and published in previous research, including the Latin American Congress of Wood Structures (CLEM CIMAD 2019), and the Wood Conference Timber Engineering (WCTE 2021). Likewise, the IISS is an integrated indicator that allows evaluating technical, regulatory, social, and environmental aspects that condition sustainability and safety, in addition to the product presentation. In this way, importance is given to the quality and benefits of these elements for housing, while contributing for people to live in safe conditions.

The current analysis of the wood-based housing market indicates that the productive sector has the necessary potentialities to make progress with an offer that fits construction standards, due to advantages such as a low carbon footprint (compared to other materials), industrialization capacity, the adoption of domestic and international standards, and seismic, thermal, and acoustic efficiency. Measuring and revealing the technical attributes of wood allows for strengthening its weaknesses, for example, using wood preserved according to its exposure risk, giving protection against fire and biodegradation, as well as other threats linked to the location (Garay, Castle & Tapia, 2021b), which must be considered from the design, and evaluating each situation individually in advance. At the same time, there are pending tasks related to housing installation and commissioning considering the location, natural hazard conditions, and increased population demand. In this sense, many Chilean regulations currently state these aspects, but they do not have a legal weight that allows their inspection in the construction plans.

METHODOLOGY

The study material is a set of wooden houses based on the manufacturing processes of 230 companies from the field, located in the regions of Valparaíso, O'Higgins, Maule, Ñuble, Biobío, Araucanía, Los Ríos, and Metropolitan. The method consisted of the identification and cadaster of companies offering wooden homes on their web pages, which was followed by the creation of records on building typologies and their individual characterizations (based on the relevant information provided by the company for their product), classified under three criteria: (1) presentation (*Pt*); (2) sustainability (*St*); and (3) safety (*Sg*), which are explained and detailed in Figure 1A. The *Pt* attribute covers the product and company presentation, along with the services and after-sales of the product. This attribute is explained, given that companies must provide an after-sales service that leaves the consumer satisfied, and that is efficient in providing solutions for any issue. The *St* attribute is based on the construction standards and certifications that should be adopted, such as airtightness, carbon footprint, life cycle analysis, process quality, efficiency and innovation, and the acoustic and thermal characteristics of the wooden houses offered. Finally, the *Sg* attribute contemplates aspects regarding the durability of the houses and particularly their behavior when facing a fire, included in the OGUC. The information record incorporates and describes the presence or absence of this information for the houses offered, as well as their details and relevant explanations.

After completing the registration, the IISS values were determined for the different houses offered in the studied regions. In this way, the approach for the integrated indicator (IISS) was outlined, based on available regulatory information, and information from the registry. The analytical method of Saaty (2001), who suggests a sequence of calculations based on a combination of criteria that characterize the mathematical associativity between variables and their interrelationships, was used for this, giving, as a result, a consistency matrix, which contributes to the description of the dependent variable, in this case, IISS. This methodology is used based on the research published by Garay, Tapia, Castillo, Fernández & Vergara (2018); Garay *et al.* (2021a); Garay *et al.* (2021b); Garay, Pfenniger & Castillo (2021c).

The determination of the IISS began with the application of a Multicriteria Evaluation (MCE) or Analytical Hierarchy Method (AHP) proposed by Saaty (2001), which is used in the decision-making of multiple criteria and study variables to select a set of criteria based on different alternatives (Figure 1B). This methodology allows (1) identifying the parts of the system; (2) recognizing the weight of the system's parts; (3) identifying the links between parts; and (4) proposing a rational solution. It is also based on three principles: the construction of hierarchies, the establishment of priorities, and logic consistency. All this becomes necessary to avoid an arbitrary evaluation based on prejudices.

DEFINITION OF CRITERIA AND VARIABLES

The prompt definition of criteria and variables allowed identifying the attributes and their interactions following the layout found in Figure 1B. These attributes were determined as a result of onsite analysis and observations, as well as from the websites of companies that build wooden houses, and refer to the type of materials used, the market they cover, and the economic, social, and environmental context where these companies operate.

These criteria are structured in three main lines, that are detailed in Figure 1A: (1) Presentation; (2) Safety, and (3) Sustainability. Given that the IISS aims at encouraging the use of wood and highlighting the value of the structural advantages, and their techniques, it is of interest to evaluate the marketing strategies of the company and its after-sales service. Therefore, Presentation (*Pt*) seeks to identify the most relevant components reported to highlight the positive perception of wood to a successful customer acquisition; Safety (*Sg*) and Sustainability (*St*) were evaluated for the presence of the technical components declared, observed, or verified using the building rules of the OGUC and the sustainable building codes of the Chilean Ministry of Housing and Urbanism.

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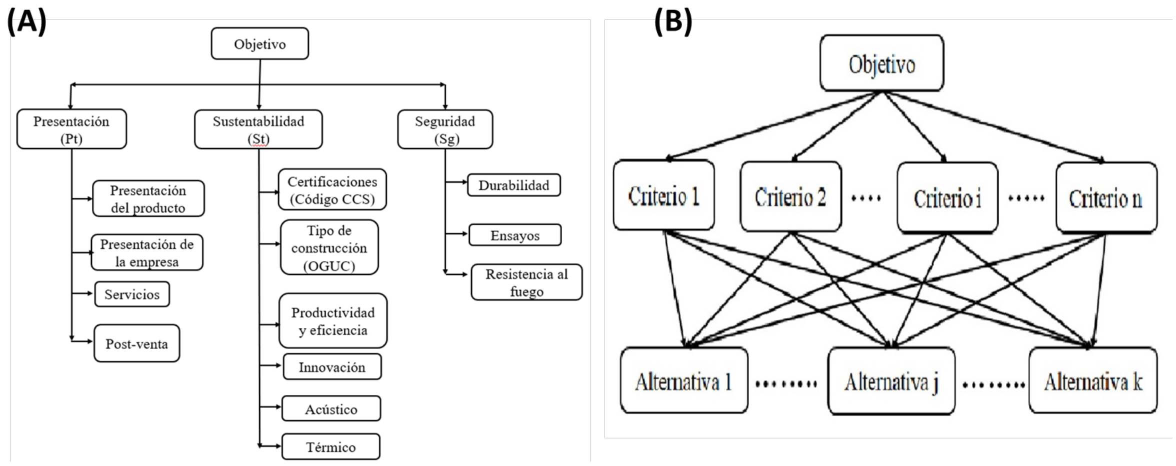

Figure 1. (A) Proposed layout of the Integrated Safety and Sustainability Indicator. (B) Standard model structure in the MCE methodology.
Source: Preparation by the authors using Saaty (2001).

1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	4	5	6	7	8	9
Extreme		Strong			Moderate			The same			Moderate			Strong		Extreme
				Less important									More important			

Table 1. Priority setting scale.
Source: Preparation by the authors based on Saaty (2001).

n=3	Presentation (Pt)	Sustainability (St)	Safety (Sg)
Presentation (Pt)	1	$1/A_{21}$	$1/A_{31}$
Sustainability (St)	A_{21}	1	$1/A_{32}$
Safety (Sg)	A_{31}	A_{32}	1

Table 2. Example of a peer comparison matrix, where A_{21}, A_{31}, and A_{32} are the possible assigned scores and "n" is the number of variables.
Source: Source: Preparation by the authors based on Saaty (2001).

SCORE ASSIGNMENT

Following the method's second principle, each element is given a value based on a scale proposed by Saaty (Table 1), which reflects its weight, relative importance, or magnitude of preference. The assignment is made using a consensus at an average value designated by a panel of experts from the construction area (in this case 2 academics, 2 businessmen, and a government representative, all anonymous), who support the regulations and engineering related to the subject, provide ad hoc bibliography, and also review the analysis of the web pages of 230 companies in the sector.

The designation of these weights follows the peer comparison methodology of the same author, namely, where the importance of one factor compared to another is established. These were presented in a square matrix, with the number of rows and columns determined by the number of factors to be weighted, as shown in Table 2.

Then the *eigenvector* or *own vector* of the matrix is determined, which represents the order of priority of the factors. To do this, the values of the scores or weights established before are standardized, dividing each value of the comparison matrix by the total sum of the values of the column that corresponds to the value, as shown in equation 1, which results in what is expressed in Table 3.

$$N(Aij) = \frac{Aij}{\sum_{i=1}^{j=n} Aij} \qquad (1)$$

Where:
N(Aij) = Standardized value of the judgment in criteria matrix of row "i" in column "j".

n=3	Factor 1	Factor 2	Factor 3	Peso Final
Factor 1	N(1)	N(1/A21)	N(1/A31)	$\sum N(A1i)/n = \beta 1$
Factor 2	N(A21)	N(1)	N(1/A32)	$\sum N(A2i)/n = \beta 2$
Factor 3	N(A31)	N(A32)	N(1)	$\sum N(A3i)/n = \beta 3$

Table 3. Standardized matrix. Source: Preparation by the authors

Matrix size (N)	2	3	4	5	6	7	8	9	10
Random index (Ri)	0	0,6	1	1,1	1,2	1,3	1,4	1,5	1,5

Table 4. Random consistency index value. Source: Preparation by the authors based on Saaty (2001).

Aij = Judgment value in the criteria matrix of row "i" in column "j".

Adding up the rows of the standards values yields the main *eigenvector*

$$\text{Eigenvector principal} = \sum_{i=1}^{j=n} N(Aij) \qquad (2)$$

The main *eigenvector* is standardized by dividing the result by the number of criteria in the matrix, which comes from the matrix of equation 2 (Saaty, 2001). The latter result is a percentage value that represents the weight value of each factor of the variables.

To confirm the validity of the assignment of scores or the relative importance of these final weights, the Consistency Ratio (Rc) is calculated, using equation 3.

$$(\mathrm{Rc} = \mathrm{Ic}/\mathrm{Ri}) \qquad (3)$$

Where:
Rc: Consistency ratio (*Rc*),
Ic: Consistency Index (*Ic*),
Ri: Random index, a value contained in a table created at the Oak Ridge National Laboratory, which is characteristic for matrices from 1 to 15 (Table 4).

While *Ic* is a value obtained from equation 4:

$$Ic = (\lambda \max - n)/(n-1) \qquad (4)$$

Where:
n = number of factors of the matrix
$\lambda_{max.}$ = calculated from the sum of the resulting values of the result of the main eigenvector (β*1*, β*2*, and β*3*) with the score assignment matrix.

This is how, based on the methodology proposed by Saaty (2001) for values greater than or equal to 0.10, the value judgments must be reviewed, since they are not consistent enough to establish the weights.

To ensure the correct application of the AHP method, this combination must be done both at the level of criteria and variables within the criterion (level 1 and 2, respectively).

IISS CALCULATION

The IISS calculation consists of the sum of the result of percentage values (weights or relative importance) between the criteria (level 1) and their respective variables (level 2), and an additional assigned score from 1 to 5, where 1 represents the worst situation for the product evaluated, and 5, the best one. Each level is detailed and described in an evaluation spreadsheet.

$$IISS=C1*V1*P1+C1*V2*P2+\ldots+C2*V1*P1+C2*V2*P2+\ldots+C3*V1*P1+C3*V2*P2+\ldots \qquad (5)$$

Where:
C_i: decimal or percentage value of the general criteria (*Pt*, *St*, and *Sg*)
V_i: Decimal or percentage value of the variable included in the general criterion.
P_i: Score assigned to the study variable, with 1 being low compliance and 5 being the one with the highest compliance.

From this model, the percentage value or relative importance of the variable alone within its respective criterion can be defined as a "local weight" (V_i in the model), and the result Ci x Vi as a "global weight", which accounts for its importance throughout the model.

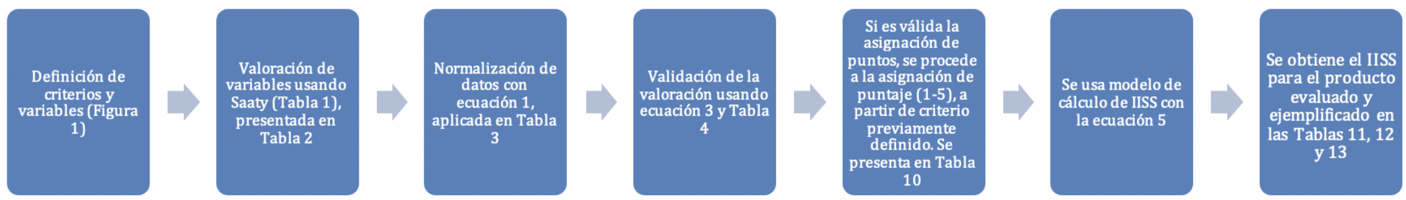

Figure 2. Methodological sequence for IISS weighting and consistency evaluation. Source: Own preparation

Description	Intervals		
Low	1	-	2,33
Medium	2,33	-	3,67
High	3,67	-	5,00

Table 5. Characterization interval for the IISS.
Source: Preparation by the authors.

	Presentation	Safety	Sustainability
Presentation	1	2	3
Safety	0,5	1	2
Sustainability	0,33	0,5	1

Table 6. Cross-per matrix for the levels of the three criteria (Pt; Sg; St). Source: Preparation by the authors.

IISS WEIGHTING AND CONSISTENCY ASSESSMENT

At this stage, the following hierarchy was established, based on the information collected and analyzed from the 230 companies consulted:

Presentation (*Pt*); Safety (*Sg*); Sustainability (*St*)

The classification of the information provided by each company for their product is classified according to these three criteria, considering the importance with which these are presented and described through the internet as a means of dissemination and acquisition of goods and services, with suggestive power from visual stimuli, as well as learning power (de Lourdes, 2006). For this, the website must comply with different accessibility parameters (Varas, Agüero, Guzmán & Martínez, 2015), whose emphasis should be placed on identifying the most relevant components, including technological and technical compliance, and sustainability, which are part of the production chain. This method was used due to the difficulties of direct access caused by the COVID 19 pandemic.

Regarding the criterion associated with safety, the structural properties against earthquakes and fire are considered as most relevant, given the importance users give them, especially in the domestic context, that is prone to earthquakes and fires (Castle, *et al.*, 2020, Garay *et al.*, 2021a). In addition to this, companies, especially small ones (SMEs), still consider that sustainable construction implies an extra cost, which the client cannot pay (Fajardo, 2014; Hatt, Saelzer, Hempel & Gerber, 2012).

RESULTS AND DISCUSSION

APPLICATION OF THE INTEGRATED SAFETY AND SUSTAINABILITY INDICATOR (IISS)

Liss modeling, weighting, and consistency assessment

The modeling of the problem is represented in Figure 1, hierarchized from the first level of general criteria to the second level of variables that have been considered to determine the level of compliance of the products offered by companies.

The sequence of steps for the IISS calculation is presented in Figure 2.

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	Product presentation	Company presentation	Services	After-sales service
Product presentation	1	0.5	2	3
Company presentation	2	1	3	5
Services	0.5	0.33	1	2
After-sales	0.33	0.2	0.5	1

Table 7. Cross-peer matrix for the variable levels of the Pt criterion. Source: Preparation by the authors.

	Certifications * (CCS, CEV)	Type of construction (OGUC, 5.3.1)	Productivity/ efficiency	Innovation (sustainable construction)	Acoustic comfort	Thermal conditioning
Certifications * (CCS, CEV)	1	0.20	0.25	0.33	0.5	0.5
Type of construction (OGUC, 5.3.1)	5	1	2	3	4	3
Productivity/efficiency	4	0.50	1	2	3	2
Innovation (sustainable construction)	3	0.33	0.5	1	0.5	0.5
Acoustic comfort	2	0.25	0.33	2	1	0.5
Thermal conditioning	2	0.33	0.5	2	2	1

Table 8. Cross-peer matrix for the variable levels of the St criterion. Source: Preparation by the authors.
*CCS: Sustainable Building Codes and/or CEV: Housing Energy Certification.

The characterization interval for the IISS is presented at three levels (Table 5) and the general criteria comparison matrix is prepared (Table 6)..

As indicated in the methodology, the procedure requires determining the Consistency Ratio, which yields a value of 0.9%, namely, high consistency in the assessment of the criteria, so the model is considered accepted.

The resulting IISS is compared in three cross-peer matrices (one for each criterion *Pt*, *Sg*, and *St*, explained in Tables 7, 8, and 9), considering the minimum to the maximum value that can be obtained, with the resulting IISS value classified as Low, Medium, or High (according to Table 5's ranges), depending on the compliance with the criteria, respectively (calculation examples in Figure 4).

The comparison matrix for *Pt* shows an Rc of 0.65%, namely, high consistency in the data assessment, so the model is accepted.

The Sustainability criterion (*St*) evaluates compliance with greater environmental commitment, where the information needs to be available, although potential customers cannot always afford the associated costs (Hatt *et al*., 2012). There is interest in sustainability criteria, though they often end up giving greater purchase preference based on low costs, thus defining the following selection hierarchy: Type of construction > Productivity and efficiency > Efficiency > Thermal Cond. > Acoustic > Certification.

The comparison matrix for *St* shows an Rc of 4.2%, hence, high consistency in the data assessment, so the model is considered accepted.

Regarding the Safety criterion (*Sg*), and due to the recurrence of fires and the presumption of compliance with seismic resistance, fire protection regulatory parameters are privileged over the others. This is related to a social issue rooted in the population, regarding the fear of earthquakes and fires. For this

Safety	Durability and treatment (OGUC, 5.6.8)	Tests (OGUC)	Fire resistance (OGUC, MINVU)
Durability and treatment (OGUC, 5.6.8)	1	2	0.50
Tests (OGUC)	0.50	1	0.33
Fire resistance (OGUC, MINVU)	2	3	1

Table 9. Cross-peer matrix for the variable levels of the Sg criterion. Source: Preparation by the authors.

Criterion	Weight	Variables	Local	Global	Score
Presentation	0.539	Product presentation	0.2718	0.1465	1 to 5
		Company presentation	0.4824	0.2600	1 to 5
		Services	0.1575	0.0849	1 to 5
		After-sales service	0.0883	0.0476	1 to 5
Sustainability	0.164	Certifications (transparency)	0.0667	0.0198	1 to 5
		Type of construction (OGUC, 5.3.1)	0.4000	0.1189	1 to 5
		Productivity/ efficiency process	0.2667	0.0793	1 to 5
		Innovation (sustainable construction)	0.0667	0.0198	1 to 5
		Acoustic	0.0667	0.0198	1 to 5
		Thermal conditioning	0.1333	0.0396	1 to 5
Safety	0.297	Durability and treatment (OGUC, 5.6.8)	0.2973	0.0487	1 to 5
		Testing (transparency)	0.1638	0.0268	1 to 5
		Fire resistance	0.5390	0.0883	1 to 5

Table 10. Local and global weights or weightings of criteria and variables. Source: Preparation by the authors.

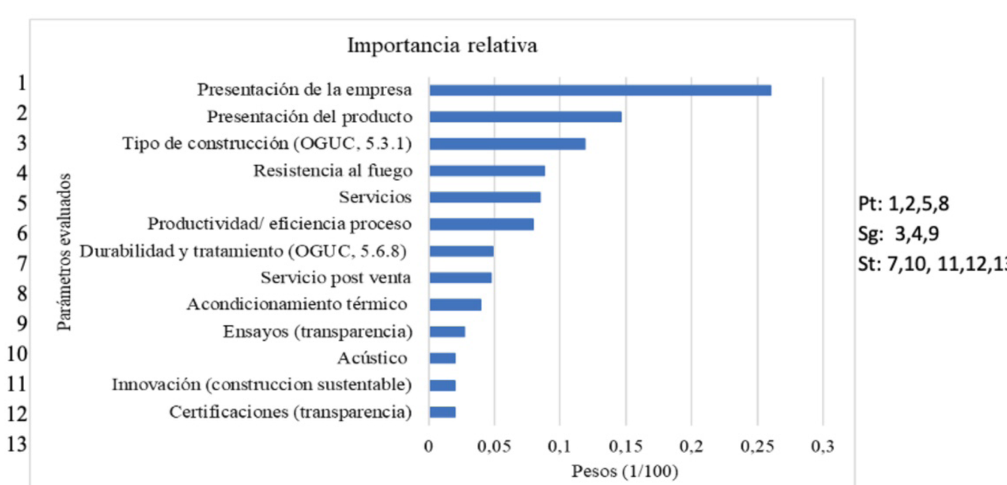


Figure 3. Evaluation of relative importance of parameters. Source: Preparation by the authors.

A) Ejemplo de cálculo IISS, valorización "ALTA"

Empresa	Imagen producto	Descripción	Otras Observaciones
Construkit		Casa Base, modalidad prefabricado	Se destaca por la publicidad de los tratamientos e innovación del proceso: eficiencia

Criterio	Variable	Ptaje	Peso global	Producto
Presentacion	Presentación del producto	3	0,146	0,44
	Presentación de la empresa	4	0,260	1,04
	Servicios	3	0,085	0,25
	Servicio post venta	2	0,048	0,10
Sustentabilidad	Certifiaciones (Código CCS)	3	0,020	0,06
	Tipo de construcción (OGUC, 5.3.1)	5	0,119	0,59
	Productividad/ eficiencia proceso	5	0,079	0,40
	Innovación (construccion sustentable)	5	0,020	0,10
	Acústico	4	0,020	0,08
	Acondicionamiento termico	4	0,040	0,16
Seguridad	Durabilidad y tratamiento (OGUC, 5.6.8)	4	0,049	0,19
	Ensayos (transparencia)	4	0,027	0,11
	Resistencia al fuego	3	0,088	0,26
	SUMA	49	1	3,78

B) Ejemplo de cálculo IISS, valorización "MEDIA"

Empresa	Imagen producto	Descripción	Otras Observaciones
Construkit		Modalidad industrializada, panel SIP	Empresa se destaca los tratamientos empleados a las piezas que utiliza

Criterio	Variable	Ptaje	Peso global	Producto
Presentacion	Presentación del producto	4	0,146	0,586
	Presentación de la empresa	3	0,260	0,780
	Servicios	2	0,085	0,170
	Servicio post venta	2	0,048	0,095
Sustentabilidad	Certifiaciones (Código CCS)	2	0,020	0,020
	Tipo de construcción (OGUC, 5.3.1)	1	0,119	0,119
	Productividad/ eficiencia proceso	5	0,079	0,079
	Innovación (construccion sustentable)	2	0,020	0,020
	Acústico	2	0,020	0,020
	Acondicionamiento termico	2	0,040	0,040
Seguridad	Durabilidad y tratamiento (OGUC, 5.6.8)	4	0,049	0,049
	Ensayos (transparencia)	2	0,027	0,027
	Resistencia al fuego	3	0,088	0,088
	SUMA	34	1	2,09

C) Ejemplo de cálculo IISS, valorización "BAJA"

Empresa	Imagen producto	Descripción	Otras Observaciones
Casas Entrelagos		Vivienda prefabricada, formato kit completo	Sin observación

Criterio	Variable	Ptaje	Peso global	Producto
Presentacion	Presentación del producto	2	0,146	0,29
	Presentación de la empresa	2	0,260	0,52
	Servicios	3	0,085	0,25
	Servicio post venta	2	0,048	0,10
Sustentabilidad	Certifiaciones (Código CCS)	1	0,020	0,02
	Tipo de construcción (OGUC, 5.3.1)	3	0,119	0,36
	Productividad/ eficiencia proceso	3	0,079	0,24
	Innovación (construccion sustentable)	4	0,020	0,08
	Acústico	1	0,020	0,02
	Acondicionamiento termico	3	0,040	0,12
Seguridad	Durabilidad y tratamiento (OGUC, 5.6.8)	3	0,049	0,15
	Ensayos (transparencia)	1	0,027	0,03
	Resistencia al fuego	1	0,088	0,09
	SUMA	29	1,000	2,26

Figure 4. Examples of IISS calculation by type of valorization: (A) "High"; (B) "Average", and (C) "Low" levels. Source: Preparation by the authors.

reason, the following selection hierarchy is established: Fire resistance > Durability and treatment > Tests

The comparison matrix for *Sg* yields an Rc of 1%, high consistency in the data assessment, therefore, the model is accepted.

Finally, the local and global weights are presented in Table 10.

The relative importance of the evaluated parameters reflects the order of priorities under which the various corrective actions must be focused on. This is how, from the assignment of weights to obtaining the global and local weights, it was obtained that the parameters of "project presentation", "type of construction", and the actions regarding Fire Resistance had greater relative importance in the study (Figure 3).

Company	Product picture	Description	Pt	St	Sg	Other Observations	IISS	value
Construkit		Basic house, prefabricated	1.829	1.387	0.567	This stands out by advertising the treatments and innovation of the process: efficiency.	3.78	High
Casas Calera de Tango		Turnkey housing, prefabricated	2.175	1.030	0.465	This stands out through a scaling process, offering from a basic kit to a turnkey modality.	3.67	High

Table 11. IISS application, example of "High" value indicator. Source: Preparation of the authors based on the information provided by the evaluated companies.

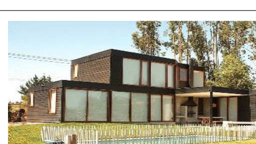
Company	Image	Description	Pt	St	Sg	Other Observations	IISS	value
Constructora ROKAR		Traditional house	1.886	0.971	0.340	Good presentation. A more detailed description of housing materials is missing. Lacks detail or innovations, or types of certificate.	3.20	Average
		Modular	1.886	1.09	0.340		3.32	Average
Easywood		Industrialized, SIP panel	1.716	1.209	0.513	The company stands out for the treatments used for the pieces it uses.	3.44	Average
Fundación vivienda		Single slope, prefabricated	1.796	0.595	0.164	This stands out through the presentation of the company, but not its products.	2.55	Average
Decocasas		Not specified	1.210	1.030	0.164	This stands out through its sustainability and design or use of its materials to generate acoustic and thermal comfort.	2.40	Average

Table 12. IISS application, example of "Average" value indicator. Source: Preparation of the authors based on the information provided by the evaluated companies.

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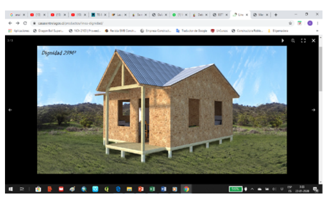
Company	Image	Description	Pt	Sg	St	Other Observations	IISS	value
Constructora ARQOS		Rustic model	1.51	0.54	0.16	Fire risk due to fuel overload.	2.21	Low
Casas Interlagos		Prefabricated, complete kit format	1.16	0.83	0.26	No comments.	2.26	Low
Constructora Rinconada Ltda.		Prefabricated, SIP, and SmartPanel	0.90	0.97	0.16	It does not have its own website; it is associated with a Ministry page (SERVIU).	2.04	Low
Constructora ROA	No sample picture	Associated with commercial page	0.76	0.63	0.16	Associated with commercial page.	1.55	Low
Casas Rucaray		Builder	1.33	0.71	0.26	Facebook page only.	2.31	Low

Table 13. IISS application, example of "Low" value indicator. Source: Preparation of the authors based on the information provided by the evaluated companies.

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GENERATION OF THE INTEGRATED SAFETY AND SUSTAINABILITY INDICATOR (IISS)

Once the presented methodological steps have been completed, it is possible to present the resulting model, which can be applied in the evaluation of dwellings published on web pages of wood construction companies, and then onsite observations. Figure 4 shows examples of how the IISS calculation methodology was applied from a valuation classified as "high", "average" and "low", as appropriate.

IISS APPLICATION

To apply the model, the most representative situations inspected (230 companies from their websites) were considered, which are summarized in Tables 11, 12, and 13.

Examples of dwelling typologies are presented in the tables above, describing those with a "High" assessment indicator (Table 11), which is explained mainly by these having high scores on the *Pt* criterion, superior in this category to companies with the "Average" indicator, and highlighted in Sustainability (*St*) thanks to certain aspects informed as energy-saving materials (double-glazed windows) and the use of certain innovations (wood stabilizers).

Those types who obtained a high value on the *Pt* criterion (Table 12) were classified with the "Average" indicator. This assessment highlighted meaningful attributes of the company (over a product description), such as background, sales system, and annual reports with production details, among others. There is less clarity in sustainability and safety compared to the previous group, as the environmental virtues of the wood they use were declared, but not the participation of any type of certification that would endorse them. While some companies are stronger in declaring sustainability, others are stronger in declaring safety, when working with treated wood or designing reinforced structures with high regulatory compliance.

The reasons why some companies, responsible for the information they provide about their products, had a "Low" indicator (Table 13) can be summarized in the following three points: 1) They do not have their own web page and are referenced by other sources; only provided identification and contact information: phone or e-mail; 2) They are associated with an institutional page or only use social media such as Facebook, standing out for giving price information, minimum technical specifications, and product image; and 3) They have a basic website, equivalent to an online blog, with a gallery of images of their projects, without verification of technical or design conditions; they only present contact details.

The application of the IISS is of great importance because it can be implemented to cover needs that are being incorporated in other countries, such as the impacts of disasters and the safety of the houses and their users (Castillo *et al.,* 2020), for which it is required to find agreements and improve coverage from insurance companies.

In addition, insuring a home could lead to the development of a maintenance culture, charged to that insurance so that the installations function properly, and so that the durability and resilience of houses to natural events increases. Also, if the living conditions are adequate, the health risks of present and future users would be reduced. From the economic point of view, it can be mentioned that properly made inspections can increase the purchase value by up to 40%, so banks would be more inclined to give loans (Dolan, 2018).

Finally, well-insured houses are also a marketing strategy that can be complemented with the promotion of the attributes of a wooden home, which could persuade the public to opt for this type of structure.

The wood construction sector is making great strides. Rapid and correct measures will allow its inclusion in the sustainable building market, namely, through the progressive adoption of sustainable building codes.

The analysis presented here has implications for the requirements to be implemented to install homes in forest fire areas, similar to the strategies of Australia, Canada, and the United States, where the regulations consider demands by location, exposure, and risk. In Chile, there is a lack of progress in inspection for the installation and insurance of housing, although progress should be acknowledged in the area of hospitals and high-rise buildings, where the inclusion of LEED or Passive house certifications has made it possible to incorporate higher demands. Unfortunately, these advances have not reached the most common houses, such as those of all Chileans.

Faced with disaster situations, experts propose that the building code should be on a par with on-site inspection actions, as is the case in countries such as the United States, Japan, and New Zealand, where laws support inspections at the beginning, during, and end of the work and whose associated costs are part of construction permits, which represent 0.5% or less of the total work (Dolan, 2018).

Linking the IISS to these inspections can be another benefit since by making sure that the installations are done properly, the durability and resilience of houses to events that trigger disasters and facilitate purchase-sale and insurance companies relations increase. In the same vein, if the habitability conditions are adequate, the risks to user-health are reduced.

For all these reasons and more, it can be argued that the wood construction sector is heading in the right direction, so measures must be adopted quickly so that this material and all those who work with it are included in these processes. Materials and trained professionals are available; just collaboration, inclusion, and technical advice are required.

CONCLUSION

The integration of presentation, sustainability, and safety criteria to generate a combined IISS indicator for wooden houses manufactured in central Chile, allows assessing the technical, structural, and applicability aspects of wooden housing, as a highly competitive construction product, in a growing and increasingly diverse market context.

As a result, the degree of importance of different variables and their technical coefficients (expressed in rankings and prioritization between wood-based constructive choices) made it possible to obtain a hierarchical order or ranking of wood material use options under the current regulatory and installation restrictions, and after-sale processes, under normal operating conditions for habitable territories in Central Chile.

The IISS is a contribution to housing assessment and would have greater significance if it were complemented with an onsite evaluation, to verify other factors and contribute to improving the productive chain by reaching an agreement about strategies.

The results allow ranking the products of companies that manufacture wooden houses according to the three attributes needed, so consumers can buy in an informed way, and not just be led by the aesthetic characteristics of the houses. Due to the lack of technical quality and clarity of information regarding compliance with the OGUC, sustainability codes and/or sustainable housing certifications (CVS) have not yet been adopted by the Chilean market. The application of this indicator can contribute to categorizing available housing, where consumers may find themselves faced with purchase decisions where issues such as preservation treatments, thermal insulation, fire protection, standardized construction systems, and process sustainability are valued and quantified, both by the customer and the manufacturer.

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