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DIAGNOSIS, MANAGEMENT, AND TREATMENT OF A HERITAGE-BUILT ENVIRONMENT IN SOUTH CHILE

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Abstract. In Chile, photography arrived at the end of the 19th century together with the establishment of settlements of migrants from central Europe to southern Chile. The aims of this study are: (i) contextualise functional states of existing buildings in a specific sector of the historic Valdivia city centre; (ii) determine the state of conservation of the 42 cases under study; (iii) conduct qualitative and quantitative analyses of the main pathologies presented in the sample; (iv) perform an analysis focused on the urban context according to façade alignment, façade visibility index, and ratio of height versus street width; and (v) comparatively analyse the results achieved. This research reflects the importance of developing innovative procedures and mitigation strategies focused on preventive maintenance actions and future control systems that can maximise the resilience of a specific local context (Los Ríos region) and its surroundings. This study revealed that the number of pathologies detected was directly proportional to the state of conservation of the cases, classified by the functional service life model. Properties in Condition C were mainly affected by pathologies of a structural nature, which indicates that their functionality is not guaranteed, and a deeper inspection is needed for conservation and preservation actions.

Keywords: diagnosis assessment, built environment, heritage, timber buildings, South Chile.

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1. Introduction

Over the world, natural and even man-made risks facing built heritage are myriad, forming a trend towards the ultimate destruction of the built environment if not arrested on time (Adewumi, 2022). Preserving heritage is completely fundamental as it fosters the past ways of life which are germane to the present and a window to the future. Sustainable development (Nasser, 2003) and increased economic investment (Ruijgrok, 2006) can only be achieved when heritage is well protected through proper conservation. Historic city centres are sites that are of special interest given their cultural, social, historical, architectural, and urban value. Internationally, it is established the sustainability of the heritage-built environment as three main parameters: economical, environmental, and societal (Kayan, 2019). However, the composition of this series of variables, they have the purpose of forming comfortable and efficient environments capable of increasing the quality of life and well-being of their residents, and the mission of public administrations is to preserve this task (Anisimova & Anisimov, 2022; Niehaus et al., 2021). However, they are not free from damage due to environmental, anthropic, and natural disaster causes, especially in the case of southern Chile. This is due to the country being emplaced in the Ring of Fire (Williams et al., 2018). This coastal area of the Pacific Ocean is well-known as one of the most active subduction zones in the world that generates intense seismic activities, with a high probability of tsunamis and volcanic eruptions (Prieto, 2021). In analysing Chilean architectural heritage, it is necessary to consider the intrinsic vulnerability of heritage buildings as a main factor, which is determined by many variables concerning vulnerability as well as external risks (D'Ayala et al., 2020). In this sense, their protection and preservation and the incorporation of sustainability criteria are some of the main challenges to achieving a good built environment throughout the country through urban renewal and preservation (Zumelzu & Espinoza, 2019; Zumelzu, 2016). Particularly in central areas of southern Chile, the increase in the deterioration of the urban environment is reflected in environments of low spatial quality, excessive building densification, progressive deterioration of built heritage, lack of vegetation and maintenance of sidewalks, low visibility on façades, and the presence of blind walls in streets and passages, which have forced the inhabitants to redefine their social relations and connection with the built environment (Zumelzu et al., 2022; Pizarro et al., 2022). The built urban heritage, as part of the cultural, architectural, and urban heritage, affects individual development, and it is a fundamental pillar of the sustainable development of urban centres (Tweed & Sutherland, 2007), given that sensory aesthetic experiences positively influence the well-being of the individual (Luna, 2020). Research on historic city centres has revealed that traditional architectural environments are statistically better valued, presenting a higher rate of perception of well-being and a sense of belonging by those who inhabit them, inducing a feeling of comfort and security at a physical and social level (Rajapakse, 2017). In this sense, urban renewal can contribute significantly to sustainable development through the implementation of plans that promote the conservation and preservation of built architectural heritage (Farhan et al., 2022). Considering these findings and the fact that not all heritage buildings are located in protected areas or historic centres, there is a need to study their urban context to ensure adequate conservation of properties and their built environments around the city, particularly in the cities of southern Chile (Mohamed et al., 2020).

The aim of this article is to understand the connection between built heritage, built environment, and the degradation processes of heritage building conservation (HBC) in the city of Valdivia. This study intends to highlight the relevance of this type of research for urban design in contexts with a high presence of heritage buildings and the need to move towards methodologies and tools for the sustainable management of built urban heritage in cities of South America.

This article is divided into five parts. First, a state-of-the-art and bibliographic compilation of the case studies is presented to develop an identification file that contains relevant information for the architectural study. The second part focuses on the diagnosis of pathologies of the sample, in which three main types of support analysis are defined: (i) state of conservation, (ii) pathologies, and (iii) urban heritage according to three criteria defined by Oliveira (2013) and Alonso de Andrade et al. (2018): Façade alignment, façade visibility index, and ratio of height versus street width. The third part consists of the realisation of a photographic catalogue of pathologies that will account for the research carried out. Fourth, a comparative analysis of the results obtained through sample characterisation is discussed to orient the agents that affect the state and preservation of the built heritage from three perspectives (range of functionality, pathological presence, and urban morphology). Finally, conclusions are drawn about the necessity of new tools and methods concerning the analysis of the state of conservation (HBC) to preserve the built heritage in central areas in southern Chile.

2. Literature review

The existing body of literature presents a diverse array of studies that integrate the principles of sustainability and degradation within the realm of urban environmental contexts worldwide. These studies extend beyond the confines of Southern Chile, encompassing cities on a global scale. In the midst of urban development across various international cities, the focus remains on cultivating opportunities for heightened growth and fostering enhanced synergies between individuals and the constructed surroundings (Van Kamp et al., 2003; Zumelzu & Herrmann-Lunecke, 2021).

Concerning some parameters related to improving the urban context, highly visible façades are recommended (Alonso de Andrade et al., 2018), between 50% and 70%, which would imply more active and safer streets. These types of façades generate a panoptic effect, causing positive emotions for the individual in front of others and their environment, whereas very long, monotonous fronts with blind walls can have negative effects on the mental well-being of individuals, inducing a feeling of rejection and negatively affecting interactions with the environment (Hosni & Zumelzu, 2019). A good façade permeability allows for a direct relationship between the environment and the property, which generates greater interaction on the part of the user. On the contrary, having a low or null permeability generates a negative relationship between these agents, which can result in different types of interactions, such as vandalisation of the property, due to the little relationship it has with its built environment (Alonso de Andrade et al., 2018; Zumelzu et al., 2022).

The ratio of building height to street width is also a key spatial design factor (Oliveira, 2013). A correct ratio between the height of the building and the width of the street can lead to greater spatial comfort and positive benefits for mental well-being. In the same way, the alignment of the façade fronts can contribute positively to the urban landscape. The presence of blocks with low alignment percentages (less than 50%) induces feelings of insecurity given the sensation of disorder they present; however, they may also be due to the existence of front gardens, which contribute positively to the landscape. Recent evidence shows that the presence of trees on the street and wide sidewalks (three or four metres wide), in good condition, is also associated with a higher perception of well-being (Udeaja et al., 2020). The latter is especially important for women, the elderly, and people with disabilities, where wide sidewalks generate well-being, comfort, and safety (Mouridatis por Nowak et al., 1997).

Numerous studies have systematically shown that buildings with historical or artistic value can generate feelings of happiness and positive mental well-being in streets and public spaces. Adding the variables described above to these values yields urban spaces of great historical, social, and cultural value, which would intensify the need for architectural protection and conservation (Zagroba et al., 2020). Nevertheless, the integral management of built heritage is the main challenge of the 21st century. International organisations and national governments are recognising the need to generate new tools to support the comprehensive planning of architectural and urban heritage contexts (Tweed & Sutherland, 2007), incorporating all stakeholders involved in the process (Bandarin & Van Oers, 2012). In the Chilean context, the Ministry of Housing and Urbanism ([MINVU] in Spanish) is the main entity in charge of carrying out regulations and urban planning throughout the country. This ministry regards the provisions contemplated in the Urbanism and Construction Regulations (General Law of Urbanism and Construction) and its General Ordinance of Urbanism and Construction (OGUC in Spanish). They developed the Communal Regulatory Plans (PRC in Spanish), which designate properties (HBC) and zones of historic conservation (HZC) (Pérez & Ortega, 2021) in relation to the conditions and characteristics established in Article 2.1.43 of the OGUC. Management in the Chilean context is carried out by the Urban Development Division (UDD) of the MINVU. Within the framework of Chile's Urban and Housing Policy, special emphasis is being placed on cities and their neighbourhoods as focuses of urban integration policies. Among the dimensions that are addressed are social integration, economic development, and environmental balance, thereby incorporating, with special relevance, the protection and enhancement of heritage as the founding axis of the identity of the communities and regions of Chile (Niehaus et al., 2021; Prieto, 2021). The main policies for the protection and recovery of the urban heritage context aim to revalue the cities of Chile, with the goal of creating more attractive cities for citizens via urban planning and safeguarding character and local identities, thereby promoting the protection of urban heritage quality. These policies are also part of the objectives of the National Centre for Conservation and Restoration of Chile – to organise and implement policies for the conservation and restoration of heritage at the national level (Valdebenito et al., 2021).

3. Materials and methods

This study uses qualitative and quantitative methodologies to assess the pathologies and risks presented by the HBC of the city of Valdivia to understand the connection between the built heritage, its environment, and its own degradation processes of the constructive materials (Pizarro-Reyes et al., 2022; Silva & Prieto, 2021). The case study corresponds to 42 HBCs in the city centre of Valdivia. To carry out this work, the investigative activities were divided into five stages (Figure 1).

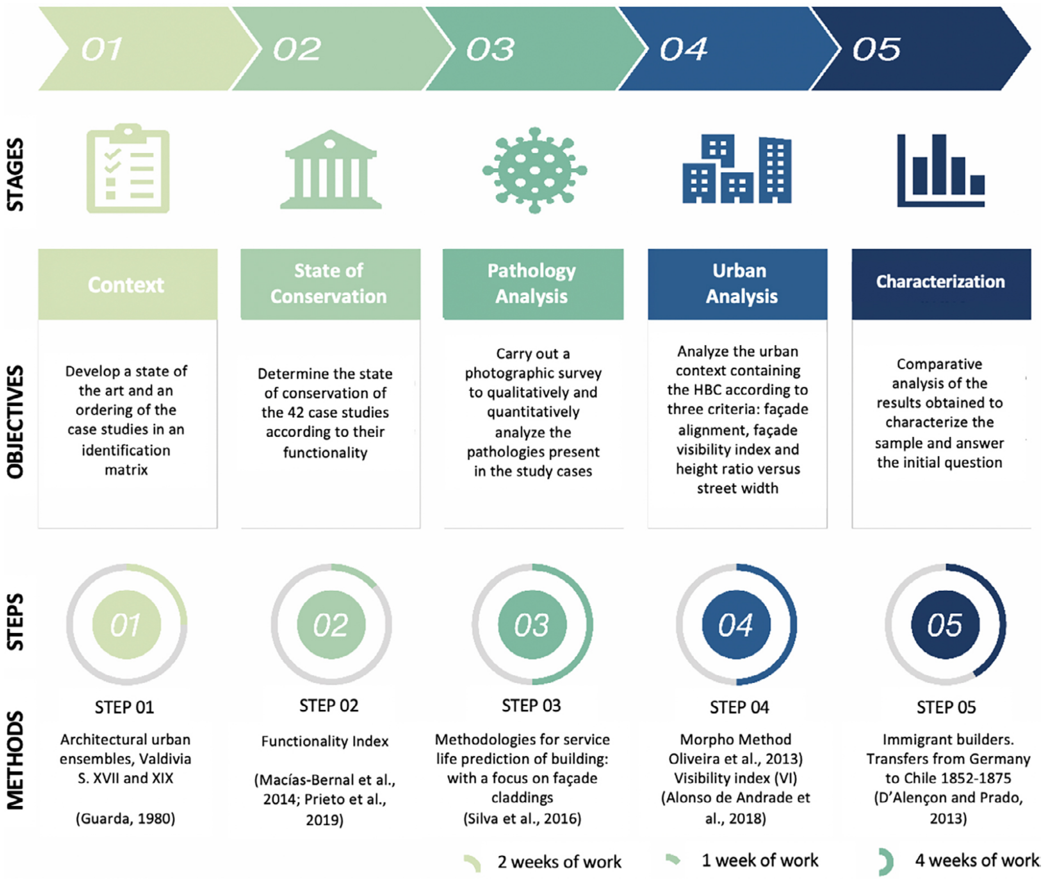

Figure 1. Diagram of the research methodology

The first stage consisted of developing a state-of-the-art and bibliographic compilation of the case studies to develop an identification file that contained relevant information for the architectural study. The second stage focused on the diagnosis of pathologies of the study cases, in which three types of support analysis were defined: state of conservation, pathologies, and urban heritage. The third stage comprised the realisation of a photographic catalogue of pathologies, accounting for the research conducted. Fourth, the urban context that contained the HBCs was analysed according to three criteria: façade alignment, visibility index, and ratio of height versus street width. Fifth, a comparative analysis of the results was conducted through sample characterisation (Pizarro-Reyes et al., 2022).

3.1. Contextualisation of the case studies

The novelty of this study lies in its analysis of the urban sustainability and functional states of the existing heritage buildings in six sectors of Valdivia and using machine learning algorithms to achieve method's results. Valdivia has a quite small population (166,080 inhabitants, estimated in the last census conducted in 2017). It is currently the capital of the 14th Region (Los Ríos); it was founded in 1552. Valdivia's cultural heritage comprises a series of elements scattered throughout the city (Cabello-Briones et al., 2021). The most notable features of these buildings are related to their Spanish and Pre-Hispanic origins, fortifications dating from the Spanish Empire, and German colonisation in the 19th century, which clearly marked the urban layout and the current collective urban identity of the city (Báez-Montenegro et al., 2012; Guarda por Mann et al., 2016).

The research relied on an innovative multiscale analysis ranging from several individual heritage buildings with different characteristics to the scale of the city in which the buildings were located (Niehaus et al., 2021), thus encompassing the cultural context of southern Chile. The sectorisation of the case studies allowed an orderly survey to be carried out, in addition to recognising the architectural characteristics of each area studied. The sample was divided into six study areas (Figure 2).

Concerning the raw materials in which the case studies were erected, the use of wood as the primary building material has a long history in Chile, particularly for building churches and other important structures (Carpio & Prieto, 2021; Cabello-Briones et al., 2021; Saelzer et al., 2019a, 2019b). The most common typology of these buildings comprises a large volume of two floors, with a continuous façade to the street and few ornaments, although with carefully designed proportions. The case studies under analysis show the following main characteristics (Prado et al., 2011): (i) foundations are formed by wooden beams supported by timber and concrete logs, without infill materials; (ii) the wooden structures have a post-and-beam construction type; (iii) the type of joints is characterised by the presence of wood billets, the union of a spiked box or half-wood laces; (iv) the buildings have a rectangular architectural plan, with an entrance hall and a central corridor that provides access to the other rooms; (v) external claddings are in wood, with horizontal weatherboarding and larch canopy covers; (vi) generally, the buildings are a maximum of two storeys; in some buildings, the height of the first floor is greater than the ground floor; (vii) the most common use is housing (and the buildings are private properties) (Figure 3) (Prieto, 2021). These features were constituted from the analysis of the state of conservation of the HBC, extracted from the survey carried out previously by the FONDECYT project n°11190554, which followed a fuzzy inference system based on Macías-Bernal et al. (2014) and updated by Prieto et al. (2019).

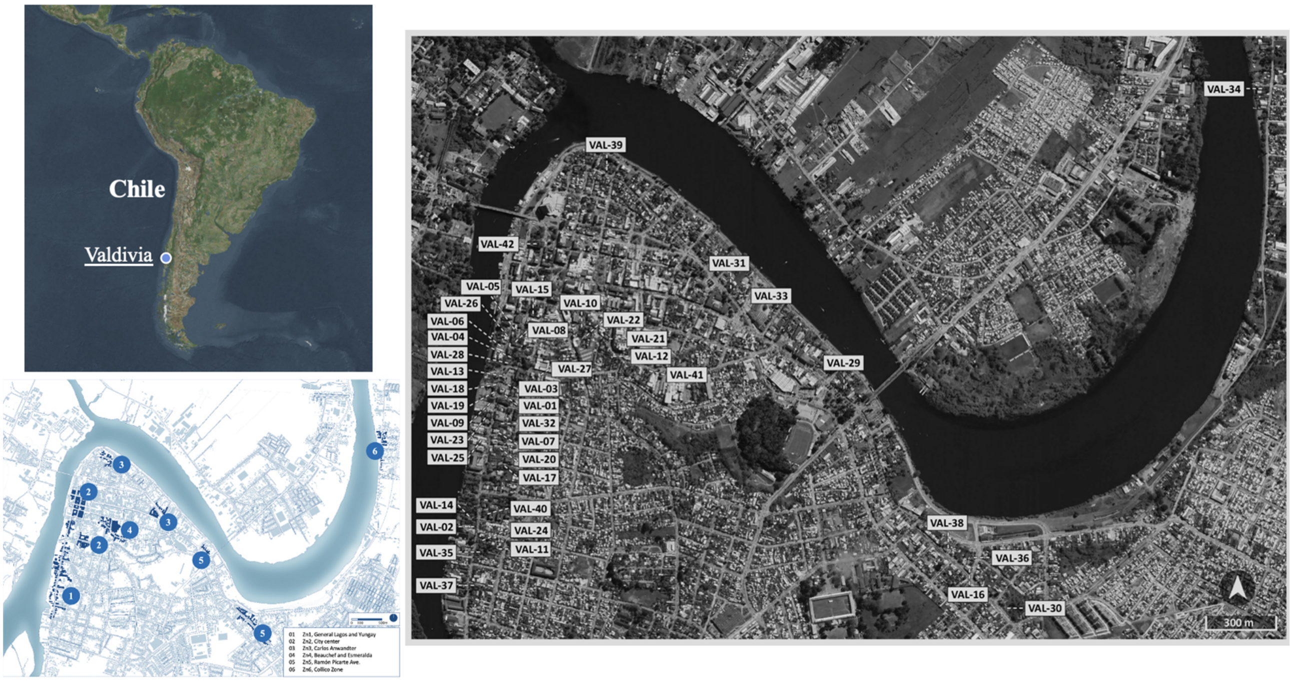

Figure 2. Location of the studies under analysis, Valdivia, South Chile

Figure 3. Cases studies – 42 HBCs in the city centre of Valdivia (South Chile)

3.2. Functional service life analysis

Fuzzy sets theory, proposed by Lofti A. Zadeh (1965), has been established as a powerful instrument for scenarios with significant levels of associated uncertainty, as in cases in which they are intended to model phenomena that occur in the real world, such as the degradation of heritage buildings and their more direct urban contexts (Niehaus et al., 2021). Evaluating the functional service life of buildings and their relationship with environmental degradation agents in the environment is, without a doubt, a complex system of relationships between different factors, which generally requires the opinions of professional experts. In this study, the model considered 17 input variables, which identified the main indicators or parameters to be considered during the evaluation and diagnosis stages of the case studies. The variables were classified as follows: (1) five variables related to intrinsic vulnerabilities of buildings: (i) geological situation, (ii) roof design, (iii) built environment, (iv) construction system, and (v) conservation (Table 1); and (2) 12 variables involved in the consideration of external hazards: (i) modification of the state of loads, (ii) facilities, (iii) overloads, (iv) ventilation, (v) fire, (vi) inner environment, (vii) rainfall, (viii) wind and temperature, (ix) population growth, (x) property value, (xi) furniture value, and (xii) occupancy (Table 2).

The fuzzy inference system ($FBSL_{2.0}$) generates, as output (semi-qualitative index), a ranking of priorities actions considering three possible scenarios related to functional service life of buildings and components: (i) Condition C (between 9 and 19 weighted points): the vulnerabilities and risks of failure were considered intolerable and immediate intervention was required; (ii) Condition B (between 20 and 29 weighted points): costs and benefits were considered and balanced; (iii) Condition A (between 30 and 51 weighted points): the vulnerabilities and risks were considered to be so small that they did not require any type of intervention (Figure 4) (Niehaus et al., 2021).

As shown in Figure 4, the first level of intermediate fuzzy variables on the hierarchical structure is the next level. For Vulnerability-A, Vulnerability-B, Static-Structural Risk-A, Static-Structural Risk-B, and Anthropic Risk, these variables were generated by inference rules based on the entry variables. For example, Vulnerability-A was generated through a set of diffuse rules involving the variables of roof design and the preservation variable (Table 1). Regarding the composition of fuzzy proposals, the min–max composition or the Mamdani inference mechanism was used.

The output model was obtained after the defuzzification stage, in which a crisp value represented the fuzzy information produced by the inference. The fuzzy system uses the centre of the area (COA), also known as the centroid; it uses the centre of the area of fuzzy Set B as a proxy value, functional service life (Moreno-Velo et al., 2007), which is one of the most common and successful methods for defuzzification processes. The most notable property of this method is that it is continuous, which means that a small change in inputs does not imply an abrupt change in outputs. Its discrete version can be interpreted as a Riemann sum (Eqn (1)).

$$\text{Functional service life index}\left(FBSL_{2.0}\right)=\frac{\sum_i y_i \cdot \mu_B\left(y_i\right)}{\sum_i \mu_B\left(y_i\right)}. \quad (1)$$

The result of the model contributes to the knowledge of the state of conservation users, owners, and interested parties (stakeholders) in charge of future decision making related to the management of conservation and preventive maintenance in sets of buildings located in particularly

Table 1. Input factors related to intrinsic vulnerabilities and valuation descriptions (Prieto et al., 2019)

Vulnerabilities	Quantitative and qualitative valuation	Description
Geological location	1.0 – favourable	Optimum ground conditions in terms of stability
	4.0 – unfavourable	Unfavourable ground conditions in terms of stability
Roof – design	1.0 – favourable	Fast evacuation of water
	8.0 – unfavourable	Complex and slow evacuation of water
Environmental conditions	1.0 – favourable	Building without complex constructions around it
	8.0 – unfavourable	Building located inside of complex constructions around it
Constructive system	1.0 – favourable	Uniform characteristics of constructive system
	8.0 – unfavourable	Heterogeneous characteristics of constructive system
Preservation	1.0 – favourable	Optimal state of conservation
	8.0 – unfavourable	Neglected state of conservation

Table 2. Input factors related to external hazard effects and valuation descriptions (Prieto et al., 2019)

Hazards	Quantitative and qualitative valuation	Description
Static-structural		
Load state modification	1.0 – favourable	Apparently modification
	8.0 – unfavourable	Disorderly modification
Live loads	1.0 – favourable	Live load below than the original level
	8.0 – unfavourable	Live load higher than the original level
Ventilation	1.0 – favourable	Natural cross-ventilation in all areas
	8.0 – unfavourable	Natural cross-ventilation nowhere
Facilities	1.0 – favourable	All facilities are in use
	8.0 – unfavourable	The facilities are not possible to be use–
Fire	1.0 – favourable	Low fire load in relation with combustible structure
	8.0 – unfavourable	High fire load in relation with combustible structure
Inner environment	1.0 – favourable	Maximum level of health, cleanliness and hygiene of the building's s–aces
	8.0 – unfavourable	Low level of health, cleanliness and hygiene of the building's spaces
Atmospheric		
Precipitations	1.0 – favourable	Area with low/medium/maximum annual rai–fall
	8.0 – unfavourable	Area with maximum annual rainfall
Temperature	1.0 – favourable	Area with low temperature differences
	8.0 – unfavourable	Area with maximum temperature differences
Anthropic		
Population growth	1.0 – favourable	Population growth greater than 15%
	8.0 – unfavourable	Population growth less than 5%
Heritage value	1.0 – favourable	Properties with great historical value
	8.0 – unfavourable	Properties with low historical value
Furniture value	1.0 – favourable	Social, cultural and liturgical appreciation (high value)
	8.0 – unfavourable	Social, cultural and liturgical appreciation (low value)
Occupancy	1.0 – favourable	High occupancy in the building
	8.0 – unfavourable	Low occupancy in the building

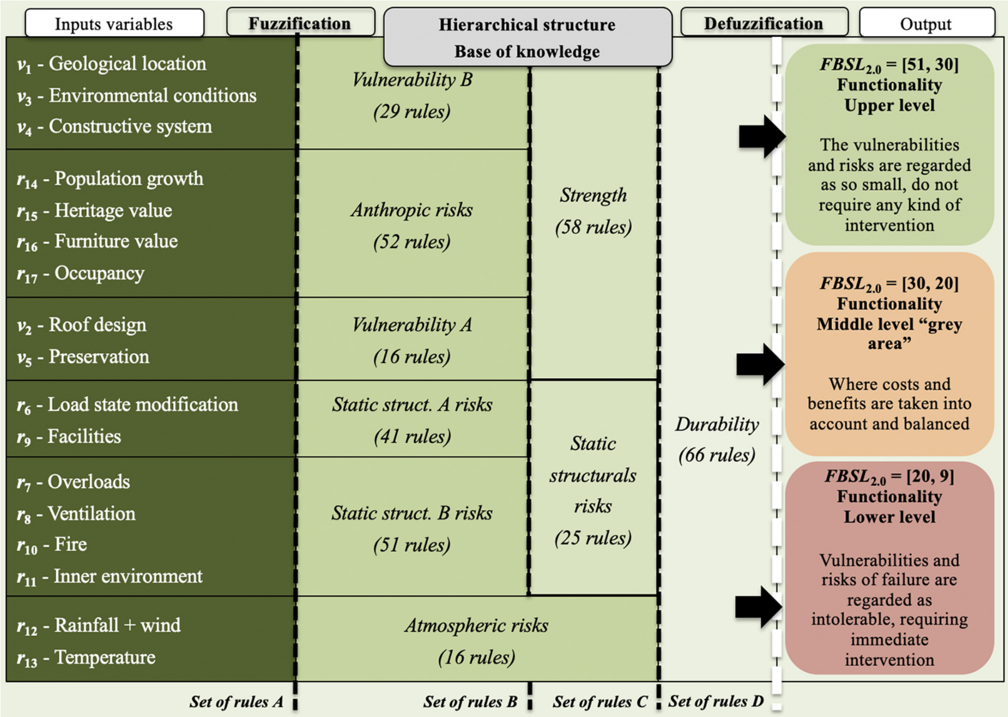

Figure 4. Hierarchical assembly of the Fuzzy Building Service Life extended ($FBSL_{2.0}$) model based on fuzzy logic (Prieto et al., 2019)

local contexts (Cabello-Briones et al., 2021). These kinds of methodologies present some benefits compared with traditional methods based on Boolean logic – their ability to learn and generalise based on experience and examples, combining numerical precision with transparency in the form of linguistic rules (Cabello-Briones et al., 2021).

3.3. Analysis of anomalies

The analysis of anomalies included a survey and photographic analysis of the façades of the study cases under examination, emphasising the registration of the anomalies found. For this, photography was used as a tool to support the diagnosis process, taking as a reference the methodology for predicting the service life of timber claddings (Silva et al., 2016). The anomalies will be classified into two groups (Figure 5): (i) aesthetic or visual erosion anomalies, code AA, related to slight defects related to the maintenance of the property (Prieto & Silva, 2020); (ii) anomalies of loss of integrity, code AB, related to loss of material integrity, caused by external agents, including three types of injuries: physical injuries such as humidity, dirt, erosion, mechanical injuries such as deformation, cracks, detachment, and chemical injuries such as efflorescence, oxidation and corrosion, the presence of organisms and chemical erosion (Silva & Prieto, 2021). Subsequently, a planimetric survey was carried out to determine the quantitative measurement of the portion affected by the several anomalies detected. This resulted in a statistical analysis of the most frequent anomalies based on the geographical sector in which the case studies were emplaced.

3.4. Analysis of urban heritage

The built environment was analysed through a photographic survey, focused on three main concepts of the urban fabric and supported by the principles of Oliveira (2013): building alignment, ratio of height and width of the street, and visibility index (Alonso de Andrade et al., 2018). This study sought to understand how the relationship between architectural work and its context can affect its preservation and enhancement.

The environment was qualitatively evaluated using two criteria based on the Morpho methodology (Oliveira, 2013): (i) Alignment of the percentage of façades that are arranged in the building line on each side of a block. The dominant alignment on each edge was first identified, and then the number of buildings on the street was expressed as a percentage (%) of the total number of buildings on that street. A scale was established where 0 (or close to zero) indicates absence of alignment and 1 (or 100%) indicates the presence of a single alignment; (ii) Ratio of building height and width of streets, existing proportion between the dimension of the street and the height of buildings. The ratio of these is widely used in international urban development standards and is applied in a 1:1 ratio (building height/street width). This allows for determining the sensation of closure experienced by the pedestrian when walking the street, establishing the levels shown in Table 3.

To evaluate the design of the streets, the visibility index (VI) was assessed (Alonso de Andrade et al., 2018). The visibility of the front was calculated by combining a quantitative measure, the degree of visual permeability, and a qualitative classification scale of the type of space that was visible using the criteria shown in Table 4.

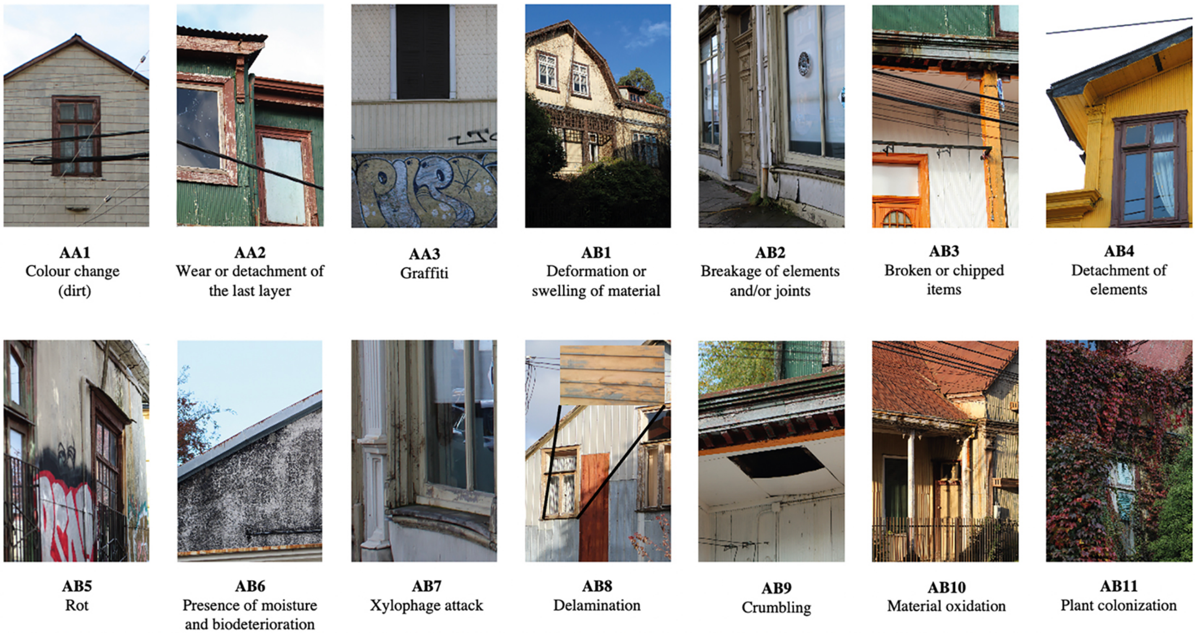

Figure 5. Classification of anomalies in timber claddings, based on Prieto and Silva (2020)

Table 3. Proportion of building height and street width ratios (Pizarro-Reyes et al., 2022; Oliveira, 2013)

Ratios of building height to street width	Qualitative description of ratio of height of buildings, with respect to the feeling of enclosure of the street
Ratio: < 1:4	Little feeling of enclosure
Ratio: 1:2–1:3	Moderate enclosure on a street
Ratio: 1:1	Minimum value to provide a comfortable walkway
Ratio: < 2:1	The building height is double that of the street, leading to feelings of claustrophobia and perceptions of insecurity for pedestrians

Table 4. Type of visibility of the façade (Alonso de Andrade et al., 2018)

Type of space	Qualitative description of the space
V1	Front without visibility
V2	Front with visibility into empty space
V3	Front with visibility into private space
V4	Front with visibility into public space

Following the identification of the types of visibilities present, the visibility indices (VI) of each edge of the studied block were calculated by expressing the percentage of permeability of the front as a function of the total length of the street, as shown in Eqn (2):

$$VI = 1 - (V1/(V1 + V2 + V3 + V4)). \quad (2)$$

The planimetric survey of the façades being studied offers information on their surfaces, presenting a value in metres with respect to the edge of the block of each façade. Thus, each façade was classified, as shown in Table 4 (façade visibility type), and its permeable surface was measured to calculate the percentage of incidence of each façade with respect to the edge of the block being studied. The values obtained indicate the level of permeability of the façade; the closer it is to 1, the more permeable it is. This urban analysis was carried out to determine the indirect agents that indicated the state of conservation of the HBC studied, offering insights into how the context indirectly affected the preservation of the properties.

4. Results and discussion

4.1. Analysis of the state of conservation and the functionality index

The case studies were identified and divided into sectors. They were arranged into a new table (Table 5) that shows the score obtained after the application of the $FBSL_{2.0}$ functionality model.

Table 5. Summary of conservation status: 42 case studies

Functionality index $FBSL_{2.0}$	Condition	Functional state	N° of case studies	% of the sample
[30–51]	Condition A	The functionality of the building is acceptable, it does not need periodic inspections or interventions	2	5%
[20–30]	Condition B	The building requires periodic inspections	33	78%
[9–20]	Condition C	The functionality of the building is not guaranteed	7	17%

The results showed that of the 42 study cases, 33 cases (78%) were in Condition B, which indicates that they present an acceptable state of conservation, requiring periodic inspections and moderate maintenance work. Seven cases (17%) in Condition C were located in the same area (Zone 1). This implies that their functionality is not guaranteed and that immediate actions must be initiated. The remaining two cases (5%) were in Condition A, indicating that their state of conservation was optimal, requiring only minor maintenance.

Figure 6 shows that 78% of the buildings were in an acceptable state of conservation, which indicates that it is possible to improve their current conditions. This also coincides with the degree of protection and management presented by the properties, with those with a score greater than 15 (in DDU 240) being in the best state of conservation. In addition, the properties with the worst state of conservation were located in urban areas. Of the seven buildings in this condition, three were located on Yungay Street, consistent with a change in its architectural programme, going from residence to public facility.

4.2. Incidence of pathologies in the study cases

Given the results of the conservation diagnosis, special emphasis was placed on the seven cases that present a functionality condition of C. Buildings in Zone 1 of the study area, General Lagos and Yungay, were subjected to field visits. Using photography, surveys pertinent to the study cases were carried out, and the current states of the buildings were recorded.

Taking as reference the $FBSL_{2.0}$ functionality index (Prieto et al., 2019) and the assessment table for historic conservation properties of the DDU-240 and current DDU-400 of the MINVU (2018), a new identification card was prepared as support for the photographic record, listing the pathologies to study (see Figure 7). In addition to the basic information of the real estate, the existing pathology and the place affected by it were identified.

In the seven cases in Condition C, there were at least two anomalies of the type of loss of integrity, including type AB2 (breakage of elements and/or joints), found mainly in frames of openings, cornices, and ornamental elements; and AB10 (material oxidation, pathology present

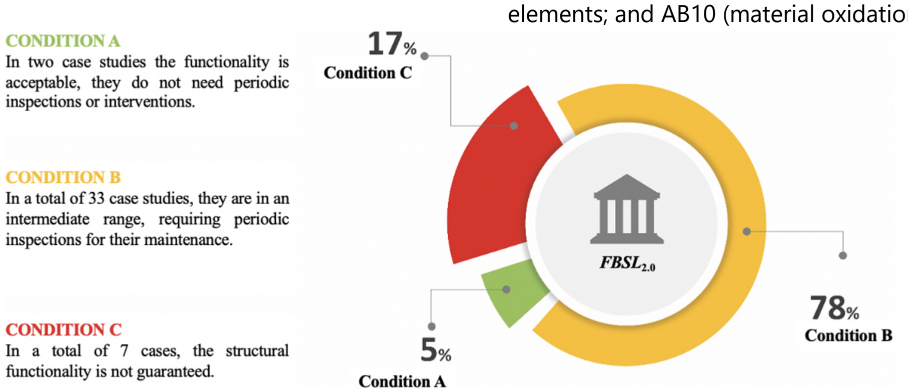

Figure 6. Classification of the state of conservation of 42 HBC

Figure 7. Study cases in functionality condition C

in galvanised tin cladding and mansards or lofts). In addition, the presence of anomalies of the aesthetic type was observed, such as AA2 (wear or detachment of the last layer, damaged paint) and AA3 (graffiti present mainly in buildings with the presence of a plinth).

An ordered analysis was carried out following the established zones. This assessed the different types of pathologies that affected the buildings depending on the sector in which they were located as well as the pathologies with the highest incidence in the area and the proportion of façade they affected. Figure 8 shows an example of a case study analysed from the photographic survey in which the different pathologies observed are described. For the application of the proposed model, three steps were carried out: (i) on-site inspection, identifying the presence of pathologies, leaving a record of this in the proposed cadastre card; (ii) planimetric survey of the façades, using photographs as a template, through AutoCAD 2018 software; and (iii) quantification of the area affected by the pathology.

According to the sectorisation of the case studies, the results are as follows: The 42 study cases represented a total of 5,570.55 m^2 of façade, which were divided into the six previously analysed study areas. The comparative analysis of the areas showed that the pathology with the highest incidence in the buildings was AA2 (wear or detachment of the last layer), with 1,441.44 m2 of façade affected, equivalent to 26% of the whole sample. The foregoing reflected the general state of the buildings studied, since 78% of the sample was in Condition B in terms of functionality, indicating that their conservation was in a medium state; therefore, the main failure was maintenance. In this case, the last layer of the façade directly affects how the property is perceived by users and researchers.

4.3. Built urban heritage: Façade alignment

The properties studied were classified into two types of alignment: property with frontage in the building line or property with a front garden. From this analysis, we observed that the percentages of alignment varied depending on the study area. For example, on General Lagos Street, in Zone 1, we found percentages between 20% and 70%, the optimum being 70% alignment and the most unfavourable being 20%. In Zone 2, we found even more diverse percentages, such as some cases with alignment that reached 100% and others with very unfavourable alignment, at 13%, due to the zone being located in the historical centre of the city (Figure 9). This great variability between the percentages of façade alignment is due to the existence of front gardens, as the current regulations of the PRC indicate that in the Zu-7a zone (Typical Zone; Illustrious Municipality of Valdivia, 2004), located on General Lagos Street, the front gardens must be at least 5 m to new constructions (Table 6).

However, given the antiquity of General Lagos and Yungay Streets, we found the existence of buildings without front gardens because they were built before the modification of local regulations. A comparison of these results with the presence of pathologies revealed that the buildings directly facing the street present anomalies of the aesthetic type, such as the presence of AA3 (graffiti) versus the buildings that contain front gardens, since these protect them from anthropic risks, such as vandalisation.

Table 6. Specific regulations Zu-7a, Typical Zone

Zu-7a	
Minimum property area	1000 m^2
Minimum property front	20 m
Maximum % of floor occupation	40%
Grouping system	Isolated
Maximum building height	9 m measured on the vertical plane of the facade or three floors, with the possibility of adding a mansard roof
Minimal front yard	5 m

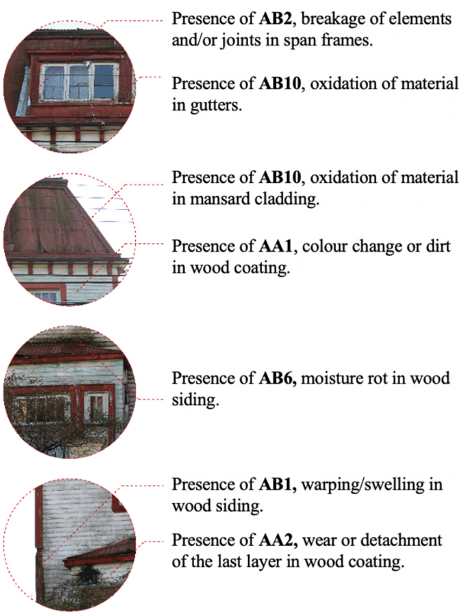

Figure 8. Photographic survey case study VAL-18, study of pathologies

Figure 9. Façade alignment study

However, they also reduce the relationship between property and public space, as they are private front gardens, generating a kind of vegetal barrier, which, if regulated, could contribute positively to the urban landscape.

4.4. Street height and width ratio

The relationship between street width and building height was analysed and applied in a 1:1 ratio (building height/street width). This allows for determining the sensation of closure experienced by the pedestrian when walking the street, establishing four types of levels, as explained in Table 3. As with the alignment of the façade, a diagnosis of the blocks adjacent to the case studies was carried out to assess how the street profile can generate certain types of reactions in the user, exploring the relationship between this concept and the presence of pathological agents. Figure 10 shows an example of a height ratio study in which the relationship between the width and height of the streets can be observed, as well as the existence of front gardens, which generate a sensation of widening the street. This contributes to the sensory-visual relationship with the pedestrian when relating to the environment in a positive way. These outcomes were specifically observed in General Lagos with Sotomayor Streets (Zumelzu & Hermann-Lunecke, 2021).

In the case of Zone 1, the proportion bordered on the 1:2 range, indicating that a good sense of enclosure can be perceived in practically the entire section studied, indicating a fairly optimal area for foot travel and giving a sense of security. As General Lagos Street is an area of building heritage interest, it is important to have a good degree of enclosure as this indicates that it is an easily accessible site for the community. The properties located in Zone 2 and Zone 3 presented a more unfavourable enclosure index, for example in Yungay, Lautaro, and Yerbas Buenas streets, due to their location in central areas according to the current PRC, ZU-1c (Table 7). The central area of the city and urban corridors had the greatest presence of high-rise buildings, due to what current regulations indicated in regulation ZU-1c.

Table 7. Specific regulations ZU-1c

ZONA ZU-1c (Res. Nº 101 / 09.12.2001, D.O. 27.02.2002)	
Minimum property area	4000 m^2
Minimum property front	40 m
Constructability Index	3.2
Maximum % of floor occupation	80%
Grouping system	Isolated
Minimum building height	6 m, measured on the vertical plane of the facade or 2 floors
Maximum building height	6 floors or 21 m
Minimal front garden for streets	Carampangue street 5 m Yungay street 5 m O´Higgins street 3 m Janaqueo street 3 m

Therefore, in all the zones identified by the current PRC as ZU-1c, we found buildings ranging from 6 m to 21 m in height, with some exceptions that exceeded the maximum height by regulation, for example, in Lautaro, Yungay, and O'Higgins streets. If found close to an HBC, these anomalies could negatively affect the image of the property. Nevertheless, to protect the HBC, the buildings are subject to the provisions of the second paragraph of Article 60 of D.S. 458 V. and U. of 1976. Typical zones are also established. In this case, the zone defined as ZU-7a includes the area called the "Typical Zone" of General Lagos Street, stipulating the following regulations:

- All building projects located on the same property or on a property adjacent to that of a Historic Preservation Property must include, at the time of its presentation to the Municipal Works Directorate for approval, a plan showing the façade of the new building and the Historical Property on the same scale and according to the location that one will have with respect to the other.
- The new building must maintain formal, architectural, and volumetric harmony with the HBC.
- The new constructions carried out in the Typical Zone of General Lagos Street must comply with the provisions of Article No. 30 Paragraph 1 of Law No. 17,288 on National Monuments.

4.5. Visibility index (VI)

The third concept analysed is the façade visibility index (Alonso de Andrade et al., 2018), in which three qualities were analysed (see Table 2) to explore the existing relationship between the public space and its properties through the permeability that they present in its façades.

The analysis of the built environment involves a photographic survey, focused on three main concepts of the urban fabric and supported by the principles of Oliveira (2013): building alignment, ratio of height and width of the street, and visibility index (Alonso de Andrade et al., 2018). This study sought to understand how the relationship between architectural work and its context can affect its preservation and enhancement. A qualitative analysis was conducted to classify the types of visibilities present. The fronts were measured, and the visibility index was calculated (see Eqn (1)) to determine, based on the permeability of the property, the relationship between the property and its environment. The closer the visibility index is to 1, the better the relationship. Figure 11 shows an example of the type of classification carried out and its quantitative measurement, which indicates the visibility index present in the study area (Alonso de Andrade et al., 2018).

Subsequently, an analysis of the six study areas was carried out, from which we obtained positive results. In the blocks studied on General Lagos Street, indices with values between 0.80 and 1 were found, showing that, in general, the properties present a positive relation of visibility with their spatial environment. There were some exceptions, with values close to 0.4; however, these were isolated cases. Most buildings with a V2 classification and a front length with reduced visibility had a visibility index of 0.80. This classification responds to the existence of important spaces of front gardens or vegetation in front of the road, which reduces its visibility from the opposite edge, especially observed on Yungay and General Lagos streets.

The foregoing is the result of low normative regulation with respect to front gardens. Although the properties were found in two types of PRC zones, front gardens were allowed in both, where minimum measures were established, but there were no indications regarding tree planting, plant material, sizes, or minimum distances from the buildings. This results in features such as front gardens with low maintenance, invasion of plant material on the façades of the buildings, or even fronts without visibility, directly affecting the conservation of the property and the relationship between it and its built environment (Alonso de Andrade et al., 2018; Pizarro-Reyes et al., 2022).

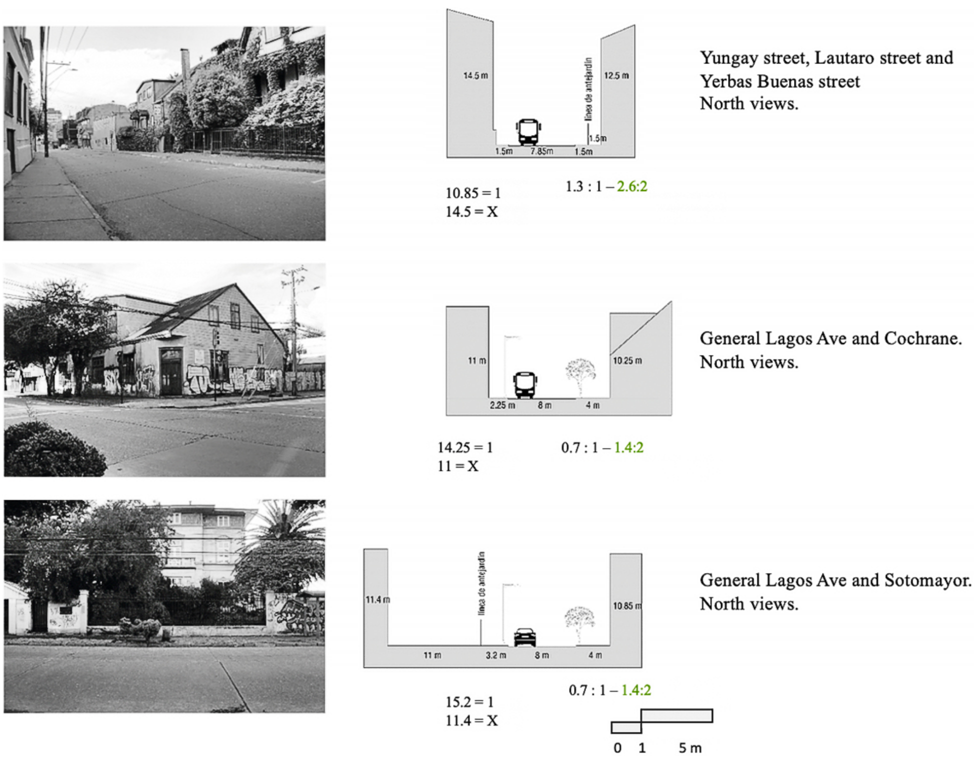

Figure 10. Radio study of height vs. width of street, Zone 1

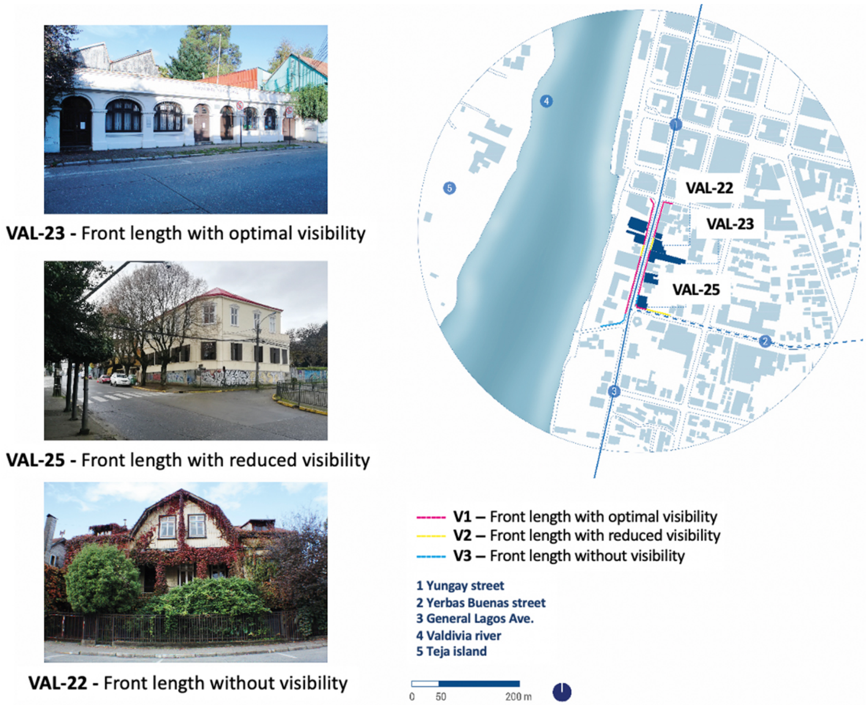

Figure 11. Façade visibility index

4.6. Discussion: Diagnosis of pathologies of the historical building conservation of the city of Valdivia

Comparing the three analyses revealed interesting results regarding the presence of pathologies in the HBC. The first comparison was of the conservation conditions, according to the range of functionality shown, with the presence and quantity of pathologies found in each case study. We observed that the buildings in Condition C, in addition to being all in the same study area (Zone 1), presented two more pathologies of a structural nature: AB2 (breakage of elements and/or joints) and AB10 (oxidation of material). Therefore, we used two common factors: the type of pathology and the location of the properties. In the case of General Lagos, we observed a small difference between buildings with façades facing west versus buildings with east façades, since the former had a higher proportion of AA2 and AB10 pathologies compared to the latter. This implies that the greater the exposure to sunlight, the greater the wear of the material that covers the façades, such as paint.

By expanding the sample to the rest of the cases, we observed that properties in Condition B typically had at least two pathologies of an aesthetic nature: AA2 (wear or detachment of the last layer) and AA3 (graffiti), which affected significant proportions of the façade. They also presented pathologies of a structural nature, in which the proportions of the affected façade were usually much lower. With respect to buildings in Condition A, they only presented pathologies of an aesthetic nature related to the maintenance of their last layer, such as AA1 (change of colour or dirt).

On the appearance of pathologies of an aesthetic nature, a relationship was perceived in the positioning of the buildings in the properties that contained them. Thus, we compared the presence of pathologies with the urban conditions presented by the immediate contexts of the buildings according to the three concepts studied. The first relationship concerned the proportion of façade alignment and the presence of pathologies. Buildings with a direct façade facing the street presented AA3 (graffiti pathology); this is directly related to the absence of front gardens, which exerts a kind of protective barrier against risks related to anthropic actions. Although the review of the regulations showed that the areas determined by the PRC of Valdivia as ZU-7a and Zu-1c must have a front garden, this was not always the case. Therefore, due to the construction date of the buildings, we found cases with the absence of this space, which explains the low percentages of alignment of the façades studied.

Further, the relationship between the ratio of height versus street width (enclosure index) and the state of conservation of the buildings was reviewed. According to international literature, a good enclosure index is one that presents a 1:2 ratio, where for each metre of height of the building, the street must be two metres wide, which translates into a good design ratio in the profile of the street, generating a good spatial sensation for the pedestrian (Oliveira, 2013; Zumelzu & Herrmann-Lunecke, 2021). In the areas studied, good indexes were presented, which can be interpreted as a good design of the streets that contained the HBCs as sites with easy accessibility for the community, which is of great value for the preservation of the heritage of the built urban area.

Finally, when exploring the relationship between the visibility index and the presence of pathologies in buildings, we observe that those buildings and their contexts that have low visibility indices are linked to the presence of blind walls, front gardens with large plant matter, and a low relationship between the property and its context, which can translate into an increased risk of pathological damage due to human actions and low maintenance.

5. Conclusions and future research work

This study presents an opportunity to experience a new way of applying photography to architecture, exploring its relationship with urban heritage beyond that of a simple documentary tool. Delving into the relationship between the property, its context, and the presence of pathologies that put its conservation at risk through the use of images allows us to advance the application of new types of analysis and methodologies. Through an exhaustive survey of the case studies, we identified the pathologies that affect the materials that make up the façades analysed.

This study revealed that the number of pathologies detected was directly proportional to the state of conservation of the case studies, classified by the functional service life model. Properties in Condition C were mainly affected by pathologies of a structural nature, which indicates that their functionality is not guaranteed, and a deeper inspection is needed for conservation and preservation actions. In these sets of cases, we found the presence of pathologies AB2 (breakage of elements and/or joints) and AB10 (oxidation of material) to be the most common. However, we also observed urban conditions that generated potential risks for the preservation of these buildings. These were related to the presence of pathologies of an aesthetic nature, such as AA1 (change of colour or dirt) and AA3 (graffiti), since having façade fronts directly facing the street increases the risk of pathologies caused by anthropic actions.

Regarding the urban context of the built heritage and the three criteria under study (façade alignment, visibility index, and the ratio of height versus street width), despite exhibiting weak relationships with the obtained results, it is crucial to persist in this comparison in future research. The three applied methods indicate their potential as planning tool, with strength lying in their integration of dimensions. This integration allows for the exploration of specific conditions necessary to the enhancement of the urban built heritage in central areas within this context. This assessment can track the evolution of the urban context over time, delving into both the present city and its history. Furthermore, it can project into the future, evaluating the morphological impact of potential actions or projects on the built heritage in a specific urban area. Such methods have the potential to directly influence initiatives promoting the safeguarding and intervention of the heritage environment, both at the building and urban fabric levels, enabling stakeholders to make informed decisions for the valuation and protection of heritage environments.

With respect to the chosen tool, its indisputable value is appreciated as a means of registration, complementation, and dissemination, fostering the understanding and dissemination of the research. It also promotes the education of human actors, since a large part of the brain's records are taken through the eyes, using images, illustrations, and photographs as a means of learning. Photographs offer better accuracy with respect to the amount of information they deliver, as they are capable of capturing details that, at first glance, often go unnoticed.

In summary, the search for new protocols and tools for the analysis of the state of conservation of HBC led us to explicate, from three main perspectives (range of functionality, pathological presence, and urban morphology), the real agents that affect the state and preservation of the built heritage. Based on photographs, we verified how the built environment became an active agent in the conservation of these properties. We found evidence that a large proportion of the present pathological problems were caused by regulatory problems, given the low regulation in relation to the front garden spaces and heritage conservation, which opens up the possibility of contributing to current public policies. Notably, the findings of this study showcase elements and situations that might not have been considered until now. These new approaches contribute towards new management guidelines that would positively enhance the preservation of the built urban heritage of the city of Valdivia, as a prototype or an example in the South context of Chile. They also enhance stakeholders' knowledge about built environment interventions in historic city centres. The findings and tools offered in this study can be extended to new case studies or adjusted to suit new environmental locations.

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