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Assessment of the social sustainability of public housing projects in chile

Evaluación de la sostenibilidad social de proyectos de vivienda pública en chile

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Abstract

The consideration of qualitative social approaches in public housing projects is not clear in the implementation process. Public agencies lack processes that incorporate explicit social criteria for assessing public housing projects. Therefore, the inclusion of social sustainability in early planning and decision-making is limited. This study presents a structural model explaining the fundamental interdependence of social criteria that govern socially sustainable housing projects for vulnerable populations in Chile. For this purpose, this research is based on a theoretical structural equation model (SEM) derived from applying a survey administered to 188 professionals involved in public housing development. This study validates the model by implementing five public housing projects in the Araucanía Region and compared with other rating systems. A model of ten criteria and 33 indicators was validated. The overall results are consistent with the implementation of the ENVISION and CVS systems in consideration of social contributions. However, factors such as improvement in family economic capacity, housing committee involvement, and neighborhood functional integration are significant and not included in the other conventional rating systems.

Keywords: Public housing; social sustainability; SEM; Chile; Rating System.

Resumen

La consideración de los enfoques sociales cualitativos en proyectos de vivienda pública no queda clara en el proceso de implementación. Las agencias públicas carecen de procesos que incorporen criterios sociales explícitos para evaluar proyectos de vivienda pública. Por lo tanto, la inclusión de la sostenibilidad social en la planificación y toma de decisiones tempranas es limitada. Este estudio presenta un modelo estructural que explica la interdependencia fundamental de los criterios sociales que rigen los proyectos de vivienda socialmente sostenibles para poblaciones vulnerables en Chile. Para ello, esta investigación se basa en un modelo teórico de ecuaciones estructurales (SEM) derivado de la aplicación de una encuesta administrada a 188 profesionales involucrados en el desarrollo de vivienda pública. Este estudio valida el modelo a través de la implementación de cinco proyectos de vivienda pública en la Región de La Araucanía y comparándolos con otros sistemas de certificación. Se validó un modelo de diez criterios y 33 indicadores. Los resultados globales son consistentes con la implementación de los sistemas ENVISION y CVS en consideración de las contribuciones sociales. Sin embargo, factores como la mejora de la capacidad económica familiar, la participación del Comité de vivienda y la integración funcional en el entorno son significativos y no están incluidos en otros sistemas de certificación convencionales.

Palabras clave: Vivienda pública; sostenibilidad social; SEM; Chile; Sistema de calificación.

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1. Introduction

The main challenges of social sustainability today lie within the social context, characterized by escalating degrees of risk and vulnerability, which pertain to the conditions of disadvantage and the social, economic, political, and cultural gaps certain social groups face (Ortiz et al., 2018). The difficulty of addressing social factors primarily arises during the planning of public housing. This is attributable to practical assessments adopting a quantitative methodology emphasizing the number of units built and cost minimization, often neglecting significant qualitative and social dimensions. In this regard, housing developments that fail to sufficiently account for residents' quality of life, community cohesion, and social inclusion may be promoted (Murphy, 2019).

In Latin America, governmental programs lack a strong integration policy that has successfully addressed the social disintegration prevalent in housing complexes for vulnerable populations (Blanco, 2020). Examples of these neighborhoods are Villa 31 in Buenos Aires, Ciudad Neza in Mexico City, and El Agustino in Lima, urban areas with vulnerable social housing where high levels of poverty and social exclusion persist (Smith, 2017). In Santiago, Chile, this is reflected in the "Vertical Ghettos" created to satisfy the demand for social housing, but ultimately made the living conditions of their inhabitants more precarious and overcrowded (López, 2017). In this vein, it is evident that the social problem of housing in Latin America does not lie in the lack of infrastructure or the quality of the construction processes but in the qualitative elements that accompany the design and planning of housing in relation to its environment (Gilbert, 2001); (Maldonado et al., 2020); (Salingaros et al., 2006).

This is closely related to the situation currently affecting public housing planning in Chile. One option for securing housing is the DS-49 subsidy, which enables families lacking house ownership and experiencing social vulnerability and housing need to obtain a mortgage-free home or participate in one of the listed housing initiatives (MINVU, 2023). In La Araucanía region, social housing often has poor structural and habitability conditions, exacerbated by the lack of cultural and contextual adaptations that consider the specific needs of the local communities (Serrano, 2017). In this sense, La Araucanía region in Chile presents the highest historical rates of income and multidimensional poverty in the country. The rate of multidimensional poverty associated with housing and its surroundings reaches 37% and exceeds all other regions. This region is an appropriate context to apply this study in light of its vulnerability (MDSF, 2023). Hence, the challenges are related to urban planning methods and the urgent need to rethink and revise current processes to effectively address the social situation and improve quality of life standards (Forester, 2019).

Social sustainability assessment methods for construction projects are limited. In this respect, (Díaz-Sarachaga et al., 2016) describe five methods for evaluating building projects integrating social aspects. The CEEQUAL Certification System assesses infrastructure projects with environmental and social indicators, considering customers, designers, and contractors, defining four levels of achievement: Approved, Good, Very Good, and Excellent. The Infrastructure Sustainability Rating (IS) evaluates sustainability during design, construction, and operation. This method defines ratings for each phase, considering the implementation of sustainable elements and the project's performance. The Greenroads Certification System focuses on the sustainable certification of transportation projects, considering the environment, materials, construction, accessibility, and habitability, with Bronze, Silver, Gold, and Evergreen levels. The Envision Certification System version 2.0 is a comprehensive sustainability system with 60 credits in five categories. It guides the shift to sustainable and resilient infrastructure through five levels of achievement and optional third-party verification.

Concerning social sustainability, research assessing the impact of housing designated for the most disadvantaged populations in Chile remains scarce and infrequently conducted (Maldonado and Sierra, 2020). Thus, in practice, the evaluation systems for housing projects for vulnerable populations in Chile do not guarantee socially sustainable territorial conditions with a long-term approach. In this sense, (Sierra et al., 2023) propose a theoretical model that integrates criteria and indicators of the behavior of social housing projects concerning their social contribution. Even though this proposal is an advance, its formulation has been based solely on reviewing the literature and consultation with professionals in the area, without implementation in actual cases. Therefore, it is still necessary to advance in the implementation and validation of a conceptual structure that integrates social criteria and their interactions to enable decision-making in the planning and designing of socially sustainable housing projects for vulnerable populations in Chile.

This study validates a structural model of socially sustainable assessment of public housing (MESS -VP) that explains the interrelation of the criteria that determine the social sustainability of housing projects for the vulnerable population in Chile. The following sections present the state of sustainability, social criteria used to assess social housing projects, and empirical validation of public housing projects. They evaluate the

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contribution to the social sustainability of five DS-49 public housing projects through the MESS-VP and compare it to different standardized certification systems.

2. Criteria for social evaluation of housing

In exploring the impact of infrastructure on social sustainability, groups of transcendental attributes have been categorized and defined as "evaluation criteria" for a given type of infrastructure in a geographical and social context (Sierra et al. 2018; Montalbán-Domingo et al. 2020, Jafari et al. 2019). Evaluation criteria are configured as latent variables that are influenced at some stage of the infrastructure life cycle by the interest of one or more stakeholders. Usually, these evaluation criteria are measured through observable indicators appropriate to the evaluation context and type of infrastructure (Sierra et al. 2017; Montalbán-Domingo et al. 2020).

In Chile, some evaluation criteria for public housing projects that contribute to social sustainability for the most vulnerable 40% of the population have recently been studied. Barra (2018) and Maldonado et al. (2020) identified the stakeholders associated with public housing projects and the social criteria derived from a sample of housing projects in southern Chile. In addition, Sierra et al. (2023) identified the theoretical relationships between ten criteria related to housing and the neighborhood, proposing a theoretical structural model on which this study is based (See Table 1).

Table 1. Social criteria for the development of public housing in Chile (Source: Adapted from (Barra, 2018), (Maldonado et al., 2020) and (Sierra et al., 2023)).

Social criterion	Description
Family Economic Availability	Aspects that imply a change in the family income. For example, elimination of rent, transportation expenses, energy saving.
Motivation for family property	Incentive for families to have their own house and to invest in it.
Space for family development	Suitable dimensions of the space of a house, such that the family members can undertake their activities appropriately.
Direction of Community Leaders	This refers to the management of the Committee directors that promotes action to access public housing subsidies.
Connectivity and access	Access to basic services that enable an optimal quality of life (includes to schools, health centers, safety, public transport, leisure infrastructure).
Community Health and Safety	Aspects that contributes to health and safety in the neighborhood. For example: garbage treatment plans, capacity of emergency services close to the neighborhood.
Functional integration in the neighborhood	It is the capacity and diversity of urban infrastructure to enable entertainment, cultural-social development and the inclusion of physically-challenged people in the neighborhood.
Consideration of public opinion	This refers to the opinions of the families in the application process, planning and selection of the type of house.
Social identity and culture	This refers to promoting cultural relevance in the neighborhood according to the social and cultural diversity of the families, and the presence and valuation of the historical or natural heritage.
Integration of the design in the context	This refers to the harmonic design of a project, so that it does not disturb the landscape or is adapted to the wider context in which it is located.

3. Structural Equation Model (SEM)

Structural equation models establish the dependency relationship between variables. They try to integrate a series of linear equations and establish which of them are dependent or independent of others. Within the same model, the variables that can be independent in one relationship can be dependent on others, which is why they become helpful tools (Lizana et al., 2019).

SEMs are characterized by two main elements. The first evaluates multiple and cross-dependency relationships. The second is the degree to which unobserved concepts are represented in these relationships and to which the measurement error is considered in the estimation process.

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SEM specialists agree that there are six phases to apply this technique. a) Specification, b) identification, c) parameter estimation, d) evaluation of fit, e) respecification of the model, and f) interpretation of results make it up (Cupani 2012).

Since the model presented has latent or unobserved variables, it is necessary to identify each with a statistical value to calculate the estimates of their effects. The estimated values evaluate a parameter that characterizes the population through a sample. If the sample faithfully represents the population, the statistic is assumed to represent the parameter well. For the estimated values in a model to be acceptable, they must have a load ≥ 0.07. From the perspectives of absolute fit, incremental fit and parsimony fit, some statistical values to consider are the Absolute Goodness of Fit, the RMSEA, the PNFI, the IFI and the CFI. Absolute Goodness of Fit determines the degree to which the general model predicts the correlation matrix, and for SEM, the Chi-square likelihood ratio statistic is the only statistical measure (Escobedo et al. 2016). The model has an acceptable fit if the Chi-square/degrees of freedom values are from 2 to 3 and with limits of up to 5. The Root mean square error of approximation (RMSEA) represents the anticipated fit with the total value of the population and no longer with that of the sample. If RMSEA is less than or equal to 0.05, it indicates an error in the approximation of the model to reality. The Parsimony normed fit index (PNFI) relates the constructs to the theory that supports them. The closer it is to 1.0, the greater their relationship. The incremental model fit measures compare the proposed model with the existing one, the null model. In this sense, the incremental fit indices (IFI) and comparative fit index (CFI) with values close to 0.90 or higher are those that show a better model fit (Kline 2016).

4. Methodology

This study is a mixed type (qualitative and quantitative) and consists of two stages, as shown in (Figure 1), which guide the analysis.

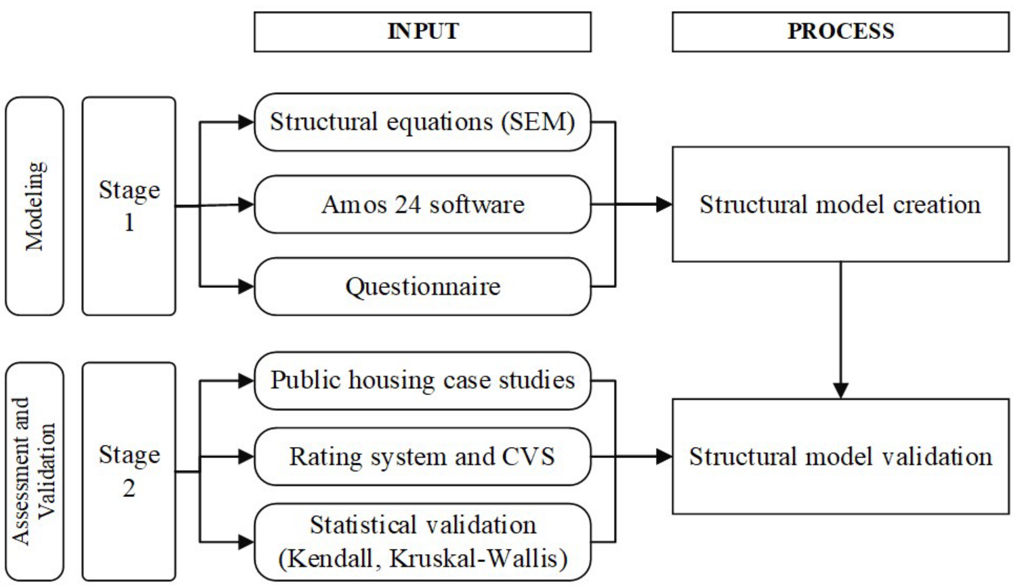

Figure 1. Methodological outline.

4.1 Stage 1: Structural model creation

In the first stage of model construction, structural equation modeling (SEM) facilitates the simultaneous analysis of a series of interactions and assesses the connections between unobservable constructs and latent variables. This model requires a sample size greater than 100 subjects (Kline, 2016). However, the sample size can be validated so that SEM significance tests are reasonable. The structural model of social criteria illustrated the correlations and occurrences of observable and latent variables to aid in assessing social housing in Chile. Model identification was evaluated following the two-step identification rules involving individual measurement analysis and structural model identification. The AMOS 24 software was used (Arbuckle, 2016) to apply SEM during the research process.

Following (Sierra et al., 2023) the criteria were validated using an SEM and a database obtained through an online survey of professionals with social housing experience. This survey obtains the significant observable variables that respond to each evaluation criterion and confirms the

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relation among criteria. Specifically, the consultation was addressed to qualified professionals engaged in the decision-making process in social housing planning in Chile affiliated with the Ministry of Housing and Urban Planning (MINVU) at the central level, and regional agencies derived from MINVU, municipal authorities, consultants (technical assistance entities), social housing developers, and NGOs. In addition, participating professionals were required to meet education, training, and experience requirements. First, a technical or professional education in construction, urban planning, or social sciences was required. Second, the focus was on respondents trained in social housing development. Third, respondents had at least 1 year of experience in public housing or associated programs. The survey was applied in 2019 and 2020, and its sample characterization is illustrated in (Table 2). This study is based on a sample of 188 respondents with a response rate of 75%.

Table 2. Characterization of the respondents. (Adapted from (Sierra et al. 2023))

Type	Characteristic	Amount	Percentage
Academic level	Technical	7	4%
	University	144	76%
	Graduate studies	37	20%
Professional	Construction engineer	58	31%
	Social Worker	37	20%
	Architect	42	22%
	Others	50	27%
Work Experience	1 to 2 years	26	14%
	3 to 10 years	86	46%
	11 to 15 years	36	19%
	More than 15 years	39	21%
Institution	(Consultant) Technical assistance agency	76	40%
	SERVIU 1	39	21%
	MINVU 2	3	2%
	Builder	13	7%
	Municipal	10	5%
	Others	47	25%

Note: (1) Housing and Urban Planning Service; (2) Ministry of Housing and Urban Planning.

The questionnaire was designed based on established social evaluation criteria obtained from discussions with experts from public agencies and developers of private social housing projects. The questionnaire has three parts. The first provides informed consent, requests approval, and requests professional information from respondents. The second question asks about their experience with public housing developments. The third asks them to assess the indicators for each public housing criterion, responding to the importance of each for the respective criteria on a Likert scale of 1 to 5, where "1" means No importance/influence and "5" means Extreme importance/influence. The indicators included in the questionnaire respond to each evaluation criterion and are derived from the studies by (Sierra et al., 2023) and (Maldonado and Sierra, 2020) after a review of the literature, interviews, and validation by experts (see (Table 2)). Once designed, the questionnaire is disseminated nationwide by the MINVU technical assistance agencies via e-mail. Likewise, it was extended to the internal and external networks of MINVU collaborators, as well as to professionals of the Social Development Department in the housing area in all the municipalities in Chile.

4.2 Stage 2: Structural model validation

4.2.1 Case study

Five case studies of the DS-49 subsidy in Chile, known as the Fondo Solidario de Elección de Vivienda (Housing Choice Solidarity Fund), were selected to assess the structural model (Figure 2). This is a benefit granted by the State through MINVU. This subsidy is intended for families who do not own a home and are in a situation of social vulnerability and housing need. Its main objective is to enable these families to acquire a home without having to opt for a mortgage loan in the Araucanía Region. The selected case studies have the following characteristics.

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1. Case study 1, located in the commune of Padre Las Casas. With a total of 81 dwellings with 5 different designs, it was executed between 11 January 2021 and 27 March 2023.
2. Case study 2 is the continuation of social housing in the commune of Pitrufquén, with a total of 159 units with 3 housing types, starting on 28 February 2020 and ending on 20 August 2021.
3. Case study 3, located in the municipality of Lautaro, comprises 160 homes within a megaproject, including green spaces, paving, and community facilities. It began on 14 April 2020 and ended on 7 October 2021.
4. Case study 4, located in Nueva Imperial, has 160 dwellings. It includes different types of housing, including for people with disabilities, as well as green spaces and recreational areas. It began on 20 August 2021 and ended on 11 May 2023.
5. Case study 5, located in the commune of Galvarino, began construction on 19 October 2021, ending on 7 November 2022. There are two housing types designed in addition to recreational areas.

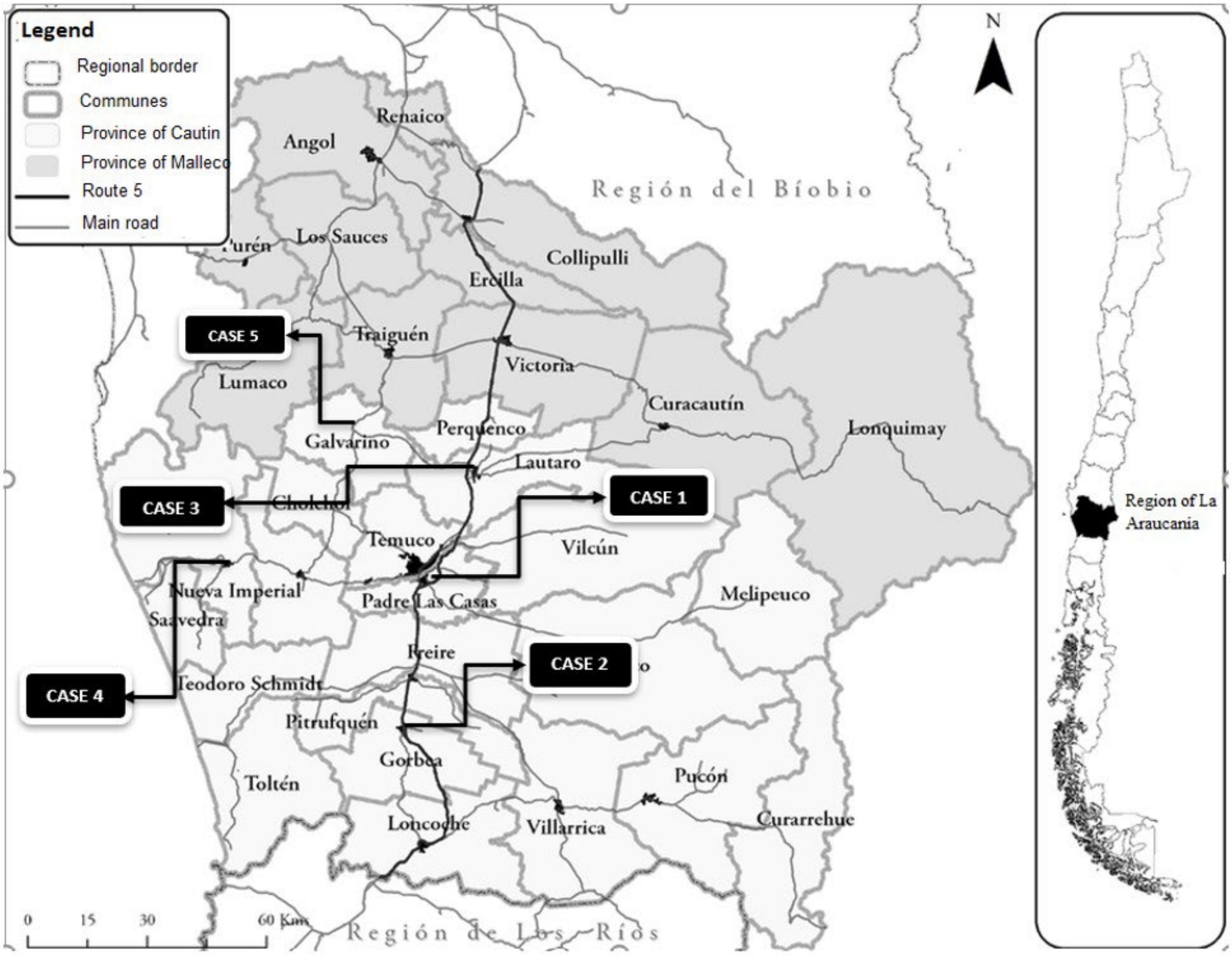

Figure 2. Georeferencing of case studies.

4.2.2 Assessment of case studies through MESS-VP

Projects' social contributions are calculated using activation rules that allow the impact of each criterion to be redistributed according to the weight associated with each relationship. The activation and inference rules are related to artificial intelligence tools of neural networks. They are applied to cognitive maps of cause-effect relationships to evaluate the dynamic behavior of indicators in an evaluation system. This rule allows the operationalization of conceptual network models to support decision-making (Nápoles et al., 2018).

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Each node in a cause-effect interaction model means a concept (criterion), and the connections (arrows) between the nodes denote causal relationships, with weights (factor loading) reflecting the magnitude and direction of the effect. Specifically, the social contributions Ai t+1 are calculated using the modified activation rules of (Stylious and Groumpos, 2004); where neurons also consider their past value. This rule is preferred when updating the activation value of independent neurons, i.e., neurons that are not influenced by any other neural processing entities (See (Formula 1)). Where Ai is the value of the criterion obtained through the initial values collected (Table 3), Wij corresponds to the weight (or correlation of (Figure 3)) between criterion i and j, and Atj is the criterion that has an impact.

$$A_i^{t+1} = Ai + \sum_{i=1,i\neq j}^{j} Wji * Atj \quad (1)$$

In our case, the MESS-VP structural equation model from Step 1 can support decision-making by estimating the social contribution of the projects. This estimate is calculated using the activation rule of Formula 1. In this way, from the value of the indicators of each project in the case study and the factor loadings of the MESS-VP (Table 3), the Ai initial values (t=0) of each evaluation criterion are determined. From reviewing the background of each project, the values of each indicator are determined by a Likert scale of five points, equivalent to the information capture that created the structural model (where "1" means zero or lower contribution of the project to the indicator and "5" is the maximum contribution of the project to the indicator). In addition, (Formula 2) shows the sigmoid threshold function that activates the next time cycle t +1 and limits the output response for all system indicators (Stylios, et al. 2008).

$$f(A_i^{t+1}) = \frac{1}{1+e^{-\lambda A_i^{t+1}}} \quad (2)$$

Thus, the social contribution is the arithmetic average of all the criteria at the point of reaching stability after four iteration cycles. That is, until the most significant distance of the path among the interactions of the structural model is completed (Figure 3).

4.2.3 Comparison through Rating System and CVS

The proposed structural model's results are compared with those obtained through two certification systems. These systems are the Sustainable Housing Certification System Chile (CVS) and the ENVISION certification. These systems are selected for analysis and comparison at the national and international levels. It should be noted that only credits (criteria) that address the social area alone that apply to the social contribution of projects are employed. Based on a review of both systems, the criteria selected to compare Envision are Quality of Life and Leadership. Analogously, the criteria selected to compare CVS are Health and Wellness, Energy, Environmental Impact, and Immediate Surroundings.

(Diaz-Sarachaga et al., 2016) Describe Envision as a system with 60 sustainability credits consisting of a series of dichotomous Y/N questions organized into five categories addressing the pillars of sustainability (environmental, economic, and social). In addition, it acts as a comprehensive framework to guide the necessary change in the planning, design, and implementation of sustainable and resilient infrastructure. Rather than being a strict set of rules, it serves as a guide for decision-making (Diaz-Sarachaga et al., 2016).

The Sustainable Housing Certification System (CVS) in Chile seeks to promote sustainable and efficient housing, improve residents' quality of life, reduce the environmental impact, and encourage innovation and best practices. This initiative aims to gauge and voluntarily certify dwellings based on their sustainability performance (MINVU 2021). The credits used are Health and Wellness, Energy, Environmental Impact, and Immediate Surroundings.

Credits for each case study project are determined according to the guidelines in the Envision and CVS manuals. The credits for each criterion per project are normalized, and the arithmetic average representing the case study is obtained. From this point on, the constructs and the total social contribution results are compared according to the approaches of each system.

4.2.4 Statistical validation

The techniques established to validate the results are consistency analyses using the SPSS 21.0 software. The Kruskal-Wallis test is a nonparametric method for testing whether a data set comes from the same population. Intuitively, it is identical to ANOVA, with the data replaced

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by categories. Since it is a nonparametric test, the Kruskal-Wallis test does not assume normality in the data and is valid in small samples as opposed to the traditional ANOVA. The only requirement is that the data be on an ordinal scale (Ramírez and Polack, 2019). The Kruskal-Wallis test compares three or more independent groups when the normality of distributions cannot be assumed. The objective is to determine whether there is a significant difference in the variable "assessment system" (i.e., Structural Model, Envision, Sustainable Housing Certification Chile) for the five study cases.

In addition, a Kendall analysis is also performed, which is used to study the agreement between two or more sets of ranks (Ramírez and Polack, 2019). The value of W ranges between 0 and 1. A value of 1 means total agreement, and 0 means total disagreement. A tendency of 1 is desired, and new rounds can be performed if the first round does not achieve significant agreement (Sierra et al., 2016).

5. Result

The theoretical model depicted in (Figure 3) summarizes graphically the final relationships found. The continuous arrows correspond to significant causal relationships in the proposed direction. The final structures of the model were derived through an iterative process based on the original conceptual framework and the model outputs (Cupani, 2012). The statistical models validate a unidirectional relationship among the criteria illustrated in (Figure 3). The environmental conditions dimension affects the criteria comprising the functional conditions of the dwelling. The goodness-of-fit statistics for the model in (Figure 3) indicate that the RMSEA (0.066) and the Parsimony-Adjusted Measurements Index (0.614) met the usual criteria (<0.05 and >0.6, respectively). In addition, the incremental fit index (IFI) and comparative fit index (CFI) values were acceptable but still below typical thresholds (0.9), and Chi-square (879.888) with 434 degrees of freedom (Lizana, 2019).

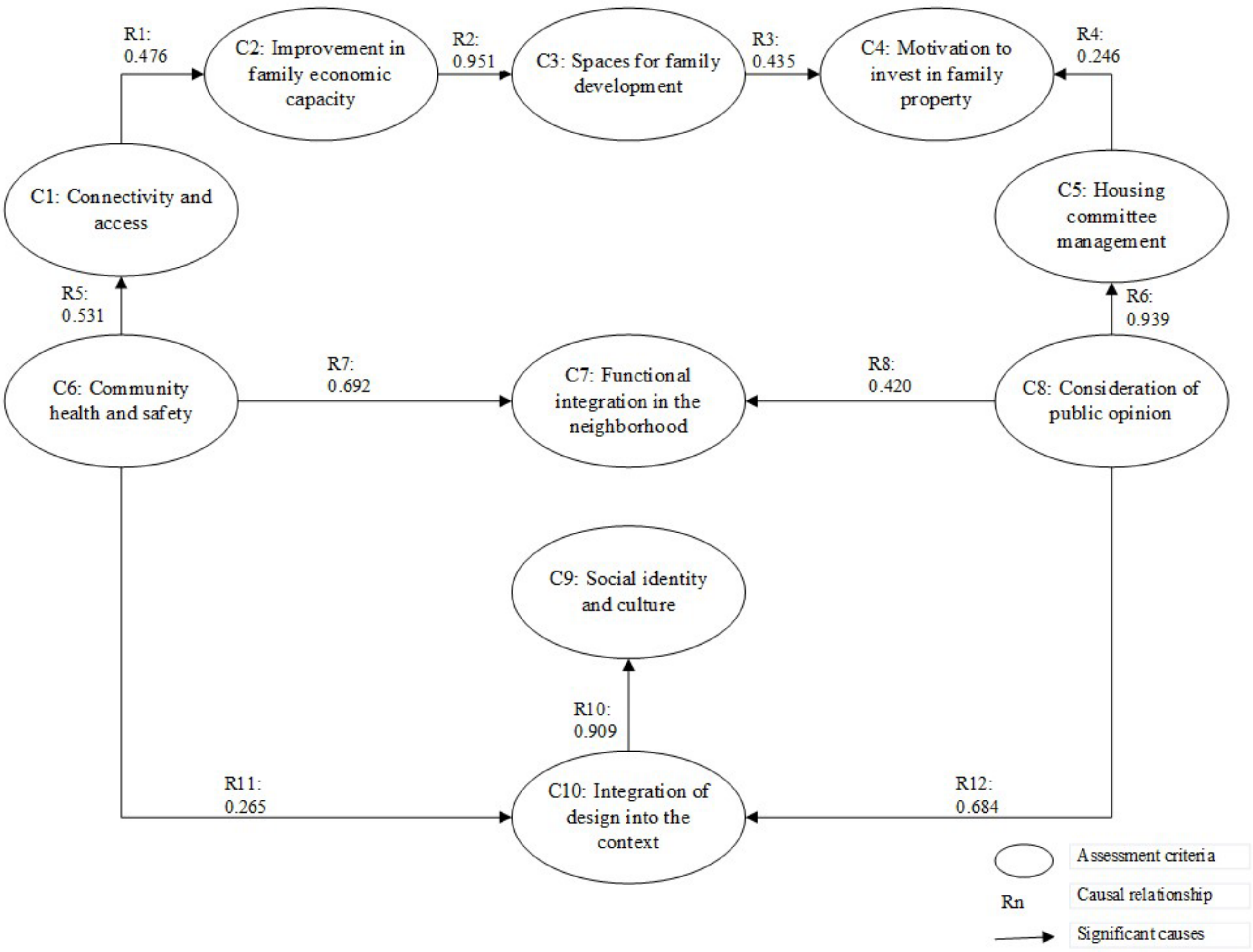

Figure 3. Structural model (Sierra et al., 2023).

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The variables consulted in the survey, and their factor loadings are shown in (Table 3). The factor loadings are weights that relate the indicators to the criterion they represent using a linear regression. SPSS 24.0 software was used to test the reliability of the study (Sierra et al., 2023).

Table 3. Reliability of the indicators and value for study cases.

Criterion	Indicator (Sierra et al. 2023)	Factor loading (Sierra et al. 2023)	Case study 1	Case study 2	Case study 3	Case study 4	Case study 5
C1	Frequency of public transport.	0.66	5	1	3	3	1
	Distance to public and commercial services.	0.81	4	3	2	3	4
	Capacity of adjacent services (health center, schools, police).	0.82	3	3	2	2	4
	Accessibility for environmentally friendly modes of transportation (walking, cycling, etc.).	0.72	4	2	2	3	2
C2	Savings through good connectivity and transportation offerings.	0.68	3	1	2	3	2
	Savings on heating.	0.79	5	4	2	5	1
	Savings by leasing or dividend.	0.77	5	5	5	5	5
C3	More customized space distribution.	0.71	5	4	4	4	2
	Heating.	0.71	4	4	2	5	2
	Outside noise.	0.74	1	4	3	5	2
C4	Existence and influence of an organizing committee.	0.87	4	3	5	2	3
	Committee promotes the enhancement of family assets.	0.89	3	3	5	3	2
	Complementary subsidy incentivizes family property ownership.	0.64	3	2	4	2	2
C5	Number of activities carried out by the committee.	0.86	3	2	5	2	2
	Term of office of community leaders.	0.88	3	2	5	3	2
	Percentage of support for community leaders.	0.69	3	2	5	3	2
C6	Equipment for community spaces (lighting, benches, etc.).	0.68	4	2	3	3	3
	Absence of uncultivated (unequipped) areas in the environment.	0.70	1	2	4	5	2
	Access to emergency services (health centers, police, etc.).	0.72	4	4	1	3	4
	Geographical safety of the location.	0.69	3	5	4	5	3
C7	Variety of equipment (benches, sports equipment, etc.).	0.87	3	2	2	2	4
	Equipment capacity.	0.88	4	2	3	2	3
	Universal accessibility design.	0.61	2	3	4	3	2
C8	The selection of attributes from the committee's family diagnostic record.	0.80	3	3	5	5	2
	Free opinion of the committee members.	0.87	3	3	5	4	3
	The committee's percentage of agreement.	0.80	3	2	4	4	2
C9	Diversity and culture.	0.89	2	2	4	4	3
	Contextualized historical and cultural heritage.	0.82	2	2	3	3	2
	Diversity and empathy.	0.83	4	3	4	4	3
C10	Participatory design.	0.75	3	2	4	3	1
	Design harmony for political conditions.	0.74	3	3	5	5	3
	Harmonic design through the study of environmental disturbances.	0.81	1	3	3	5	3
	Harmony of design through project architecture.	0.72	3	1	5	3	3

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(Figure 4) depicts project performance through the structural decision-making model (MESS-VP). Thus, the scope of each social criterion assessed per case study is represented and then aggregated through the arithmetic mean among the different criteria. From this point, the results are as follows: In first place is Case Study 3 from the commune of Lautaro with an average of 73% and a standard deviation of 0.191; in second place is Case Study 4 from the commune of Nueva Imperial with an average of 70% and a standard deviation of 0.183; in third place Case study 1 from the commune of Padre Las Casas with an average of 64% and a standard deviation of 0.115; in fourth place Case study 2 from Pillalelbun with an average of 55% and a standard deviation of 0.128; in fifth place Case study 5 from the commune of Galvarino with an average of 51% and a standard deviation of 0.077.

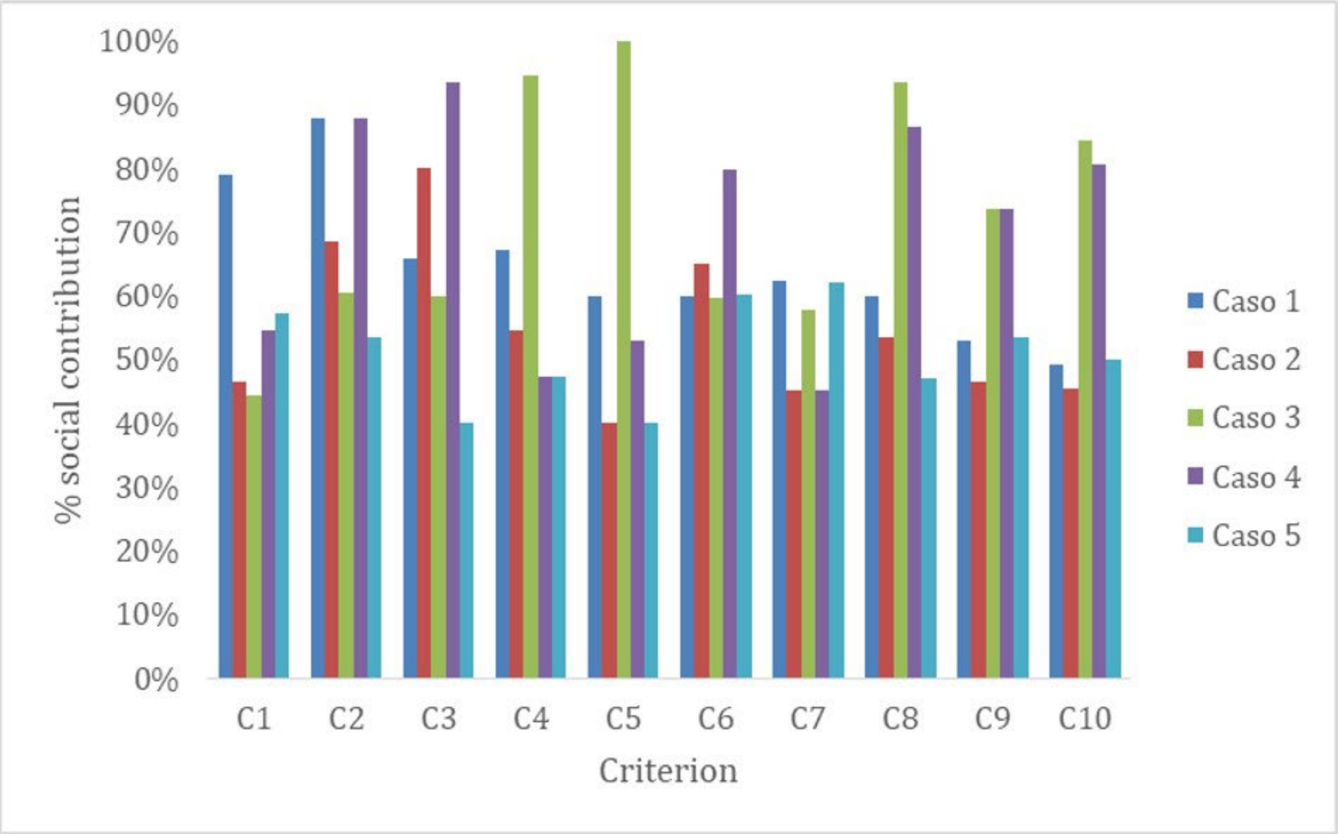

Figure 4. Social project yields (MESS-VP t=0).

Then, the results yielded by each social evaluation method are presented. The results were categorized according to the arithmetic mean on the same scale. The Envision certification system produced the following outcome: In first place is Case Study 4 with an average of 32.5% and a standard deviation of 0.220; in second place Case study 3 with an average of 29.8% and a standard deviation of 0.208; in third place Case study 1 with an average of 29.7% and a standard deviation of 0.229; in fourth place Case study 2 with an average of 24.8 and a standard deviation of 0.229; and in fifth place Case study 5 with an average of 13% and a standard deviation of 0.134.

Finally, we present the results obtained through the Sustainable Housing Certification, Chile. In first place is Case Study 1, with an average of 53% and a standard deviation of 0.316; in second place is Case Study 4, with an average of 51% and a standard deviation of 0.243; in third place Case Study 3, with an average of 43% and a standard deviation of 0.261; in fourth place Case study 2 with an average of 34% and a standard deviation of 0.294; and fifth place Case study 5 with an average of 23% and a standard deviation of 0.148.

(Table 4) presents the general results of social contribution without homogenization for each case study and evaluation system. The structural model (MESS-VP) presents social contribution values differentiated without interaction (t=0) and with the interaction of other criteria (t=4). The initial values determined directly by the factor loadings of its indicators are concentrated between 51% and 73%. The influence of the interaction between criteria in the system increases the contribution and shortens the differentiation gap between 73% and 78%. This order is followed by

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the CVS (sustainable housing certification) with intermediate values between 23% and 53%. Ultimately, the Envision system exhibits less value performance, ranging from 14% to 33%. These differences are due to the variation in metrics and criteria to be assessed between systems. Differentiation is influenced by the methodologies and priorities associated with each system's various variables and constraints. Qualitatively, the structural model presents more evaluation and classification options closer to the context's representation. However, the Envision and CVS methods present more constraints when evaluating dichotomously, leaving classification options without representation.

Table 4. Project social contribution to each assessment system.

Study case	MESS-VP		CVS	Envision
	t=0	*t*=4		
Case 1	64%	76%	53%	30%
Case 2	55%	73%	34%	25%
Case 3	73%	77%	43%	30%
Case 4	70%	78%	51%	33%
Case 5	51%	73%	23%	14%

(Table 4) represents the social contributions of each case study according to the three evaluation systems. The three systems were compared exclusively based on their social constructs, although they presented different response states and conceptual variability in their indicators. This qualitative analysis is presented in the discussion section of this paper. Thus, the comparison is possible after adjusting the evaluation metric by normalizing the values in (Table 3). To adjust the metrics of each system the values are normalized based on the range between the maximum and minimum of each case study. The scale adjustment makes it possible to compare different variables on a common scale, which is essential when variables have different units or ranges of values (Han et al., 2011).

(Table 5) presents the yield of the projects after normalizing. The order of contribution of the MESS-VP systems with and without criteria interaction and the Envision system are consistent. On the other hand, in evaluating the CVS system, there is no coincidence in cases 1, 3, and 4.

Table 5. Project yields with adjustment scale.

System	Case 1	Case 2	Case 3	Case 4	Case 5
MESS-VP (t=0)	61%	16%	88%	100%	0%
MESS-VP (t=4)	60%	0%	80%	100%	0%
ENVISION	85%	59%	86%	100%	0%
CVS	100%	36%	67%	95%	0%

The Kruskal-Wallis test found no statistically significant differences among the assessment methods. In other words, the three methods behave similarly, and there is no statistical evidence that some of them stand out over the others in terms of the variables analyzed with a p-value of 0.0963.

The Kendall analysis suggests no significant differences exist in the agreement of the five projects assessed regarding the Envision and Chilean sustainable housing certification systems and the structural decision-making model. This indicates that the projects behave similarly regarding the general social sustainability assessment.

6. Discussion

The findings indicate that the proposed model for social evaluation of public housing projects in Chile (MESS-VP) incorporates characteristics such as Housing committee management and Consideration of public opinion, which are absent in other certification systems. Indeed, considering context is a limitation of conventional certification systems that are specifically project-based (Díaz-Sarachaga et al. 2018). Community and stakeholder engagement is essential for incorporating social capital into developing a sustainable infrastructure life cycle (Valdés-Vásquez and Klotz, 2010).

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According to the results in (Table 4), the MESS-VP scores are higher in all five case studies than in the ENVISION and CVS certification systems. The MESS-VP system requires additional indicators and levels of compliance for the sustainability of social housing compared to other systems. ENVISION and CVS indicators do not normally apply to the specific development of social housing projects; their scope covers all infrastructure and residential buildings, respectively (Laali et al., 2022) (Goijberg and Madrid, 2020). ENVISION and CVS use dichotomous indicators that affect the sensitivity in measuring the sustainable contribution of such projects. In this vein, (Diaz-Sarachaga et al., 2016) evidence gaps in implementing international certification systems when contrasted with conditions in developing countries. Nevertheless, the results of this study reveal similarities. For example, in every case, the criterion of Improvement in family economic capacity (or its equivalent) is considered; however, the proposed model takes a more specific approach, considering the indicator of Savings due to access to transportation and services. A similar case occurs with the criterion of Functional integration in the neighborhood, where the MESS-VP is approached not only from the accessibility point of view but also includes social and cultural cohesion, which holds paramount significance in the national context.

Other criteria consistent with the measurement of other systems are Connectivity and Access. In this case, Envision considers them as Improving access to community mobility, Promoting sustainable transport, and Improving access and orientation (ISI, 2018). The equivalent case in CVS is Universal accessibility, Access to public transportation, Sustainable transportation, and Proximity to basic facilities and services (MINVU, 2021).

The factors influencing sustainability are interconnected: they function within a system where effects arise from one another or even exhibit cyclical effects stemming from the same factor at a prior moment (Slootweg et al. 2001). This is even more noticeable in housing projects and social aspects to adequately represent the contribution to sustainable development. In this sense, the proposed model identifies the effect of certain criteria on others after each evaluation cycle. In other words, it is determined that the Motivation to invest in family property, Functional integration in the neighborhood, and Identity and culture are criteria influenced by the rest of the system in assessing the social sustainability of public housing. Similarly, Citizen Health and Safety and Consideration of Public Opinion are independent triggers influencing the rest (Sierra et al., 2023).

The proposed MESS-VP emphasizes assessing the contribution to the social sustainability of public housing initiatives in Chile, incorporating the interplay among latent criteria. Thus, the results are limited to the social contribution; the environmental and economic aspects of sustainability still need to be investigated and integrated into future lines of development. In addition, replicability in other Latin American contexts requires reconsideration of the important aspects, their factor loadings, and the correlation of their interactions.

7. Conclusions

This study validated a structural equation model based on social criteria applied to public housing projects in Chile. The model comprises ten criteria (latent variables) that address social housing decision-making and the neighborhood community from the social sustainability perspective. These criteria are Community Health and Safety; Consideration of public opinion; Improvement in Family Economic Capacity; Motivation to Invest in Family Property; Connectivity and Access; Housing Committee Management; Functional Integration in the Neighborhood; Integration of Design into the Context; Spaces for Family Development; and Social Identity and Culture. The criteria structure is also defined by 30 indicators (observable variables). In addition to applying five case studies, the social contribution was determined through the structural model (MESS-VP) of social projects in the Araucanía region. Ultimately, the outcomes derived from the model were juxtaposed with several social certification schemes, such as Envision on an international scale and the Chilean Sustainable Housing Certification domestically. A statistical analysis found no statistically significant differences between these evaluation methods' characteristics. The results of the model are only valid for public housing. The MESS-VP model is constrained by its exclusive focus on the social dimension, neglecting environmental and economic factors, hence restricting a comprehensive view of sustainability. In addition, the results are limited to a national scope in Chile, and the case study's results only represent the sample of five projects investigated. They cannot be generalized to other cases. The structural model was built from a sample slightly more petite than recommended, even though it presents good goodness of fit, and the actual cases in which it was implemented were consistent with other certification systems.

This study supports the decision-making process of public agencies responsible for allocating social housing. By utilizing these criteria and the interrelationship structure, progress can be made in assessing the social benefit of housing projects. This contributes to the assessment and sustainable planning of public housing from a social point of view. Future research should extend the model by integrating socioeconomic and environmental aspects. Furthermore, other housing programs (rural housing and buildings or rental systems) should be included.

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9. Notes on Contributors

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