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EDITORIAL
STELLA SCHROEDER
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EDITORIAL

Editorial

STELLA SCHRÖEDER 1

Hacia un Urbanismo Resiliente e Inclusivo

El avance implacable del crecimiento urbano y los desafíos globales contemporáneos han colocado a nuestras ciudades en el epicentro de las problemáticas del siglo XXI. Más de la mitad de la población mundial vive en áreas urbanas, y esta cifra sigue en aumento, presionando a los sistemas sociales, económicos y ambientales. Sin embargo, las ciudades también representan una oportunidad única para fomentar el desarrollo sostenible. Para aprovechar esta oportunidad, es crucial contar con directrices claras y requisitos específicos que se adapten a las necesidades locales.

Chile, con su geografía única y una historia marcada por desastres naturales, se encuentra en una posición singular para reflexionar sobre los retos del urbanismo moderno. Desde terremotos y tsunamis hasta sequías e inundaciones, el país ha demostrado una notable capacidad para responder a emergencias. Sin embargo, el enfoque tradicional reactivo ya no es suficiente. El futuro exige ciudades que no solo puedan resistir adversidades, sino también adaptarse, transformarse y prosperar en un contexto de cambio constante. Este es el eje de la resiliencia urbana, un concepto que va más allá de la mera resistencia para incluir la capacidad de transformación y adaptación ante la incertidumbre.

En este marco, Chile ha comenzado a implementar marcos normativos como la Ley 21.364 sobre prevención y respuesta ante desastres. Esta legislación establece una base para la acción local, pero su implementación efectiva requiere un enfoque integral que combine infraestructura resiliente, educación comunitaria y planificación territorial informada por datos. Un ejemplo destacado es Nonguén, un barrio de Concepción, donde las políticas públicas unidimensionales y mal evaluadas han perpetuado vulnerabilidades en lugar de mitigarlas. Este caso evidencia la necesidad de que las intervenciones urbanas no solo reparen lo dañado, sino que también transformen los territorios en espacios más equitativos y sostenibles.

La gestión del riesgo no es el único desafío. Las desigualdades estructurales también configuran nuestras ciudades y afectan la calidad de vida de sus habitantes. Santiago de Chile enfrenta profundas disparidades en el acceso a servicios básicos como la educación preescolar. La distribución desigual de la oferta educativa, influenciada por factores económicos como el valor del suelo, perpetúa un ciclo de desigualdad que limita las oportunidades de las comunidades más vulnerables. Esta problemática no se limita a la educación, sino que también afecta a otros grupos, como los adultos mayores, cuya distribución geográfica refleja una falta de planificación urbana adaptativa para esta creciente población.

A pesar de estos retos, los espacios públicos tienen el potencial de actuar como catalizadores de cambio positivo. La investigación en La Reina Alta, en Santiago, destaca cómo los espacios públicos resilientes pueden abordar riesgos geológicos mientras fomentan la cohesión social. Más allá de su función recreativa, estos espacios pueden servir como puntos de encuentro que fortalecen las relaciones comunitarias y promueven la equidad. Invertir en su calidad y accesibilidad no es un lujo, sino una necesidad para garantizar la cohesión social y el bienestar colectivo.

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Figura 1, 2 Mercado Arica. Fuente: Ignacio Sáez. 2018

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El análisis de casos internacionales aporta perspectivas valiosas. En Ibagué, Colombia, un estudio sobre caminabilidad demuestra cómo la calidad de la infraestructura peatonal influye directamente en la salud y el bienestar urbano. Del mismo modo, el proyecto comunitario „Camino al Barrio" en Cali refuerza la importancia de la participación ciudadana en la transformación de los espacios públicos. Estas iniciativas evidencian que el diseño y la gestión de estos espacios son herramientas esenciales para construir ciudades resilientes e inclusivas.

La tecnología y la innovación también juegan un papel crucial en este proceso. Herramientas avanzadas como los sistemas de información geográfica (SIG) y los modelos computacionales están redefiniendo nuestra capacidad para comprender y abordar los problemas urbanos. En Ecuador, el uso de SIG permitió mapear vulnerabilidades climáticas y diseñar soluciones basadas en datos, mientras que, en Irán, las tecnologías avanzadas ayudaron a evaluar la calidad de las aceras urbanas. Estas metodologías no solo mejoran la precisión del análisis, sino que también democratizan la planificación al hacer que la información sea accesible para todos.

Sin embargo, la tecnología por sí sola no puede resolver los problemas urbanos. Su efectividad depende de cómo se integre en un enfoque holístico que combine innovación técnica, gobernanza participativa y planificación estratégica. Es esencial adoptar un enfoque proactivo que prepare a las ciudades para futuros escenarios de cambio e incertidumbre.

El concepto de resiliencia urbana, como se desprende de los estudios presentados, trasciende la simple capacidad de resistir shocks. Se trata de construir ciudades que puedan adaptarse y prosperar en un panorama dinámico. Esto exige un compromiso con la equidad, la sostenibilidad y la innovación, así como una participación ciudadana activa. Las soluciones no pueden ser impuestas desde arriba; deben surgir de un diálogo continuo entre gobiernos, comunidades y expertos, reconociendo la diversidad de necesidades y perspectivas que configuran nuestras ciudades.

El futuro de las ciudades chilenas, y de las urbes del mundo, dependerá de nuestra capacidad para abordar estos desafíos con creatividad y colaboración. Las políticas públicas deben ir más allá de soluciones superficiales y fragmentadas, adoptando enfoques integrales que reflejen las complejidades de la vida urbana. Invertir en espacios públicos, reducir las desigualdades estructurales y fortalecer las capacidades locales no son objetivos aislados, sino componentes esenciales de una visión más amplia de sostenibilidad y resiliencia.

Las ciudades deben ser vistas no solo como espacios físicos, sino como ecosistemas vivos, interconectados y profundamente influenciados por nuestras decisiones. Este enfoque holístico no solo permitirá enfrentar los retos del presente, sino también construir un legado para generaciones futuras. La resiliencia debe ser un esfuerzo colectivo que integre justicia social, sostenibilidad ambiental e innovación tecnológica en un marco integral. Los estudios presentados en esta edición ofrecen una hoja de ruta clara hacia este objetivo.

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RESILIENT PUBLIC SPACES TO FACE THE ENACTMENT OF LAW 21.364 ON THE NATIONAL DISASTER PREVENTION AND RESPONSE SYSTEM.[1]

THE CASE OF THE "LA REINA ALTA" SECTOR IN THE SANTIAGO FOOTHILLS, CHILE

ESPACIOS PÚBLICOS RESILIENTES FRENTE A LA PROMULGACION DE LA LEY 21.364 DEL SISTEMA NACIONAL DE PREVENCIÓN Y RESPUESTA ANTE DESASTRES . EL CASO DEL SECTOR "LA REINA ALTA" EN EL PIEDEMONTE DE SANTIAGO, CHILE

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La accesibilidad a espacios públicos seguros ha tomado cada vez más interés en el contexto urbano, sobre todo en aquellos países que comparten el Anillo de Fuego del Pacífico. Lugares capaces de albergar requerimientos de prevención y respuesta ante desastres. Por su parte, la entrada en vigencia de la Ley Nº 21.364 en Chile, que establece el Sistema Nacional de Prevención y Respuesta ante Desastres, abre la discusión sobre las posibles formas de implementar -en la escala comunal- los mecanismos que permiten operativizar la prevención y respuesta ante desastres en los territorios habitados vinculados de alguna manera a la comunidad involucrada. Los municipios deben hacerse cargo de la actualización de los Planes de Emergencia Comunal y los Planes para la Reducción del Riesgo de Desastres. Sin embargo, aún no existe claridad sobre la aplicabilidad de estos instrumentos. La investigación tiene por objetivo definir grados de vulnerabilidad para el sector de La Reina Alta, en Santiago, Chile respecto a los riesgos asociados a la presencia de la Falla San Ramón y a las quebradas cordilleranas, para priorizar la necesidad de inversión pública de escala comunal. Por medio de una metodología exploratoria mixta se hace un levantamiento cartográfico de La Reina Alta que incluye indicadores de riesgo asociados a la Falla San Ramón y a las quebradas cordilleranas, déficit de accesibilidad a parques y plazas públicas, y ubicación respecto de las áreas de riesgo. Los resultados muestran que es posible apoyar la formulación de proyectos municipales de habilitación de espacios públicos con criterios resilientes que aborden, tanto la infraestructura aplicable para mejorar estándares, como la institucionalidad, el capital social, y la educación a la comunidad con entrega de información respecto de los tipos de riesgo que enfrenta su territorio.

Palabras clave: espacio público, resiliencia, Ley Nº 21.364, falla San Ramón, vulnerabilidad, La Reina.

Accessibility to safe public spaces capable of complying with disaster prevention and response requirements has become increasingly important in the urban context, especially in countries that share the Pacific Ring of Fire. The enactment of Law Nº 21.364 that creates the National Disaster Prevention and Response System opens the discussion on the possible ways of implementing communal mechanisms that allow disaster prevention and response to be operationalized in inhabited areas involving the community. The municipalities must oversee updates to the Communal Emergency Plans and the Disaster Risk Reduction Plans. However, there is still no clarity on how applicable these instruments are. This research aims to define degrees of vulnerability for the La Reina Alta sector, in Santiago, Chile, that are related to the risks associated with the San Ramón Fault and its mountain ravines, to prioritize the need for public investment at the communal level. A cartographic analysis of La Reina Alta uses a mixed exploratory methodology, including risk indicators associated with the San Ramón Fault and the mountain ravines, the lack of accessibility to parks and public squares, and their location regarding risk areas. The results show that it is possible to support the formulation of municipal projects to develop public spaces with resilient criteria that address both the applicable infrastructure to improve standards, as well as institutionality, social capital, and community education, providing key information regarding the types of risk that their area faces.

Keywords: public space, resilience, Law Nº 21.364, San Ramón Fault, vulnerability, La Reina.

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I. INTRODUCTION

Accessibility to safe public spaces has increasingly become of interest in the urban context, especially in those countries that share the Pacific Ring of Fire[4]; places capable of hosting disaster prevention and response requirements (Antinao *et al.*, 2003). In addition, the possibility of having resilient spaces with adequate infrastructure allows the inhabitants not only to take shelter but also to inform themselves in the event of a catastrophe. In this way, public space can become essential in local-level planning, as a scenario where the recognition, congregation, and organization of the community involved can be carried out (Berroeta *et al*., 2016).

For the Chilean case, the enactment of Law Nº21.364 of 2021 (Ministry of the Interior and Public Security [MISP], 2021) established the National Disaster Prevention and Response System. This modifies how the State handles disaster risk management, creating the National Disaster Prevention and Response Service (hereinafter, SENAPRED), which replaces the National Emergency Office of the Ministry of the Interior (ONEMI). Chile's public and private entities are organized at different scales. They address the national, regional, provincial, and communal levels, including local governments, which play a greater role at the latter level through the priority allocation of budgets to finance the development of disaster risk management instruments (Pontigo & Inzulza, 2023). However, so far it is not clear how this action could be operationalized spatially in the area under municipal control, which opens the discussion and allows proposing ways to approach it, especially in public spaces intended for people to shelter, where today it is possible to focus resources through public investment (Berroeta *et al.*, 2016).

This research is based upon a case study under the implementation of Law Nº21.364 in the inhabited area of Santiago Andean foothills, analyzing access to parks and squares (CNDU & INE, 2019b; CNDU & INE, 2019a) to provide protection conditions to safeguard the lives of those living there (Romero & Vásquez, 2005). The research aims to define degrees of vulnerability for the specific "La Reina Alta" sector located in the commune of La Reina, in the eastern part of the Metropolitan Region. It is one of the areas subject to the geological risks associated with the San Ramón Fault (hereinafter SRF), which extends along the area (Inzulza-Contardo *et al*., 2021), with its crisscrossing ravines (Easton *et al.,* 2018).

The article is divided into four parts. First, an applied theoretical framework is provided regarding the importance of resilient public spaces and their implementation by municipal management under Law Nº21.364. Then, the mixed exploratory methodology is outlined, with a cartographic survey that considers risk indicators associated with the presence of the SRF and the cordilleran ravines, the lack of accessibility to parks and public squares, and the location considering the risk areas. Subsequently, the results show the possibility of formulating municipal projects to provide resilient public spaces in La Reina Alta, considering a collaborative definition of resilient public space. Finally, conclusions are provided on the importance of addressing resilience in a way that goes beyond improving infrastructure standards, including institutionality, social capital, and education, providing information.

II. THEORETICAL FRAMEWORK

Resilient public spaces for disaster risk prevention

Risk is understood as a constant in Chile, so it is necessary to assume and incorporate it into the city design process to build resilient cities. For its part, urban resilience is defined as the ability of an urban system to absorb and recover quickly after an event by maintaining continuity in its services (United Nations-Habitat [UN-HABITAT], 2016). Within this system, there is an agreement that mentions that the public space is part of the built system (Allan *et al.,* 2013) capable of reducing and mitigating risks, which can contribute to a city's recovery process (Soto & Escobar, 2020). However, this requires the definition of strategies, especially at a local level (UN-HABITAT, 2016), which can be articulated within the three pillars of urban resilience: structural, institutionality, and social capital (Baeriswyl, 2014). Regarding the structural part, the urban design of public spaces and how it seeks to reduce vulnerability of the urban territory is crucial. This includes acknowledging risk areas, implementing mitigation measures, and using the scope of the IPT to coordinate land uses and permitted activities, considering the threat level presented by each sector.

4 The "Pacific Ring of Fire" is a subduction zone located on the coasts of the Pacific Ocean. It is characterized by some of the most important and active seismic and volcanic regions in the world. It comprises the mountainous area of western Argentina, Chile, Peru, Colombia, Panama, Costa Rica, Nicaragua, El Salvador, Honduras, Guatemala, Mexico, the United States, Canada, the Aleutian Islands, Russia, Japan, Taiwan, the Philippines, Indonesia, Malaysia, East Timor, Brunei, Singapore, Papua New Guinea, the Solomon Islands, Tonga, Samoa, Tuvalu, and New Zealand.

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Figure 1. Disaster risk management instruments in the new institutionality. Source: Asociacion Chilena de Municipalidades [ACHM] (2022).

Another important point is the need for an evacuation network that is properly signposted and capable of guiding the population to safe sectors.

As for institutionality, the State's presence in the area is the key actor in managing prevention measures for inhabitants and places where they congregate. In particular, care should be taken about how resources and coordination are distributed at different scales at different stages of the disaster management cycle. Similarly, incorporating and classifying spaces intended for protection, especially in the public space, as anchor places to organize preventive and reactive tasks is essential (French *et al*., 2019). This allows implementing education and information programs for the community, coordinating early warning systems, upholding public order, attending to the affected communities, and conducting the reconstruction processes (Baeriswyl, 2014).

Regarding social capital, the idea is reinforced that the community's collective action before, during, and after a disaster allows for a resilient response. In this sphere, public space becomes relevant, especially in post-disaster stages, when a series of actions related to reconstruction are required. These tend to activate communities' perceptions of urban space while conditioning new appropriation practices (Berroeta *et al.,* 2016). The public space is therefore transformed into a stage where the recognition, congregation, and organization of the community involved can take place.

Similarly, it is important to promote community participation in disaster risk reduction activities, which implement strategies and encourage concerted actions, attributing roles and responsibilities, delegating tasks, and managing volunteers for the different phases of the risk cycle (United Nations International Strategy for Disaster Reduction [ISDR], 2017). For risk management education and providing relevant information to the community, the starting point for promoting a resilient culture is publicizing the threats and factors affecting the territories' vulnerability.

The implementation of Law Nº21.364 in municipal management

Law No. 21,364 incorporates into its proposed new system a set of public and private entities with competencies in the different phases of the disaster risk cycle: mitigation, preparedness, response, and recovery. These entities are organized at the communal, provincial, regional, and national levels and seek to provide suitable disaster risk management. This process is understood as a continuous social, professional, technical, and scientific process where policies, plans and programs, regulations, instruments, standards, permanent measures, and actions for updating knowledge and disaster risk reduction are formulated, executed, and monitored to avoid the generation of new disaster risks, reduce existing risks, and manage residual risk (MISP, 2021).

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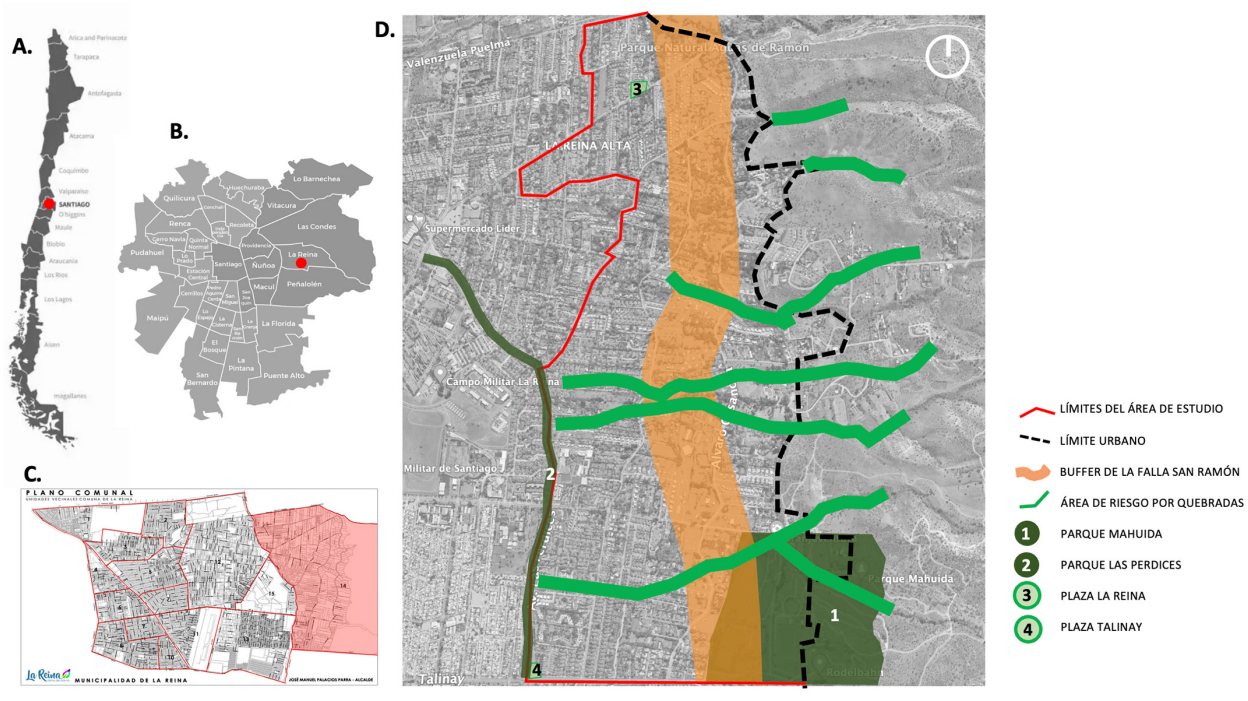

Figure 2. A. Location of the Metropolitan Region of Santiago in the country context; B. Location of the Commune of La Reina on the regional scale; C. Boundaries of the Neighborhood Unit N°14 "La Reina Alta" in the communal context and D. Layout of parks and public squares, associated with the San Ramón Fault and cordilleran ravines in La Reina Alta. No scale. Source: Preparation by the authors, based on Google images of the Municipality of La Reina and Landsat/Copernicus Google Earth Pro image, 2022; Curihuinca (2021); Ministry of Housing and Urban Development [MINVU] (1994)

For risk management instruments (Figure 1), the Communal level committee is responsible for reaching the necessary agreement to approve, by mayoral decree, the Communal Disaster Risk Reduction Plan and the Communal Emergency Plan, which are prepared in each municipality's Disaster Risk Management Unit. These documents must consider threat and risk maps. To finance these instruments, municipalities can participate in the Disaster Risk Management Program, part of the SENAPRED budget and regulated in Article 41 of Law No. 21,364.

Disaster Risk Management Plans at all levels should work in a coordinated manner. Those with a national scope will prevail over regional and, the latter, over communal ones. In addition, they must consider the local reality and the special characteristics of each area in question (MISP, 2021). In particular, the Communal Disaster Risk Reduction Plan considers the National Strategic Plan for Disaster Risk Reduction guidelines and all the necessary actions to reduce vulnerabilities in its area. It must also consider the risk and threat maps, which relate directly to the communal territory's Community Development Plan (PLADECO, in Spanish) and Planning Instruments (IPT, in Spanish).

III. CASE STUDY

The "La Reina Alta" sector, chosen as the case study, is part of Neighborhood Unit Nº14 "Reina Alta" and has the following boundaries. To the North with the communal boundary of La Reina, Valenzuela Puelma Street; to the East, the urban limit; to the South, the communal boundary on Talinay Street (its continuation to the east, to the urban limit, along Rodelbahn Road is considered); and to the west, the main intersections located outside the areas directly affected by the risks studied (Figure 2). This western edge, from north to south, is the streets of Valenzuela Puelma interior, Helsby, Onofre Jarpa, Escultora Rebeca Matte, Escritor Benjamín Subercaseux, Carlos Silva Vildósola, María Monvel, and Avenida Las Perdices.

La Reina Alta is subject to risks associated with the San Ramon Fault (Easton *et al.*, 2022) and, from north to

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Figure 3. Parque Las Perdices. Source: Photographic archive M. Ramirez, 2024

Figure 4. La Reina (left image) and Talinay (right image) Squares. Source: Photographic archive M. Ramirez, (2024).

south, the María Monvel, Las Cabras, Paidahue, Carpay, Verde, and Parque Larraín ravines (Municipality of La Reina, 2010; MINVU, 1994). Considering communal and local scales, a list of public spaces was made for municipal upkeep and control in the study area. The first relates to the parks that inhabitants of the commune in question and neighboring communes generally use. The second is linked to the squares, as spaces on a more limited scale, such as the neighborhood.

It is possible to identify two parks: Mahuida and Las Perdices. The Mahuida park is located within the risk area of the Parque Larraín ravine (MINVU, 1994) on the south-eastern boundary of the study area. The park's western sector is located within the San Ramón Fault buffer zone (Curihuinca, 2021); as such, it cannot be considered a safe zone. On the other hand, Las Perdices Park (Figure 3), a linear park, runs through a large part of the study area from south to north, on the western side, outside the San Ramón Fault buffer, and in an area without risk associated with the ravines, so it is suitable for the study.

There are only two squares, La Reina and Talinay (Figure 4). La Reina Square is used regularly by the neighbors. It is located in the northern sector of the study area. It works as an integrated and consolidated space with suitable equipment. Talinay Square, located on the south-western boundary of the study area, is small and triangular. However, it acts as a space to wait for public transport.

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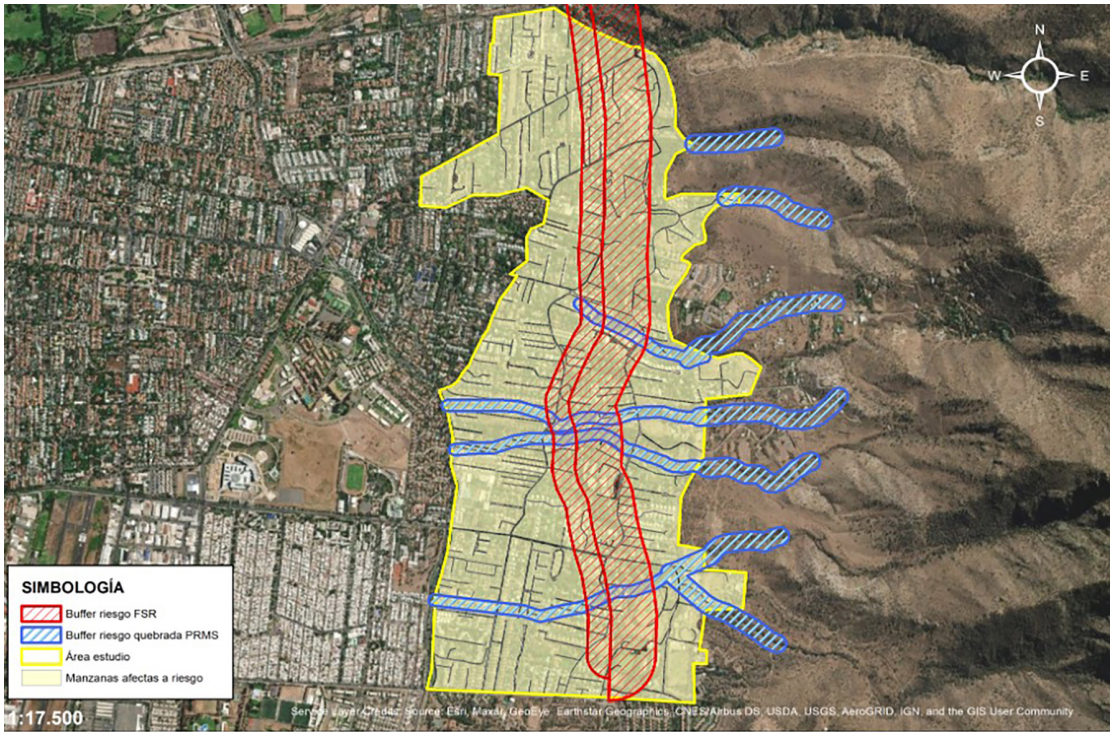

Figure 5. Risk areas within the La Reina Alta study area. Scale 1:17,500. Source: Ramírez (2024) based on INE (2017); Curihuinca (2021); MINVU (1994)

IV. METHODOLOGY

The research approach is mixed exploratory, including qualitative and quantitative methods, which are applied in the case study (Hernández et al., 2014), the Reina Alta sector, in the commune of La Reina, affected by the San Ramón Fault and cordilleran ravines. The work was carried out in two periods: from March to May and from September to October 2023.

On the one hand, the preparation of graphic and cartographic material was consulted regarding the risk associated with the presence of the SRF and the cordilleran ravines, the deficit of accessibility to parks and public squares, and the location of the analyzed blocks compared to the defined risk areas in La Reina Alta. The indicators used are data obtained from Curihuinca (2021), Santiago Metropolitan Regulatory Plan [PRMS, in Spanish] (MINVU, 1994), the standards of the Urban Development Indicators and Standards System, proposed by the Urban Development Council [CNDU, in Spanish] and the National Institute of Statistics [INE, in Spanish] (CNDU & INE, 2019b; CNDU & INE, 2019a), and resilience indicators of UN-HABITAT (2016).

The review of secondary theoretical framework sources allowed developing the collaborative concept of resilient public space, which is discussed in the section after the results.

In addition, a vulnerability ranking was generated for the study area's 19 blocks. This considers the variables of overcrowding, dependence, quality of buildings, building data, population density, accessibility to parks, and accessibility to public squares.

V. RESULTS

Risk associated with the presence of the San Ramón Fault and the cordilleran ravines

Within the study area, the seismic risk associated with the San Ramón Fault (Easton *et al.*, 2022) and the risk of landslides and flooding from the cordilleran María Monvel, Las Cabras, Paidahue, Carpay, Verde, and Parque Larraín ravines, from north to south (Figure 5), are plotted in the restriction and protection plan of the 2001 La Reina Communal Regulatory Plan (Article 8.2.1.1. Flooding. MINVU, 1994).

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	Surface area occupied by lots (ha)	N° of inhabitants
Commune Total	1,334.99	92,678
Blocks subject to risk	249.14	6,868
Total risk areas	154.45	4,260
Areas at risk from SRF + ravines	41.33	1,139
Risk areas from ravines	31.11	938
Risk areas from SRF	78.91	2,175

Table 1. Surface area (ha) and number of inhabitants exposed to risk from the SRF, cordilleran ravines, and overlapping risks. Source: Preparation by the authors based on ArcGIS GIS; Ramírez (2024)

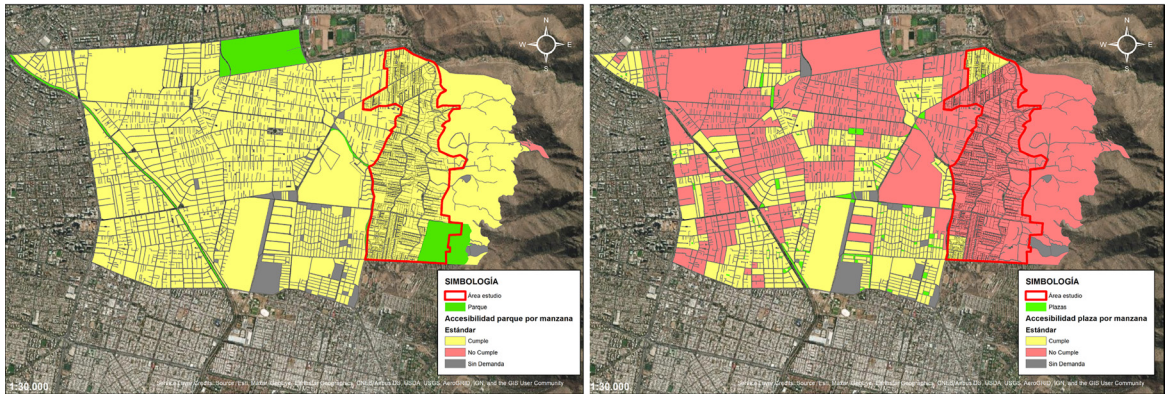

Figure 6. Accessibility to parks (left) and public squares (right). Scale 1:30,000. Source: Preparation by the authors based on ArcGIS GIS; Ramírez (2024)

Regarding the blocks affected by each of these risks or both overlapping risks (Table 1), it can be summarized that about 5% of the total population lives in the risk areas due to the San Ramon Fault and/or the cordilleran ravines, a total of approximately 4,260 inhabitants. 1,270 of the homes were built before 1997 and are located in areas at risk from the SRF and/or the ravines. These housing units do not comply with the NCH 433 Seismic Standard approved in 1996 (National Institute of Standardization [INN], 1996). In addition, 3.31% of the communal total of houses built before 1997, without Seismic Regulations, are located in risk areas, either due to SRF and/or the cordilleran ravines.

Lack of accessibility to public parks and squares

The accessibility to the commune's public parks from the study area blocks was analyzed using the Urban Development Standards and Indicators System (CNDU & INE, 2019b). This system considers a distance of up to 3,000 meters to the nearest Public Park with an area equal to or greater than 20,000 m^2. This indicator measures the weighted average minimum distance between the geometric center of each populated block and public parks. The distance is measured through the road networks, from the geometric center of each block to the nearest public park. In this way, it is possible to know the availability of potentially resilient communal public spaces, where the municipality could outline projects to host prevention tasks and respond to possible disasters.

For accessibility to public parks, it can be pointed out that the study area's blocks comply with the Urban Development Standards and Indicators System (Figure 6, left image). However, this considers Mahuida Park, which is not a candidate to be qualified as resilient since it is located in the risk area of the Parque Larraín Ravine, on the south-eastern boundary of the study area, and its south-western side is located within the FSR buffer zone. On the other hand, the condominium typology predominates in

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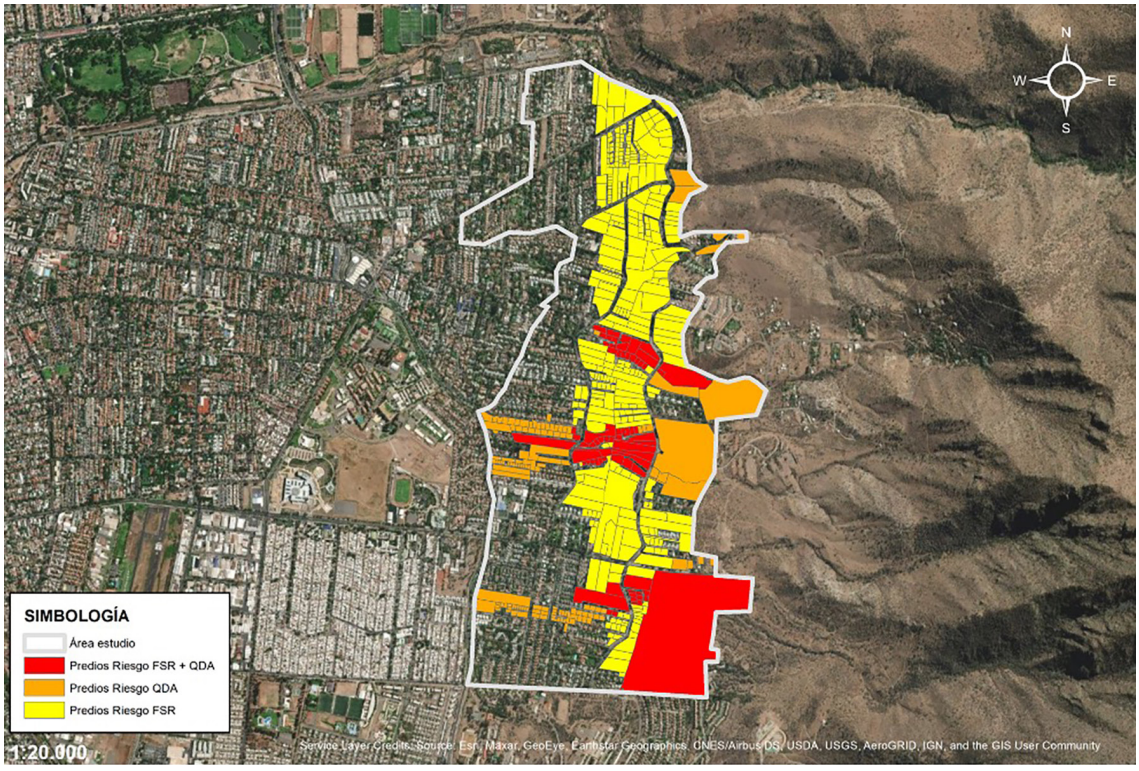

Figure 7. Properties at risk from the SRF and the cordilleran ravines. Scale 1:20,000. Source: Preparation by the authors based on ArcGIS GIS; Ramírez (2024)

the study sector, with a network of passageways and zero green infrastructure or open spaces on a communal scale.

Regarding the accessibility to public squares in the study area, as for public parks, the Urban Development Standards and Indicators System is considered (CNDU & INE, 2019a), but with a distance of up to 400 meters to the nearest Public Square, which has an area between 450 m^2 and 19,999 m^2. This allows knowing the load capacity of the urban area's public squares compared to the population. Within the potentially resilient neighborhood public spaces, most of the blocks in the study area do not comply with the SIEDU standard regarding accessibility to public squares (Figure 6, right image), highlighted in red. Only two places were identified in the study area: La Reina and Talinay. The La Reina Square is located in the northern sector of the study area, while Talinay Square is located on the western southern boundary of the study area.

Property location considering the risk areas

The risks linked to the San Ramón Fault and the ravines in the study area were analyzed using the La Reina PRC Restriction and Protection Plan and Article 8.2.1.1. Flooding (MINVU, 1994). This method allows us to identify the blocks affected by the overlapping risks of the San Ramón Fault or the study area's ravines (Figure 7).

The properties affected by both analyzed risks are identified in red; the properties affected by landslides and flooding risks associated with the presence of the cordilleran ravines are marked in orange; and the properties directly affected by seismic risk are displayed in yellow, on being located within the buffer zone of the San Ramón Fault.

Vulnerability ranking of the blocks considering the analyzed factors

According to the analysis in this research, a vulnerability ranking was applied in La Reina Alta, considering a polygon formed by nineteen blocks. This included a layer analysis that considered seven variables (Table 2). For overcrowding, the number of households with more than 2.5 people per bedroom was taken into account, using data from the 2017 CENSUS (INE, 2017); for dependency, the number of people between 0 and 14 and over 65 per dwelling was considered, by census area according to the 2017 CENSUS (INE, 2017); for the quality of buildings, the average of categories (from

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Block N°	Overcrowding	Dependence	Building Quality	Building Data	Population Density	Park Accessibility	Square Accessibility	Total
1	1	1	1	1	1	1	1	7
2	1	2	1	1	1	1	1	8
3	1	1	1	1	1	1	3	9
4	1	1	1	1	1	1	3	9
5	1	1	1	1	1	1	3	9
6	1	1	1	1	1	1	3	9
7	1	1	1	1	1	1	3	9
8	1	1	1	1	1	1	3	9
9	1	1	1	1	1	1	3	9
10	1	2	1	1	1	1	3	10
11	1	2	1	1	1	1	3	10
12	1	2	1	1	1	1	3	10
13	2	2	1	1	1	1	3	11
14	2	2	1	1	1	1	3	11
15	2	2	1	1	1	1	3	11
16	2	2	1	1	1	1	3	11
17	2	2	1	1	1	1	3	11
18	2	2	1	1	1	1	3	11
19	2	2	1	1	1	1	3	11

Table 2. Weighting of the variables analyzed by block. Source: Preparation by the authors based on GIS ArcGIS; Ramírez (2024)

1 to 5) per block was considered, according to data from the Internal Revenue Service of Chile (SII); for the data on the buildings, the number of homes before 1997 was considered, per block. It is relevant to mention that the NCH 433 Seismic Standard was approved in 1996.

SII (Chilean Internal Revenue Service) data was used. The total number of inhabitants per hectare per block was considered for the population density variable. Compliance with the accessibility standards of the Urban Development Indicators and Standards System was considered for accessibility to parks and public squares. Finally, to determine the location of the studied blocks concerning the risk areas, the blocks affected by overlapping risks and the direct risk from the SRF and the ravines of the study area were identified (Curihuinca, 2021; MINVU, 1994).

The variables mentioned were later weighted on a scale of 1 to 3, where 1 represents a good standard, i.e., "complies," 2 a regular standard or "partially complies," and 3 a poor standard, which translates as "does not comply." In addition, it was determined that the blocks with a higher number (in this case, 11) were the most vulnerable since they faced a higher "non-compliance" regarding the analyzed factors.

Regarding the sector analyzed in La Reina Alta, the most vulnerable blocks are those located on the eastern edge of the study area, with a weighting of 11 (Figure 8). The indicators affecting this result most are the lack of accessibility to squares, greater overcrowding, and a higher dependent population. These findings highlight the need to provide more public spaces for neighborhood-scale permanence, which can host activities related to disaster prevention and response. Due to the lack of municipal spaces in the sector, it becomes necessary to adapt municipal spaces that today have other uses or to acquire new land for these purposes.

On the other hand, the need to improve connectivity to the network of existing, potentially resilient, public spaces becomes evident. Due to the sector's predominant housing typology, the area has been structured based on closed passageways and blind streets running east-west (Figure

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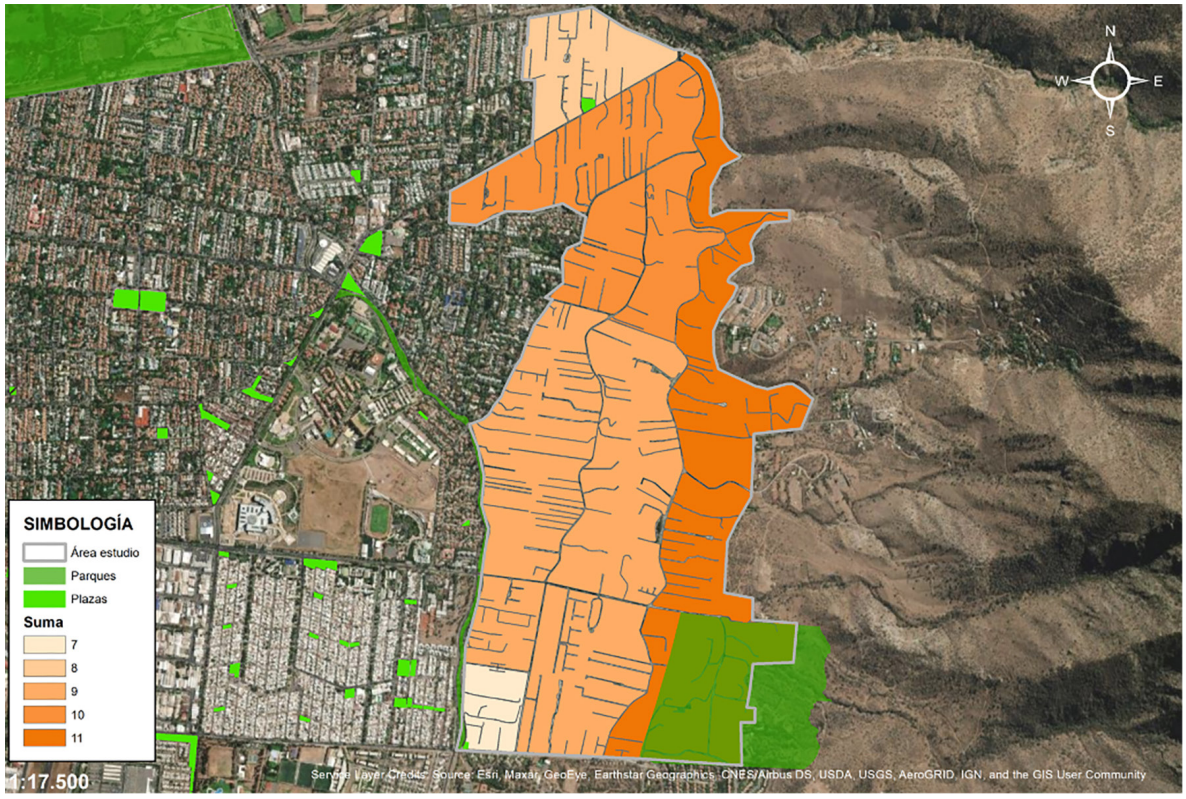

Figure 8. Determination of vulnerability by blocks, according to the factors analyzed in the study area. Scale 1:17,500. Source: Preparation by the authors based on ArcGIS GIS; Ramírez (2024)

Figure 9. A sample of the type of urbanization predominant in the study area. Scale 1:30,000. Source: Preparation by the authors based on images from Landsat/Copernicus Google Earth images and the Street View tool

9). These lead to small-scale North-South roads with little connectivity to the west, where the safe areas for the analyzed risks are located. This would undoubtedly hinder evacuation in case of an emergency.

The least vulnerable block, with a weighting of 7, is located in the southwest corner of the study area, which Talinay Square serves. The other vulnerability factors analyzed also have lower values than the rest of the blocks.

VI. DISCUSSION

The research led to the discussion of crucial aspects behind urban resilience - applied in public spaces for permanence - and that should structure the design process and later the operation stage: the resilient infrastructure dimension, the institutional dimension, and the social capital dimension (Baereswyl, 2014; Cabrera *et al*., 2020; Riquelme, 2022). As a complement, and considering the recommendations of the International Seminar for Disaster Reduction (ISDR, 2017), a fourth dimension related to education and delivery of information to the community regarding risk is incorporated.

Figure 10 presents the collaborative construction of the concept of "Resilient public spaces." First, it highlights the tangible and intangible aspects that will allow the development of resilient public spaces. The built area and infrastructure are tangible, and social capital is intangible. These two areas are articulated thanks to two hybrid dimensions: institutionality and access to education and information.

Secondly, the infrastructure dimension is conceptualized in two large groups: safe flows, defined by evacuation routes; and safe spaces to stay, such as parks and squares, located in safe areas not affected by the considered risks. The aim is to move towards flexible, multifunctional spaces designed for people, adaptable to the different stages of the disaster management cycle, and capable of responding to everyday requirements. In addition, these spaces should support prevention through education and empowerment of the affected communities. They should also be places to meet, collect, provide support, and organize the response after the disaster. However, these measures are insufficient as resilient public spaces can act as spatial and social support, housing the community, allowing its organization and strengthening.

For sheltering in a public space to be consolidated as resilient, it is necessary to combine coordinated actions between municipal units that, in general, tend to work in a compartmentalized way: the new Disaster Risk Management Departments, such as ties to SENAPRED and those in charge of developing Communal Plans for Disaster Risk Reduction

Figure 10. Collaborative construction of "Resilient public spaces". Source: Preparation by the authors based on Baereswyl (2014), Cabrera et.al. (2020), and Riquelme (2022)

and Communal Emergency Plans; the SECPLAN Communal Planning Secretariats, as units to formulate projects in public spaces; and the DIDECO Community Development Directorates, as those responsible for territorial management and community outreach.

Last, and not least, coordination between the State actors involved is needed, so that the information currently collected through Local Governments can be systematized and transformed into strategies to address disaster risk from the territories, understanding the available public spaces in safe areas as a potentially resilient network, capable of supporting Disaster Risk Management at all stages, while building a database that translates into several invaluable inputs when updating Regional Planning Instruments.

VII. CONCLUSIONS

This work reviews the foothills of the Metropolitan Region, an inhabited territory subject to seismic, landslide, and flood risks. Implementing Law 21,364 modernizes the institutions linked to disaster prevention and response. It includes municipalities as relevant actors within the disaster management cycle, opening up a broad range of possibilities regarding how the state can address this problem. The Communal Disaster Risk Reduction Plan is a concrete and strategic option to adopt the National Strategic Plan for Disaster Risk Reduction guidelines and all the necessary actions to reduce vulnerabilities in the territory of its competence.

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Implementing resilience strategies from local governments, such as educating and informing the community and providing the possibility of organizing, grouping, and sheltering in spaces of daily use such as the parks and squares of the commune (located outside the risk areas), empowers inhabitants of the risk areas or close to them to actively prepare, prevent unwanted situations, and respond to the imminent occurrence of a disaster. All this is being done while progress is being made on an urban policy and suitable regulatory changes that allow clear positions to be taken from the territory against risk at different scales, and of course, that considers the community as a relevant actor.

The condominium and closed passage typology that abounds in La Reina Alta and is seen especially in the blocks of the eastern edge of the commune, the most vulnerable to the analyzed risks, represents a greater difficulty when considering an eventual disaster. This makes the need to strengthen, maintain, and inform evacuation routes even more urgent so that they can respond, if necessary. There is also a lack of permanent public spaces located in safe spaces (apart from Las Perdices Park, La Reina, and Talinay squares), considering the estimate that about 4,260 people live in areas affected by risk associated with the San Ramón Fault and/or the cordilleran ravines.

Las Perdices Park, which was analyzed concerning the proposed resilient design criteria for the infrastructure dimension, shows great potential to become a resilient public space. Its location outside the risk areas (SFR or ravines) and its linear development from North to South allow people affected by an eventual disaster to move along the available roads and organize themselves in the potential meeting spaces. From this, it is important to understand urban resilience as a concept beyond improving infrastructure. It should seek standards to optimize institutionality, social capital, and community education, providing information regarding specific risks.

VIII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization: M.R.F., J.I.C.; Data curation: M.R.F., J.I.C.; Formal analysis: M.R.F., J.I.C.; Acquisition of financing: J.I.C.; Research: M.R.F., J.I.C.; Methodology: M.R.F., J.I.C.; Project Management: J.I.C.; Resources: J.I.C.; Software: M.R.F.; Supervision: M.R.F., J.I.C.; Validation: M.R.F., J.I.C.; Visualization: M.R.F.; Writing - original draft: M.R.F., J.I.C.; Writing - revision and editing: M.R.F., J.I.C.

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VULNERABILITY TO THE RISK OF HYDROCARBON EXPLOSION IN INFORMAL SETTLEMENTS IN THE MUNICIPALITY OF PUEBLA, MEXICO

VULNERABILIDAD ANTE EL RIESGO DE EXPLOSIÓN DE HIDROCARBUROS EN ASENTAMIENTOS INFORMALES EN EL MUNICIPIO DE PUEBLA, MÉXICO

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En la periferia norte del municipio de Puebla, México, existen asentamientos urbanos que presentan amenaza de explosión de hidrocarburos debido a la baja regulación del suelo y a la extracción informal del producto. Las condiciones de rezago social, marginación y la respuesta reactiva de las instituciones gubernamentales aumentan la vulnerabilidad. El objetivo es evaluar las variables sociales, urbanas e institucionales en asentamientos urbanos informales para explicar las condiciones multifactoriales de vulnerabilidad ante el riesgo por explosión de hidrocarburos. En metodología se aplicó el análisis multicriterio de 66 indicadores y el análisis socioespacial de distribución de la vulnerabilidad. Los resultados muestran distintos patrones espaciales de vulnerabilidad ante el riesgo de desastre por explosión debido a la presencia de ductos de hidrocarburos, la marginación, el rezago social, la baja organización y percepción del riesgo y las acciones de reactivas. Las conclusiones son que el procesamiento de variables de diferentes tipos explica la vulnerabilidad multifactorial y las diferencias en su distribución ante el riesgo de desastre en asentamientos informales.

Palabras clave: catástrofe, asentamientos informales, uso del suelo, sistemas de información geográfica

In the northern peri-urban area of the municipality of Puebla, urban settlements are threatened by hydrocarbon explosions due to a lack of land regulation and illegal extraction of the product. The conditions of social backwardness, marginalization, and the reactive response of governmental institutions increase vulnerability. The objective of this paper is to evaluate the social, urban, and institutional variables in informal urban settlements to explain the multifactorial vulnerability to the risk of hydrocarbon explosion. The methodology applied was the multi-criteria analysis of 66 indicators and the socio-spatial analysis of vulnerability distribution. The results show different spatial patterns of vulnerability to explosion disaster risk due to the location of hydrocarbon pipelines, marginalization, social backwardness, low organization, low risk perception, and reactive actions. The conclusions are that the processing of variables of different types evidences the multifactorial vulnerability to disaster risk in informal settlements and the differences in vulnerability distributions.

Keywords: catastrophe, informal settlements, land use, geographic information systems

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I. INTRODUCTION

Hydrocarbon networks provide energy for city operations; however, their positioning in urban areas and the mismanagement of explosive materials can cause significant damage to people's lives, properties, and the environment (He et al., 2021; Azari & Karimi, 2017). Oil pipelines, especially, have physical and management conditions that often lead to leaks and spills, posing threats to ecosystems, the population, and economic activities (Cram Heydrich et al., 2020).

Since the 1970s, risk studies have focused on demonstrating that disasters are the effect of human activities to achieve modernity (Mojtahedi & Oo, 2016), and are associated with the growing concentration of people, risk areas, and the climate crisis (Mattedi et al., 2024).

Risk analysis in hydrocarbon networks, including the spillage and/or explosion radii and the exposed population density (Azari & Karimi, 2017), focuses on the threat posed by the networks and their management, but overlooks the analysis of social vulnerability (Cutter et al., 2003). Given the social impacts they generate, it is important to examine the specific characteristics of social relations that emerge in high-risk territories (Montes-Neri, 2023).

Vulnerability refers to exposure to threats accentuated under poverty, backwardness, and marginalization (Birkmann, 2007). In urban areas, the primary settings for economic production, vulnerability increases due to low educational levels, low income, a lack of public and health services, and limited access to information (Mattedi et al., 2024).

Risk analysis in cases of informal urban settlements**5** in Latin America, characterized by marginalized conditions or located in high-risk areas (Montes-Neri, 2023), enables the generation and specification of information to assess vulnerability (He et al., 2021; Mattedi et al., 2024; Azari & Karimi, 2017). In this study, the hypothesis is suggested that analyzing variables with a multifactorial and socio-spatial approach contributes to assessing the vulnerability to the risk of hydrocarbon explosion in informal settlements that emerge outside urban planning processes and legality, where precarious sectors are denied access to housing. The objective is to evaluate the social, urban, and institutional variables, through indicators, to explain the multifactorial conditions of vulnerability to the risk of hydrocarbon explosion in the Jorge Murad Section C sector, Nueva San Salvador, located in the north of the municipality of Puebla, Puebla State, Mexico.

The study's structure presents the state of knowledge behind the multifactorial approach and the variables used to assess vulnerability first. Next, the case study of the Jorge Murad section C sector in Nueva San Salvador is discussed. This consists of two informal urban settlements exposed to the explosion of hydrocarbon pipelines in the municipality of Puebla. This is followed by a discussion of the methodology for designing and processing vulnerability indicators, the evaluation and distribution of vulnerability results, and the results and findings concerning previous studies. Finally, the study's contributions to analyzing vulnerability using a multifactorial approach are presented.

II. THEORETICAL FRAMEWORK

RECOGNIZING VULNERABILITY TO REDUCE RISK

Cities are the main space where humanity performs its activities and concentrates its assets. However, high concentrations of these increase vulnerability to all kinds of threats (Xiu et al., 2011). Vulnerability is a condition associated with a system's physical, socio-economic, and political processes that make it susceptible to potential impacts (Jurgilevich et al., 2021; Cutter et al., 2003).

Vulnerability as a concept cannot be directly measured; therefore, observable indicators for social, urban, and institutional variables are used (Birkmann, 2007; Jurgilevich et al., 2021; Mojtahedi & Oo, 2016) in a defined geographical space (Hernández Ajá et al., 2018; Cram Heydrich et al., 2020).

The ***social variable*** measures the social and economic dimensions (Lavell et al., 2020; Mattedi et al., 2024) through indicators on employment or income, unpaid work, access to education (Montes-Neri, 2023), housing quality (National Council for the Evaluation of Social Development Policy [CONEVAL], 2020), groups that require care (Cutter et al., 2003), social organization and representation, risk perception, responsiveness, and engagement with government authorities (Mojtahedi & Oo, 2016).

The ***urban variable*** measures the dimensions of habitability and environment (Acuña, 2016; Ochoa-

5 The Economic Commission for Latin America and the Caribbean (ECLAC) defines informal settlements as residential areas where inhabitants lack security of tenure over land or housing, ranging from informal occupation to informal rental housing. These areas usually lack basic services and urban infrastructure, and are often located in hazardous environmental and geographical areas.

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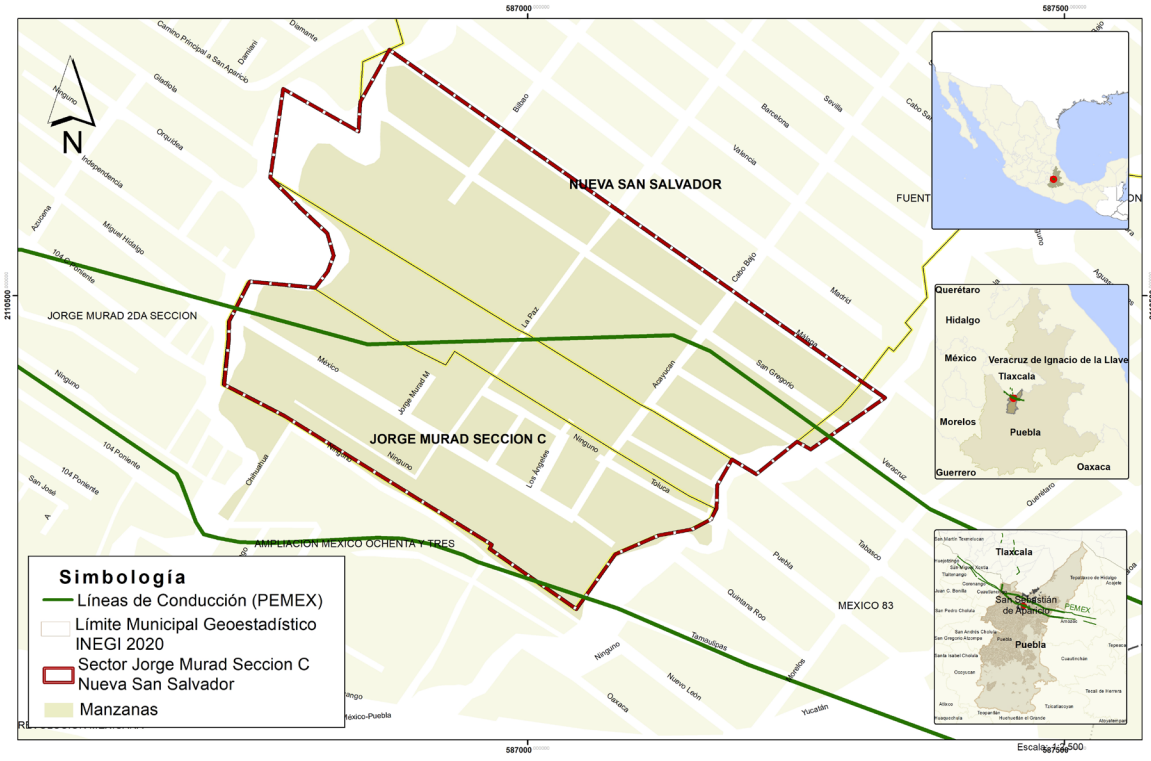

Figure 1. Jorge Murad Section C Sector - Nueva San Salvador. Source: Preparation by the authors based on the National Institute of Statistics and Geography [INEGI] (2009); INEGI (2020); Secretary of Civil Protection and Integral Risk Management (2021).

Ramírez & Guzmán-Ramírez, 2020) through indicators on infrastructure quality, coverage of health services, public security, and social assistance, risk zones, land tenure, and land planning and regulation (Cutter et al., 2003).

The ***institutional variable*** measures the political and management dimensions (Acuña, 2016; Merlinsky & Tobias, 2016) through indicators on financing and economic resources, risk identification, monitoring, evaluation, and management, professionalization, equipment, and infrastructure (Ministry of Labor, 2019). This variable is directly affected by the omission and lack of follow-up in the growth of settlements in risk areas (Abdoul Nasser et al., 2021; Cavazos-Arroyo et al., 2014).

The multicriteria analysis helps identify and classify vulnerabilities by processing indicators in different forms of land occupation (Ruiz Rivera, 2012; Mattedi et al., 2024). The socio-spatial analysis enables associating indicators with urban structure vector data to differentiate the distribution of vulnerability in a geographical space (Buzai & Baxendale, 2010; Cutter et al., 2003), facilitating data normalization and processing (Mattedi et al., 2024; Azari & Karimi, 2017). The participation of the actors involved is fundamental for recognizing and perceiving risk (Mojtahedi & Oo, 2016; Jurgilevich et al., 2021; Cram Heydrich et al., 2020).

JOREGE MURAD SECTION C SECTOR- NUEVA SAN SALVADOR

The sector comprises two informal settlements located in the north of the municipality of Puebla, State of Puebla, Mexico, with 869 inhabitants and 241 homes on the right-of-way of two hydrocarbon pipelines operated by Petroleos Mexicanos[6] (PEMEX) (Figure 1). In 1983, Nueva San Salvador was built on a 12-inch pipeline carrying liquefied petroleum gas (LPG), and in 1990, Jorge Murad Section C on the 12-inch gas pipeline and the 24-inch oil pipeline. The sector has conditions of backwardness, marginalization, risk of explosion due to hydrocarbons, and a history of gas leaks and informal extractions (Puebla Roja, 2020; Barrientos, 2020; Meza, 2017). These representative cases were chosen from

6 Petróleos Mexicanos is a national company that produces, processes, distributes, and sells hydrocarbons and their by-products in Mexico.

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the 62 settlements in the north of the municipality of Puebla that were exposed to the hydrocarbon explosion, following collaboration with neighborhood organizations that facilitated research through participatory processes.

III. METHODOLOGY

In the multicriteria analysis, 66 indicators for ***social***, ***urban***, and ***institutional*** variables were processed to assess vulnerability using a sector-wide, multifactorial approach (Cutter et al., 2003; Montes-Neri, 2023; Cram Heydrich et al., 2020; CONEVAL, 2020). The indicators were obtained from the Population and Housing Census [CPV] 2020 (INEGI, 2020), the census of 218 dwellings, 6 digital surveys and 68 applied by the authors ***in situ*** with a reliability of 90% and a margin of error of 9.61%, 4 interviews with local authorities, 5 public servants, 5 neighborhood leaders, 1 member of the board and 2 of the services committee, whose identity is kept anonymous to protect personal information.

The indicators were integrated using the mathematical expression, where the sum total ***xi*** is the total of each variable and the multifactorial one, respectively. In assigning vulnerability levels, the class limit was considered, with the upper limit ***(xmax)*** subtracted from the lower limit ***(xmin)***, and then divided into three classes to which an ordinal value was assigned for comparability: 1 (low), 2 (medium), and 3 (high) (Bollin & Hidajat, 2006, as cited in Ruiz Rivera, 2012).

The ***social variable*** considers 26 data indicators from the CPV 2020 (INEGI, 2020) (Table 1) and surveys regarding the organization, prevention, perception, and response to risk (Table 2). The ***urban variable*** considers 20 indicators obtained in nine field visits (Hernández, 2023b) and a housing census (Table 3). Urban and social indicators were added to obtain urban vulnerability (Table 4). The ***institutional variable*** considers 20 indicators on financing, identification, management, and risk reduction actions, with frequencies weighted as always (1), regularly (2), occasionally (3), and never (4) (Table 5).

The three variables were integrated to obtain the vulnerability indicators and levels (Table 6). The socio-spatial analysis was conducted in QGIS by associating the indicators with the urban block vectors (INEGI, 2016) to define the vulnerability distribution.

Economic	Economically inactive population
	Households headed by women
	Population without complete compulsory education
Population	Illiterate
	Density
	0 to 14 years old
	60 and older
	Disability
	Without health services
Housing	Without drinking water
	Without drainage
	Without electricity
	Without a slab roof
	Walls of other material
	Earthen floor
	One room
Σ xi	

Table 1. Population and Housing Indicators. Source: Population and Housing Census (INEGI, 2020)

Organization	question 4	In the sector 1, and another 0
	Organization	Board 1, Committee 2, none 3
Prevention	Question 17	None 1, I don't know 2, use WhatsApp 3, meeting for services 4, others (protect the pipelines, whistles, information for PEMEX, report activities) 5, discuss strategies with neighbors 6, disseminate information provided by the authorities 7, and convene a meeting 8
	Question 18	There isn't any 1, doesn't know 2, call a meeting 3, neighborhood alarm/notification from social media 4, turn off the light, turn off gas 5, respect the indications 6, flee 7, talk to the police/ authority/911 8, evacuate 9
Perception	Question 11	None 1, others (I don't know, I didn't know about the pipelines) 2, lack of deed of their land 3, delinquency 4, huachicol 5, risk of explosion 6, leaks 7
	Question 15	No 1, I'm not sure 2, rarely/occasionally 3, yes 4
	Question 19	There isn't any 1, neighborhood alert or communication 2, authority actions 3, surveillance 4, evacuate 5
	Refusal	Refusal to answer the survey
Answer	Question 14	None 1, federal 2, state 3, municipal 4, auxiliary board 5, board/service committee 6
	Question 16	Nothing 1, others (do not go out, avoid approaching)2, call authorities 3, neighborhood alarm 4, turn off gas and disconnect electricity 5, follow directions 6, evacuate 7
∑xi		

Table. Survey indicators. Source: Preparation by the authors, 2023 Note: Respondents could select more than one option

Habitability	Lights	1 in the whole block, 2 in a part of the block, and 3 there aren't any.
	Pavement	1 in the whole block, 2 in a part of the block, and 3 there isn't any.
	Pavement Type	1 in the whole block, 2 in a part of the block, and 3 there isn't any.
	Sidewalks	Total
Risk	Ravines	0 there aren't any, 1 there are
	Housing in a risk area	Total
	Bodies of water	0 there aren't any, 1 there are
	Pipelines	0 there aren't any, 1 there is one on one side of the block, 2 in the middle, and 3 in the whole block.
	Type of product	1 gasoline, 2 gas
	Housing in the right-of-way	Total
	High-voltage power lines	0 there aren't any, 1 there are
	Housing in the right-of-way	Total
	Industrial corridors	0 there aren't any, 1 there are
	Main roads	0 there aren't any, 1 there are
	Housing in the right-of-way	Total
Equipment	Hospital	0 in the sector, 1 in the coverage area
	Firefighters	0 in the sector, 1 in the coverage area
	Public security	0 in the sector, 1 in the coverage area
Land tenure	Urban settlement	0 incorporated into urban development, 1 registered and recognized, 2 informal
	Deed problems	0 there aren't any, 1 there are
∑xi		

Table 3. Indicators of the urban variable. Source: Preparation by the authors, 2023

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Indicator	Urban indicators	Social Vulnerability	Urban Vulnerability (Σ)
Value	1 to n	1 to n	xi

Table 4. Indicators to obtain urban vulnerability. Source: Preparation by the authors, 2023

Financing	Vertical and horizontal Inter-institutional organization
	Reserve funds for institutional strengthening
	Resource localization and mobilization
Identification	Inventory of disasters and losses
	Threat monitoring and forecasting
	Threat mapping
	Vulnerability and risk assessment
	Public information and community participation
	Risk management training and education
Management	Organization and coordination of emergency operations
	Planning emergency response and warning systems
	Equipment and infrastructure
	Simulation, updating, and testing of the inter-institutional response
Reduction	Community preparation and training
	Integration of risk in the definition of land uses and urban planning
	Watershed intervention and environmental protection
	Implementation of hazard protection and control techniques
	Improvement of housing and relocation of settlements
	Updating and application of building standards and codes
	Strengthening and intervention of the vulnerability of public and private goods
Σxi	

Table. Indicators of the institutional variable. Source: Preparation by the authors, 2023.

Multifactorial						
Variable	**Social Vulnerability**	**Urban Vulnerability**	**Institutional Vulnerability**	**Σ**	**Weighting**	**Level of vulnerability**
Indicators	n	n	n	n	1 to 3	High, medium, or low

Table 6. Multifactorial vulnerability indicators. Source: Preparation by the authors, 2023.

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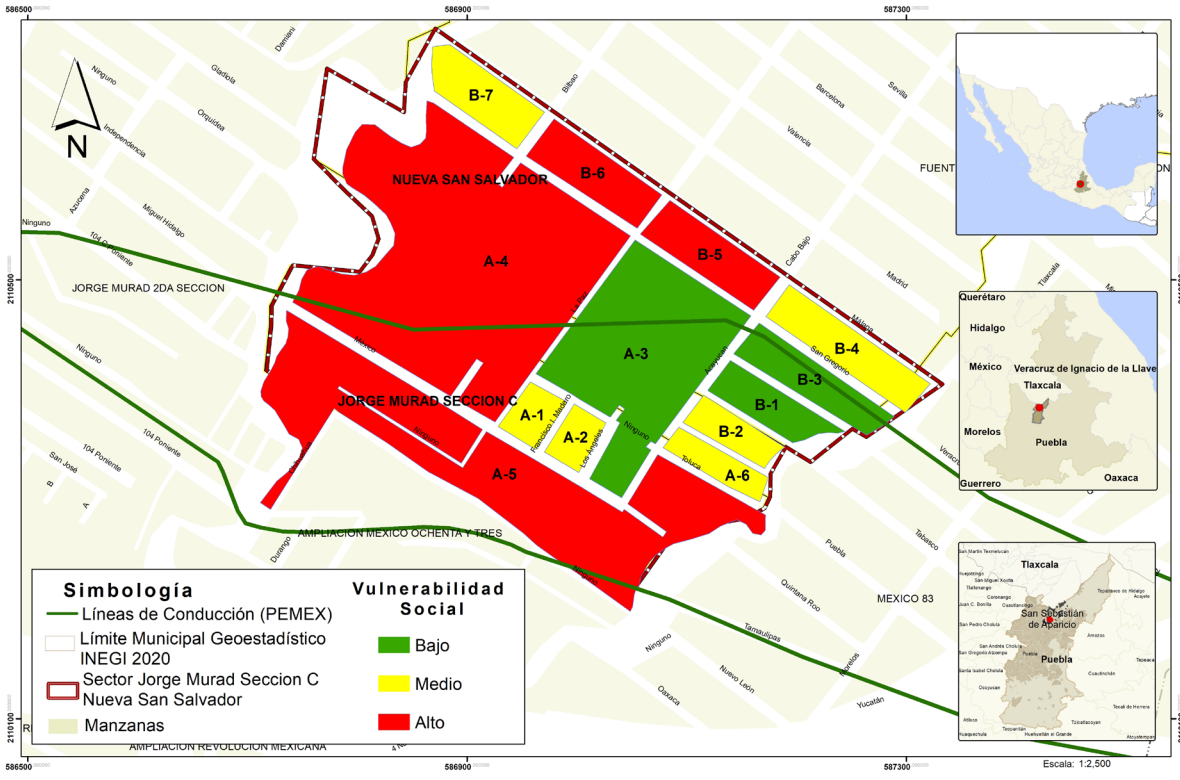

Figure 2. Social vulnerability. Source: Preparation by the authors based on INEGI (2009); INEGI (2016); INEGI (2020); INEGI (2023); Secretary of Civil Protection and Integral Risk Management (2021).

IV. RESULTS

VULNERABILITY IS A SOCIAL PROCESS

The multivariate evaluation reveals vulnerability as a process influenced by social backwardness, marginalization, omissions in urban planning, low risk perception, and reactive responses. The mapping represents the differences in vulnerability distribution across urban blocks.

A score was obtained in the socioeconomic indicators of 325; low access to education, health, and vulnerable population of 2,186; low quality of housing of 85; organization, perception, and risk prevention of 1,881, totaling 4,477 indicators. The results reveal that the perception of risk is secondary for the inhabitants, as 73.61% of the analyzed population considers crime a priority, 48.61% hydrocarbon pipelines, 44.44% the lack of public services, and 40.28% the presence of ravines. 72.22% mention that there are no actions for risk reduction.

Prevention actions are incipient, although some residents report that meetings have been called, information provided by authorities has been disseminated, and strategies have been discussed among neighbors. However, other residents indicate that these actions have not been carried out or are unaware of such efforts.

Regarding the response strategies developed by neighborhood leaders or the inhabitants themselves, it is indicated that such strategies do not exist or are unknown. In emergencies, the inhabitants evacuate their homes, follow directions, and refrain from using electricity. They also close the gas outlets, activate the neighborhood alarm, and contact the authorities. However, some inhabitants choose not to take action, unsure of what to do. Additionally, the inhabitants' lack of knowledge about the boundaries, name, and affiliation of the urban settlement to which they belong hinders the risk management processes for the municipal authorities. A high level of social vulnerability is defined in blocks[7] A4,

[7] The blocks labeled with an 'A' are part of the Jorge Murad Section C settlement, and those with a 'B' are located in Nueva San Salvador.

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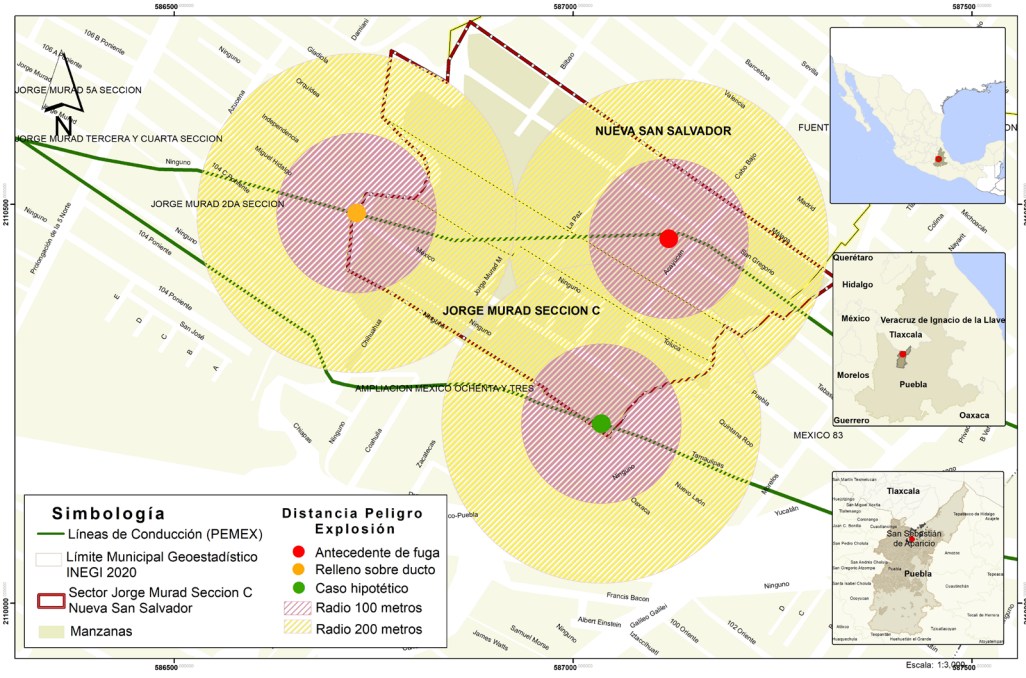

Figure 3. Danger of explosion. Source: Preparation by the authors based on CENAPRED (2021); INEGI (2009); INEGI (2016); INEGI (2023); Secretary of Civil Protection and Integral Risk Management (2021); Hernández (2023a).

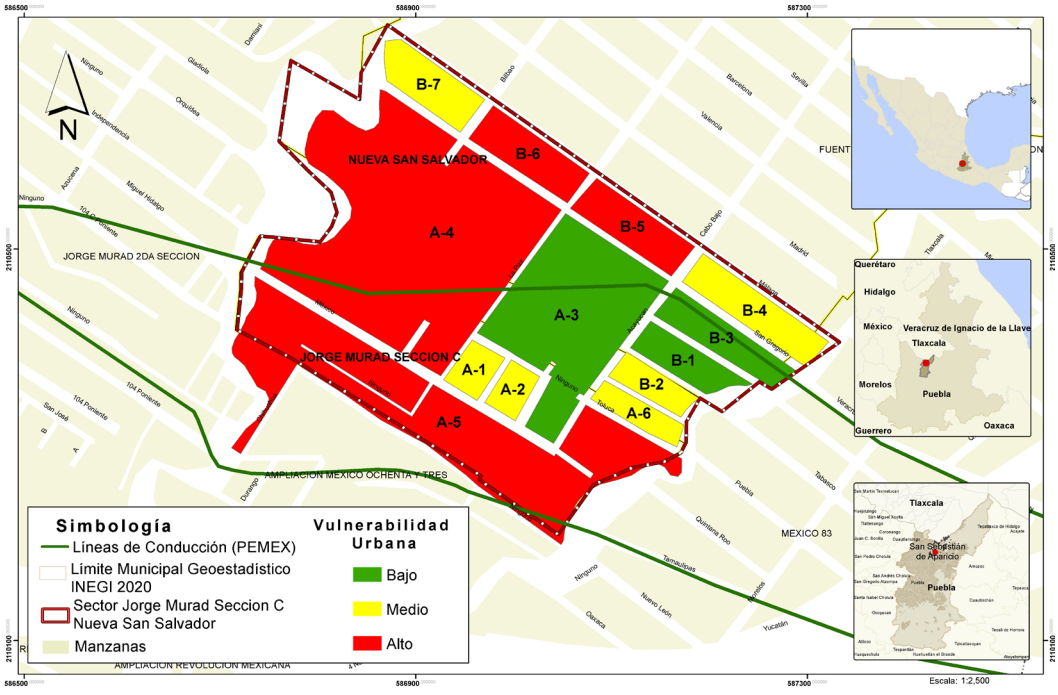

Figure 4. Urban vulnerability. Source: Preparation by the authors based on INEGI (2009); INEGI (2016); INEGI (2020); INEGI (2023); Hernández (2023a); Secretaría de Protección Civil y Gestión Integral de Riesgos (2021).

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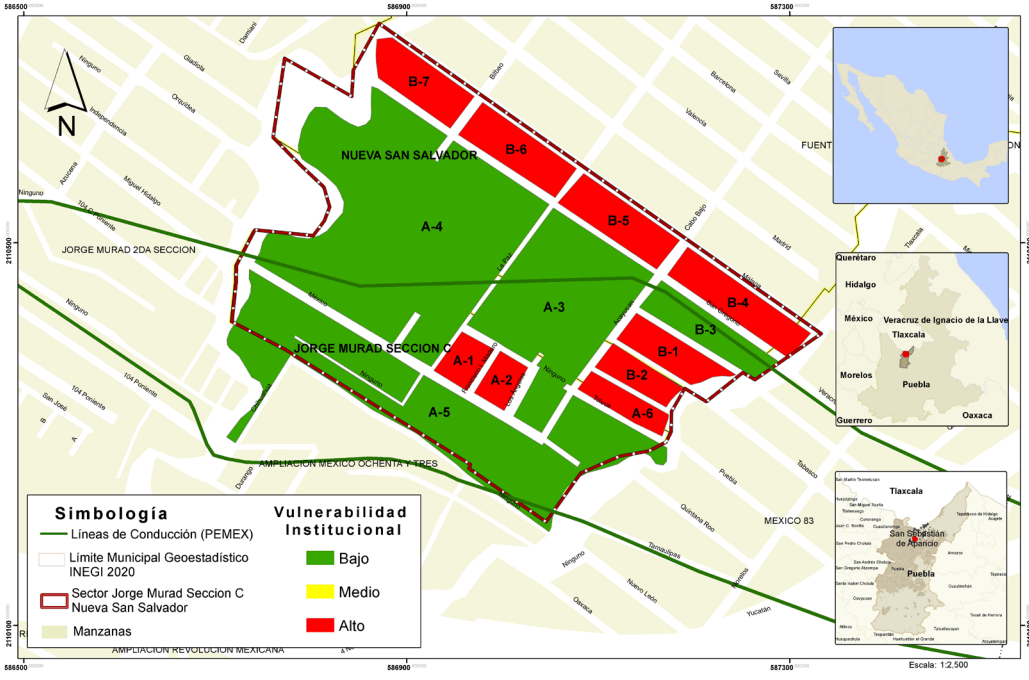

Figure 5. Institutional vulnerability. Source: Preparation by the authors based on INEGI (2009); INEGI (2016); INEGI (2020); Secretaría de Protección Civil y Gestión Integral de Riesgos (2021); Hernández (2023b).

A5, B5, and B6, medium in A1, A2, B2, B4, and B7, and low in A3, B3, and B1 (Figure 2).

A total score of 269 was obtained in the studied sectors' urban indicators. The urban conditions include unpaved roads without lighting, houses on the right-of-way of the hydrocarbon pipelines, and ravines that were filled in to build other houses. In the Jorge Murad Section C settlement, 85% of the homes do not have property deeds, and in Nueva San Salvador, the percentage is 15%[8]. The risk of a hydrocarbon explosion poses a problem for 19.44% of the inhabitants, as it makes the registration of deeds difficult. The blocks whose legal status hinders their integration into urban planning processes complicate the provision of public services.

The assistance services within the suggested radius for attention during an emergency (Secretary of State at the Office of Social Development [SEDESOL], 1999)[9] include fire stations, public security, and health centers. However, three new explosion hazard points were identified, with impact radii of 100 and 200 meters (National Center for Disaster Prevention [CENAPRED], 2021), that increase the risk zone (Figure 3).

A high level of social vulnerability is defined in blocks A4, A5, B5, and B6, medium in blocks A1, A2, B2, B4, and B7, and low in blocks A3, B3, and B1 (Figure 2).

A score was obtained in the financing indicators of 117, risk identification of 278, management of 152, and reduction of 286, totaling 883. In interviews with the technical staff of the Civil Protection Risk Management Directorate of the Municipality of Puebla (GRMPC), it was identified that limited financial resources are available for updating equipment and computer programs used for risk identification and analysis. This is because the allocation of resources depends on the Municipal Treasury, and there is no dedicated fund or economic reserve for operational purposes.

Regarding municipal information, there is no inventory, historical documentation, or monitoring of disasters or losses due to hydrocarbon explosions; instead, information

8 The municipal council has only incorporated Nueva San Salvador into its urban development plans. This process is the final step undertaken by urban settlements to request recognition for the provision of basic public services. This process speeds up the accreditation of the property.
9 In the current NOM-SEDATU-002 standard of 2022, this radius is not defined.

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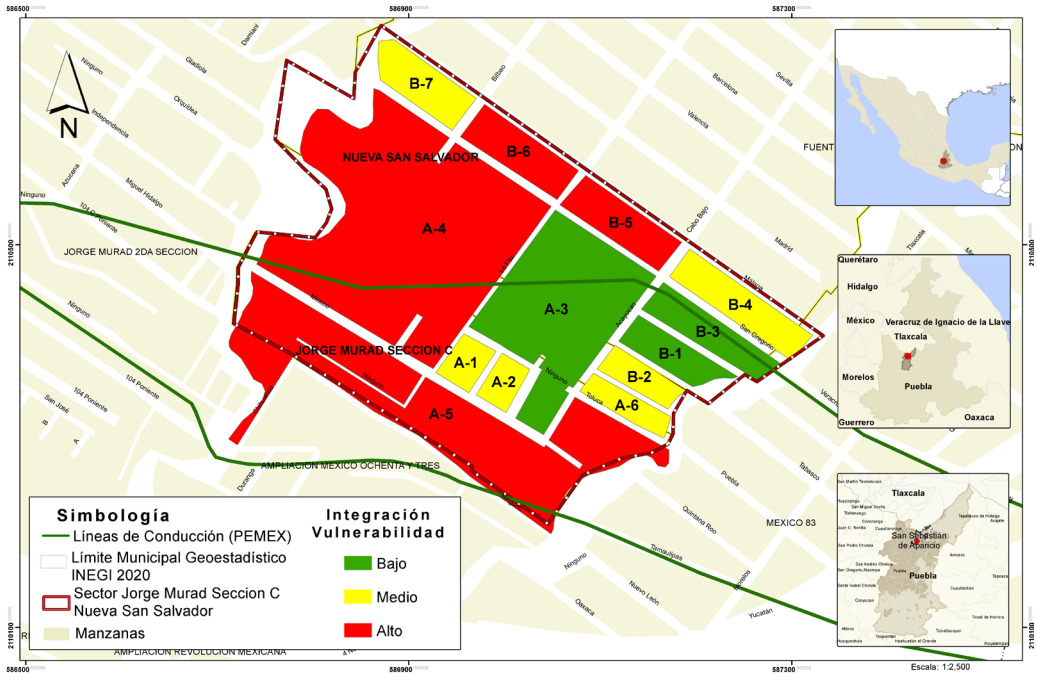

Figure 6. Integration of Vulnerabilities. Source: Preparation by the authors based on INEGI (2009); INEGI (2016).

is transmitted orally among the staff. The precise location of the pipelines is lacking, as are mapping, vulnerability, and risk assessments, and the existing information is maintained by Petróleos Mexicanos (PEMEX). Regarding professionalization, the staff does not receive continuous training, and the exchange of knowledge takes place on the staff's initiative and/or in the face of the need to solve specific management problems (Personnel-technical, personal communication, 2023).

As for risk management, although the Municipal Civil Protection Directorate (PC) is responsible for the operational phase and has the equipment needed to attend to emergencies, it lacks preventive measures for personnel and inhabitants in urban settlements. The actions of the industries and companies, such as PEMEX and Maxi Gas, are limited to technical personnel. Therefore, the Ministry of Public Security is responsible for surveillance and monitoring, which is conducted through cameras located on regulating vessels and channels with a risk of flooding.

Regarding prevention, PC conducts emergency prevention campaigns on social networks and the radio. At the same time, the Risk Management in Civil Protection Matters of the Municipality of Puebla (GRMPC) reviews civil protection plans in constructions that offer goods and services (Personal-technical, personal communication, 2023). It is worth noting that both entities lack the responsibility and resources to relocate homes.

The institutional vulnerability level is defined as high in the A1, A2, A6, B1, B2, B4, B5, B6, and B7 blocks and low in A3, A4, A5, and B3 as they are served by PEMEX (Figure 5).

Starting from a multifactorial approach, it was identified that although neighborhoods and housing conditions are characterized by backwardness and marginalization along hydrocarbon pipelines, and even though there is neighborhood organization and communication in emergencies, and engagement from local authorities to help reduce vulnerability, the threat does not disappear. Blocks A4, A5, B5 and B6 were defined as a high level; A1, A2, A6, B2, B4, and B7 as medium; and A3, B1, and B3 as low (Figure 6).

V. DISCUSSION

The vulnerability assessment, employing a multifactorial approach, involved integrating social, urban, and institutional indicators, as addressed by authors such as Acuña (2016),

Cram Heydrich et al. (2020), and Ruíz Rivera and Magaña Rueda (2020). This approach represents progress compared to other studies, such as He et al. (2021) and Abdoul Nasser et al. (2021), which analyze risk by emphasizing threats.

The study contributes to placing the profiles and capacities of the actors involved at the center of the analysis, as Mojtahedi and Oo (2016) suggested. According to Cutter et al. (2003) and Mattedi et al. (2024), the design of indicators is explored through standardization and data integration to measure and compare vulnerability at the urban block level, representing the most precise spatial approximation possible.

In social vulnerability, the indicators referring to groups experiencing backwardness (CONEVAL, 2020), lacking attention and care, and in poverty (Montes-Neri, 2023) were considered. In urban vulnerability, indicators such as marginalization, proximity to urban facilities and services, rights of way, explosion radii, and areas of affectation were considered, as mentioned by Azari and Karimi (2017). In institutional vulnerability, indicators regarding actions for financing, urban planning, access to information, professionalization, and response capacity, as a fundamental part of the management processes highlighted by Merlinsky and Tobias (2016), were considered.

It is corroborated that anthropogenic risks, such as chemical-technological ones, are often overlooked in management, and a reactive response prevails, as pointed out by Abdoul Nasser et al. (2021). As the main stakeholders, the inhabitants organize and make decisions to reduce their vulnerability. However, this is insufficient in the face of institutional omissions that fail to provide legal certainty of ownership, as noted by Cutter et al. (2003) and Ochoa-Ramírez and Guzmán-Ramírez (2020). This situation leaves disaster risk in a secondary or invisible category, as both González (1994) and Cavazos-Arroyo et al. (2014) mentioned.

VI. CONCLUSIONS

The study contributes to the lack of analyses of different types of variables that determine the multifactorial origin of vulnerability to disaster risk and its mapping (Birkmann, 2007). It is confirmed that multiple factors determine the vulnerability to the risk of hydrocarbon explosion (Xiu et al., 2011; Ruíz Rivera & Magaña Rueda, 2020). The design and processing of social, urban, and institutional indicators to define vulnerability levels (Cutter et al., 2003) in the Jorge Murad C-Nueva San Salvador Sector was provided because it represents the exposure that other informal urban settlements located in the municipality of Puebla are in (Montes-Neri, 2023). The socio-spatial analysis of indicators associated with vector data (Mattedi et al., 2024) showcases the differences in the distribution of vulnerability by urban block as the maximum possible spatial approximation (He et al., 2021; Cutter et al., 2003). The risk is presented by the population and homes' exposure to the explosion of hydrocarbons, but the vulnerability is increased by social backwardness, marginalization, and a reactive response. However, the participatory processes confirmed that the organization and outreach of the actors involved contribute to reducing vulnerability.

VII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization: R.M.H.V. and S.S.S.M.; Data curation: R.M.H.V.; Formal analysis: R.M.H.V. and S.S.S.M.; Acquisition of financing: R.M.H.V.; Research: R.M.H.V., S.S.S.M. and M.L.F.L.; Methodology: R.M.H.V., S.S.S.M. and M.L.F.L.; Project Management: S.S.S.M. and M.L.F.L.; Resources: R.M.H.V.; Software: R.M.H.V.; Supervision: S.S.S.M. and M.L.F.L.; Validation: R.M.H.V. and S.S.S.M.; Visualization: R.M.H.V. and S.S.S.M.; Writing - original draft: R.M.H.V., S.S.S.M. and M.L.F.L.; Writing - proofreading and editing: S.S.S.M.

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POST-DISASTER DISASTERS. ONE-DIMENSIONAL POLICIES WITHOUT POST-DISASTER ASSESSMENT AND RECURRENCE OF DISASTERS:

THE CASE OF NONGUEN, CHILE, AS A CHARACTERISTIC CASE OF UNSOUND POLICIES

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El análisis multidimensional es una herramienta de política pública basada en la gobernanza que contempla múltiples variables de análisis y que constituye una respuesta muy eficaz frente al riesgo de desastre. Si bien existen diversos ejemplos en el ámbito internacional, no se ha desarrollado hasta la fecha en Chile una orientación de este tipo en la respuesta a desastres por parte de la administración. Estas políticas públicas para la gestión del riesgo de desastres en Chile, específicamente aquellas que se aplican en la etapa pos-desastre, se proyectan para fortalecer las institucionalidades y desarrollar programas y estrategias enfocadas al manejo de catástrofes, conformándose en acciones que aspiran a disminuir la vulnerabilidad y desarrollar procesos de recuperación de lugares. ¿Qué sabemos de los efectos de estas políticas en los territorios? Esta investigación analiza cómo la ausencia de instrumentos de evaluación de estos resultados impide conocer el desempeño y la efectividad de los planes aplicados. A partir de una evaluación multidimensional del barrio Nonguén, en la ciudad de Concepción, Chile, se caracteriza un ejemplo típico de políticas públicas mal orientadas que explican cómo las intervenciones desacertadas pueden agudizar los problemas existentes. Este barrio se ha conformado y desarrollado hasta la actualidad en una zona de riesgo de inundación, a pesar de que se era consciente de su condición gracias a registros que datan de 100 años antes de comenzar la urbanización. Se concluye que la respuesta pública, basada en intervenciones de enfoque unidireccional que no tomó en consideración los problemas de los habitantes, ha redundado en un proceso de aumento creciente de la vulnerabilidad frente al riesgo y una recurrencia de desastres dañinos. La evaluación pos-desastre bajo una perspectiva multidimensional del hábitat permitiría intervenir los territorios con proyectos que desaten procesos de desarrollo futuro.

Palabras clave: política territorial, asentamientos urbanos, desastres naturales, gestión urbana, reconstrucción.

Multidimensional analysis is a governance-based public policy tool that considers multiple analysis variables to respond to disaster risks effectively. Although there are several examples in the international arena, no such guidance has been developed in Chile for the administration's disaster response. Existing public policies for disaster risk management in Chile, specifically those applied in the post-disaster stage, are designed to strengthen institutionality and develop programs and strategies focused on catastrophe management, shaping actions that aim to reduce vulnerability and handle recovery processes. What do we know about the effects of these policies in the regions? This research analyzes how the absence of instruments to assess these results prevents understanding the performance and effectiveness of the plans applied. Based on a multidimensional evaluation of the Nonguén neighborhood in Concepción, Chile, a typical example of misguided public policies is characterized, explaining how ill-advised interventions can exacerbate existing problems. This neighborhood continues to grow and develop in a flood risk zone, albeit aware of this condition, thanks to records dating back 100 years before urbanization began. It is concluded that the public response, based on unidirectional approach interventions that disregarded the inhabitants' problems, has increased vulnerability to risk and a recurrence of damaging disasters. A post-disaster assessment using a multidimensional perspective of the habitat would allow intervening areas with projects that give rise to future development processes.

Keywords: territorial policy, urban settlements, natural disasters, urban management, reconstruction.

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I. INTRODUCTION

Disaster risk management has evolved towards a multidimensional approach integrating territorial, social, economic, environmental, and political factors. This perspective says that disasters are not mere natural events, but manifestations of vulnerabilities accumulated in communities over time (Sandoval-Díaz, 2020). International organizations such as the United Nations Office for Disaster Risk Reduction [UNDRR] have promoted this change through frameworks such as the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNDRR, 2015), which fosters comprehensive strategies from urban planning to active participation of the communities.

Although agencies and instruments such as the National Emergency Office of the Ministry of the Interior [ONEMI] and the Civil Protection Law have been established in Chile, risk management continues to face important contradictions. Authors such as Tapia (2015) and Balboa, Carrasco, and Valenzuela (2019) have criticized the policies' lack of adaptation to local realities, highlighting the persistence of traditional approaches prioritizing reactive interventions, focusing mainly on infrastructure. This approach tends to ignore key elements, such as consultation with affected communities and incorporating social and cultural dimensions into strategies.

The theory of disasters as socio-natural phenomena, proposed by Larenas Salas (2016) and Molinari, Menoni, and Ballio (2017), emphasizes the importance of designing interventions that consider the particularities of each territory and community. However, in practice, Chilean public policies are still limited by a sectoral vision that perpetuates the vulnerability of the affected territories. This context leads to questioning how public policies effectively respond to local needs, especially in areas where historical and environmental dynamics demand more holistic approaches.

In this framework, this research proposes to renew the approach of Public Risk Management Policies, with one that integrates dimensions of the residential habitat that have been neglected until now in project planning and execution. Incorporating these elements would optimize territorial management and strengthen communities' capacity to prevent and mitigate the effects of socio-natural disasters. This approach seeks to develop an innovative perspective that connects interventions with a comprehensive and multidimensional post-disaster evaluation, which promotes sustainable solutions that meet local needs.

The Nonguén Neighborhood in Concepción, which has faced recurrent flooding, aggravated by real estate pressure and the backfilling of riverbeds, is an emblematic example of these tensions between urban development and risk management. Urban development in this area has largely ignored climatic and historical conditions, exacerbating the community's vulnerability. Analyzing the dynamics of Nonguén makes it possible to show how one-dimensional policies are not only ineffective, but can also be counterproductive.

This article seeks to examine the relationship between risk management and the community context, establishing an evaluation instrument with a multidimensional approach aimed at reducing vulnerability.

It is structured around a theoretical framework that underscores the need to overcome one-dimensional approaches to risk management in Chile, incorporating social, cultural, political, and economic dimensions to reduce vulnerabilities and strengthen community resilience to disasters. This paper presents a case study in the Nonguén Valley, a biodiversity hotspot in the Bío-Bío region, affected by recurring floods aggravated by urban expansion. Based on a case-by-case approach, the methodology combines quantitative and qualitative methods, arranged in phases: theoretical review, data collection, and formulation of a multidimensional post-disaster evaluation matrix. The results examine the interventions carried out in the Nonguén Valley, analyzing the effects and interaction between the dimensions of the residential habitat. The conclusions confirm that socio-economic factors determine vulnerability to disasters and emphasize the need for comprehensive urban planning that reduces risks and promotes community resilience.

II. THEORETICAL FRAMEWORK

Disaster risk management in Chile: A multidimensional approach versus one-dimensional interventions.

Chile, as a country highly exposed to natural risks, has acknowledged the need to develop strategies that address the impact of these events, intensified by climate change. In this context, the country has implemented the 2002 National Civil Protection Plan [PNPC, in Spanish] and the National Policy for Risk Reduction: Strategic Plan 2020-2030 (ONEMI, 2020), coordinated by ONEMI. The PNPC organizes its response in four phases: preparation and mitigation, assistance and containment, restoration of basic services, and reconstruction. However, these stages usually prioritize one-dimensional approaches, primarily focused on urban infrastructure (Rinaldi & Bergamini, 2020).

The National Strategic Plan seeks to move towards a broader approach, incorporating multidimensional variables, including social, cultural, and environmental aspects. Cities have prioritized measures such as channelization and flood defenses, which, although effective against smaller magnitude events, present significant limitations in the face of major

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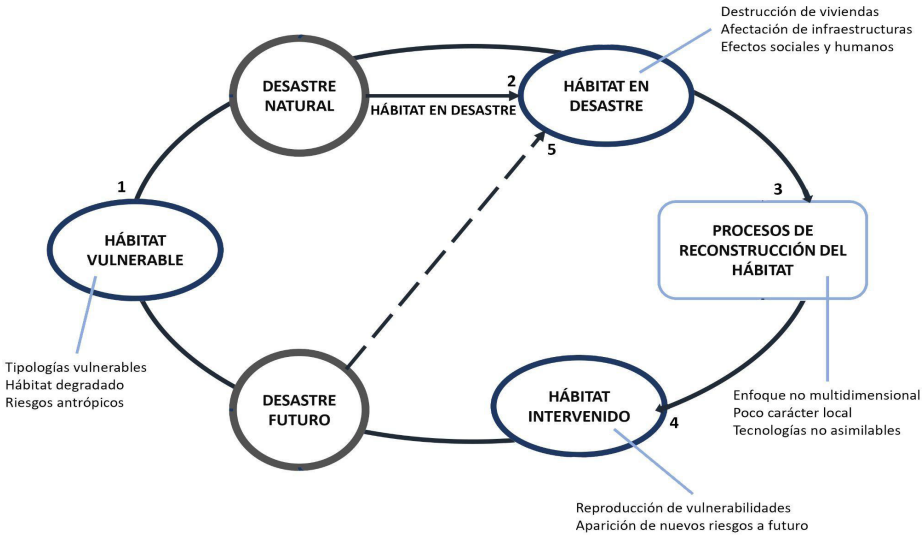

Figure 1. Reproduction cycle of the risk of post-disaster reconstruction of housing and habitat. Source: Preparation by the authors with data from Olivera and González, 2010.

disasters (González, 2017). In this sense, systemic resilience should replace the traditional vision of resistance focused on specific components, promoting a management that integrates human dynamics and natural phenomena (Larenas Salas, 2016).

Disasters affect beyond the physical sphere, generating profound changes in communities' social and cultural dynamics. One-dimensional policies tend to ignore key aspects such as citizen participation and local traditions, generating incomplete solutions and perpetuating vulnerability in the affected territories (Gordillo Bedoya, 2006; Fontana & Conrero, 2023).

Socio-economic and environmental conditions not only intensify the effects of natural phenomena, but also reflect structural and political inequities that amplify communities' vulnerability (Mileti, 1999; Quarantelli, 1998; Gaillard, 2007). These deficiencies underline the importance of a management that transcends the one-dimensional and contemplates the complexity of risk as a socio-natural phenomenon.

A critical aspect of risk management is the post-intervention evaluation, which allows measuring the impact of the policies applied and the effectiveness of the strategies in restoring communities. This assessment must address multiple dimensions, such as infrastructure, social cohesion, institutional capacity, and environmental sustainability (Canese de Estigarribia et al., 2022). On the other hand, ignoring these complementary dimensions can be counterproductive, as it perpetuates pre-existing vulnerabilities (Berke, Kartez & Wenger, 1993).

Reconstruction strategies focused solely on the physical can contribute to perpetuating conditions of vulnerability in communities, a phenomenon conceptualized as the "Risk Reproduction Cycle" (Olivera & González, 2010). In this sense, it is essential to consider people as active agents in the recovery processes, since many interventions have failed precisely because they ignore social and cultural dimensions (Rashed & Weeks, 2003; Guha-Sapir et al., 2010).

This study proposes a renewed approach to Public Risk Management Policies, which includes dimensions of the residential habitat that have traditionally been neglected in the design and implementation of plans and projects. This approach seeks to overcome the limitations of one-dimensional strategies. It promotes a multidimensional perspective that connects the interventions carried out with comprehensive evaluations after the disaster. In this way, the goal is to improve territorial management and promote sustainable and contextualized solutions that reduce structural vulnerabilities and strengthen community resilience.

III. CASE STUDY

The Nonguén Valley, located in the Bio-Bio region of Concepción, represents an emblematic case in disaster risk management in Chile. With 44 km^2, this basin is part of the "Chilean Winter Rainfall-Valdivian Forests", one of the 34 global

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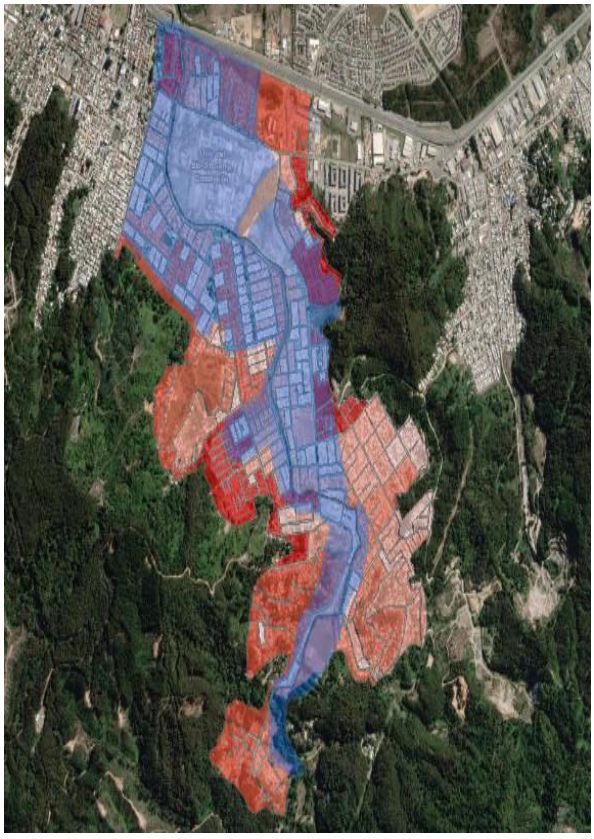

Figure 2. Planimetry of the population exposed to flooding by heavy rain. Source: Preparation by the authors, GIS with data from the 2017 Census and 2016 Flood Plan - Sernageomin, National Geography and Mining Service of Chile.

biodiversity hotspots, standing out for its high biological diversity and endemism. Throughout its history, the valley has endured recurring floods, with records dating back to 1890, which have affected its inhabitants' infrastructure and social and economic life.

The first settlements, which took advantage of the fertile and accessible land next to the Nonguén River, were formed during the agrarian reform in the 1960s. This sector, located 5 km from the city, not only catered for the food and housing needs of the city of Concepción, which was relocated here after the 1960 earthquake, but also continued to grow despite the risks. The city's recovery promoted an economic model based on state investment and industrial growth, accelerating the metropolization process in the region (León Aravena, Saravia Cortés & Bisbal, 2018).

Over the years, the anthropization process and the demographic growth in the neighborhood significantly altered the natural environment. The floods, aggravated

Figure 3. Timeline of the anthropization process and flooding in the Nonguén Valley. Source: Preparation by the authors.

by this real estate expansion that has backfilled river beds, have only increased the risk of exposure to natural phenomena. Rojas et al. (2014) point out that factors such as geomorphology, climate, and human intervention have triggered these floods, which makes the Nonguén Valley a relevant case study that can be extrapolated to other contexts, as the following mapping shows.

Currently, the sector has about 14,000 inhabitants, organized into 9 neighborhood boards and 54 social organizations that actively manage the community's needs (Burdiles et al., 2023). However, interventions to mitigate floods have been mixed. While some community initiatives address microzones, larger-scale public projects, such as the canalization of the Nonguén River in 2009, affected the entire area without adequate consultation with the inhabitants. These partial and disjointed solutions reflect a disconnect with local problems.

Figure 3 shows a timeline of anthropization and floods in the Nonguén Valley, a history marked by the transformation of the natural environment and the inherent vulnerability of the population. Despite the historical floods, the neighborhood has continued to be formed, highlighting the need to adopt comprehensive and multidimensional approaches in risk management. These approaches should consider the local context's particularities and promote the community's active participation in decision-making. Only in this way can effective and sustainable solutions be developed that mitigate the risk of disasters in the future.

IV. METHODOLOGY

The study adopts a case study approach, using quantitative and qualitative methods to establish extrapolations between the case study and the Public Policies of Disaster Risk Management [PGRD] in Chile. Given the multidimensional nature of the topic, it is suggested to proceed in the following phases:

Phase 1: Theoretical Framework. This addresses the operation of public risk management policies in Chile and multidimensional analysis as a tool for evaluating actions in post-disaster territories (Villacreses Viteri, 2024). A review of relevant national and international scientific literature between 1990 and 2024 will permit establishing a theoretical context that justifies the work and will lay the foundations for further analysis.

Phase 2: Based on the research question about the effects of post-disaster interventions on the residential habitat, a survey of actions and programs is carried out in the case study of Nonguén. This stage involves characterization and evaluation of post-disaster interventions. The objective of each action is recognized, and responses are analyzed to determine how they relate to the problems they seek to address and other dimensions of the habitat. A quantitative and qualitative data collection of the interventions is made using four sources of information: (1) documents; (2) private and public agents in the region; (3) inhabitants, through neighborhood meetings and interviews; and (4) specialized observation. The situation before 2006, the year of the most significant historical flood, is analyzed. Data from the 2002 Census were used in contrast to data after 2006, with data from the 2017 Census and information collected up to 2021. Table 1 lists the post-disaster interventions, indicates whether they have been evaluated, and categorizes them by type of evaluation.

Phase 3: Formulation of a Post-disaster Evaluation Matrix. 32 indicators were selected in a matrix that contemplates the dimensions of the habitat and incorporates innovative variables, relevant to the case and extrapolable to other contexts. The definition of Residential Habitat of the Housing Institute of the University of Chile [INVI, in Spanish] will be adopted, structured in three dimensions: 1) Physical-Spatial Dimension; 2) Socio-Cultural Dimension; and 3) Political-Economic Dimension.

Table 2 shows the results of a self-assessment of the typical case.

Phase 4: Post-disaster Public Administration Effects Analysis. This section will discuss the multidimensional impact of public administration on vulnerability.

V. RESULTS

From this phase, a record is prepared, Table 1, which reveals three key aspects: (1) a trend of interventions towards the Physical-Spatial dimension is identified, with a particular emphasis on improving infrastructure, river works, and territorial planning, which are based on technical resolutions aimed at improving basic urban structures. This finding reinforces the hypothesis that post-disaster interventions tend to be unidirectional; (2) the survey indicates that 60% of the projects analyzed do not have a subsequent evaluation; (3) only three have been evaluated by state institutions, four by citizen organizations, and five are registered in scientific research.

In this case, a multidimensional evaluation matrix was designed to evaluate the interventions and indicators, which are also extrapolated. This tool measures the effects of Public Disaster Risk Management Policies on an area's vulnerability in the post-disaster stage. The objective of the matrix is to compare the area's situation before the main disaster (in this case, the flood of 2006) with its current state (until 2021) to determine how public policies have influenced the conditions of vulnerability. Table 2 presents the results derived from the self-assessment matrix applied to the case study. It classifies the indicators by habitat dimension. The pre- and post-disaster data are determined with a positive or negative valuation according to the indicator. It is confirmed that 69% of the indicators are evaluated with negative evolution, 22% with positive evolution, and 9% remain in the same situation. Similarly, the column "Affected dimensions" observes that these predominantly territorial interventions

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	INTERVENTIONS	Approach according to habitat dimensions	EVALUATIONS	
			YES/NO	Evaluating Agent
1	Filling in wetlands for urbanization	Physical-Spatial	NO	
2	River edge interventions	Physical-Spatial	YES	Research
3	River works	Physical-Spatial	YES	State
4	Housing Deficit	Political-Economic	NO	
5	Location of community facilities	Physical-Spatial	NO	
6	Length of main roads - safety	Physical-Spatial	YES	State
7	Loss of natural landscape	Physical-Spatial	YES	Citizenry
8	Population exposed to floods	Socio-Cultural	NO	
9	Urbanization in rural areas	Physical-Spatial	YES	Citizenry
10	Vulnerable housing	Physical-Spatial	YES	Research
11	Changes in land use and vegetation cover	Physical-Spatial	YES	Research
12	Geographical dangerousness	Physical-Spatial	YES	Research
13	Fire Risks	Physical-Spatial	YES	Research
14	Rains	Physical-Spatial	NO	
15	Paving	Physical-Spatial	NO	
16	Poverty	Socio-Cultural	NO	
17	Access to Emergency Rooms (ER)	Physical-Spatial	NO	
18	Access to the Police	Physical-Spatial	YES	State
19	Access to Firefighters	Physical-Spatial	NO	
20	Waste management	Political-Economic	NO	
21	People affected by disasters	Socio-Cultural	NO	
22	Employment	Socio-Cultural	NO	
23	Governance	Political-Economic	YES	Citizenry
24	Community participation	Political-Economic	YES	Citizenry
25	Planning with risk reduction	Physical-Spatial	NO	
26	Planning instruments	Physical-Spatial	NO	
27	Cooperation	Political-Economic	NO	

Table 1.Record of interventions and evaluations after the 2006 flood. Source: Preparation by the authors.

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DIMENSION	INDICATOR	RESULTS AND EVALUATION					
		OWN EVALUATION			DIMENSIONS AFFECTED		
		PRE-DISASTER DATA	POST-DISASTER DATA	VALUATION - NEGATIVE + POSITIVE = NO CHANGE	PHYSICAL-SPATIAL DIMENSION	DSOCIO-CULTURAL DIMENSION	POLÍTICAL-ECONOMIC DIMENSION
PHYSICAL SPATIAL DIMENSION	IFE 1	Percentage of wetlands	1.73%	0.52%	-	X	X	X
	IFE 2	Proportion of the river edge following the natural landscape of the place.	92% Total Length	92% Total Length	=	X	X	X
	IFE 3	Requirement for new housing	1078 UN	968 UN	-	X	X	X
	IFE 4	Surface area of camps	2600 M2	They are none	+	X	X	X
	IFE 5	Percentage of facilities located in flood zones.	92% in the flood zone	95% in the flood zone	-	X	X	X
	IFE 6	Percentage of facilities located in areas of landslides or erosion.	10% in the landslide risk area	15% in the landslide risk area	-	X	X	X
	IFE 7	Length of main roads on the surface of the functional urban area.	Average roads 663 ML	Average roads 2263 ML	+	X	X	
	IFE 8	Percentage of non-built-up area (vacant sites)	3.27%	0.63%	-	X	X	
	IFE 9	Population density	7,217 Inhab/ km2	8,899 Inhab/ km2	-	X	X	
	IFE 10	Percentage of loss of natural areas of environmental and cultural value, due to urbanization.	0.035 Km2	0.255 Km2	-	X	X	X
	IFE 11	Percentage of the population exposed to flooding.	79.60%	85.30%	-	X	X	
	IFE 12	Number of building permits in rural areas.	235	584	-	X		X
	IFE 13	Percentage of vulnerable housing.	HIGH in 3 of 4 conditions		-	X	X	X
	IFE 14	Relationship between infrastructure and property subdivision.	541 km/235	618 km/584	-	X		X
	IFE 15	Relationship between land use and vegetation cover.	Analysis of various data.		-	X		X
	IFE 16	Condition of dangerousness of the territory.	HIGH in all conditions		-	X	X	
	IFE 17	Proportion of surface area with fire risk.	Without records	1.11 Km2 37.5% of total surface.	-	X	X	
	IFE 18	Flooding of land.	Without records	96.64%	-	X		

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DIMENSION	INDICATOR	RESULTS AND EVALUATION						
		OWN EVALUATION			DIMENSIONS AFFECTED			
		PRE-DISASTER DATA	POST-DISASTER DATA	VALUATION - NEGATIVE + POSITIVE = NO CHANGE	PHYSICAL-SPATIAL DIMENSION	DSOCIO-CULTURAL DIMENSION	POLÍTICAL-ECONOMIC DIMENSION	
SOCIO-CULTURAL DIMENSION	ISC 1	Percentage of people in poverty.	13.18%	42.51%	-		X	
	ISC 2	Distance to emergency services.	4.8 km on average	4.8 km on average	=		X	X
	ISC 3	Number of micro-landfills by urban area.	5	7	-		X	X
	ISC 4	Distance to police stations.	5.5 km on average, approx.	850 m on average, approx.	+	X	X	
	ISC 5	Distance to fire stations.	1.7 km on average	1.7 km on average	=	X	X	
	ISC 6	Number of people killed, missing, and affected, attributed to disasters.	18,141 pp	22,785 pp	-	X	X	X
	ISC 7	Exposure of the population.	HIGH in all conditions		-		X	X
ECONOMIC POLITICAL DIMENSION	IPE 1	Unemployment Rate	3.63%	4.34%	-			X
	IPE 2	Number of existing and participating regional and community organizations.	65	48	-		X	X
	IPE 3	Number of non-governmental groups participating in the design and approval processes of projects for public spaces.	Without records	15	+		X	X
	IPE 4	Existence of communal studies that establish risk areas and define restrictions on use and building, for disaster risk reduction.	YES	YES	+	X		X
	IPE 5	Existence of communal territorial planning instruments.	YES	YES	+	X		X
	IPE 6	Coverage and validity of territorial planning instruments.	30 years	30 years. Every / 10 years approx.	+			X
	IPE 7	Existence of cooperation organizations in the territory	2	without records	-			X

Table 2. Results of the multidimensional evaluation matrix. Source: Preparation by the authors.

affect other dimensions of the habitat, such as socio-cultural and political-economic dimensions. This supports the idea that post-disaster evaluations should be approached from a multidimensional perspective.

The most striking indicator in the physical-spatial dimension is the percentage of wetlands. Urbanization in the Nonguén Valley has significantly impacted local ecosystems, especially wetlands, whose area decreased from 1.73% in 2002 to 0.52% in 2015. This loss has compromised the soil's percolation capacity, increasing the risk of flooding. The inadequate channelization of the river and the construction of houses on swampy land have exposed families to greater risks, evidencing deficiencies in territorial planning. In addition, 95% of community facilities are in flood-prone areas, and 15% are at risk of landslides. Between 2002 and 2017, the population density rose by 15%, reaching 8.9 inhabitants per square kilometer, further increasing exposure to natural disasters. The expansion of the road infrastructure grew from 541.9 km to 618.4 km, and the rise in rural buildings, which went from 548 in 2006 to 1,204 in 2021, reflects deficiencies in urban planning.

Another important factor in this dimension is that most indicators affect the socio-cultural dimension. 92% of the population near the river lives in risk areas, which shows the community's vulnerability. There is also a housing deficit of 10.3%, which requires the construction of 1,078 new homes. The increase in housing in irretrievable conditions is due to prolonged exposure to floods. In addition, the existence of camps demonstrates community organization in search of housing solutions, although the location of critical facilities in disaster-prone areas generates distrust among residents.

It also affects the political-economic dimension; local economic activities, such as aggregate extraction and brick production, have intensified soil erosion and increased the area's vulnerability. Although the communal regulatory plan establishes urbanization regulations, it lacks requirements for evaluating the environmental impact of these activities. This highlights the need for an integrated territorial management that addresses the territory's challenges collaboratively and adaptively, promoting sustainable development and improving the quality of life in the Nonguén Valley.

VI. DISCUSSION

The analysis of the three main dimensions—physical-spatial, socio-cultural, and political-economic—reveals complex interactions that directly affect the community's development and vulnerability. These interrelated dimensions condition the population's well-being and ability to face social, economic, and environmental challenges.

In the physical-spatial dimension, interventions on the banks and urbanization backfills are critical aspects that significantly alter the natural environment and increase disaster risks. According to census data from 2002 and 2021, the percentage of wetlands has decreased from 1.73% to 0.52%, which negatively affects the terrain's percolation capacities and increases the flood risk. This loss of wetlands reduces the soil's absorption capacity, amplifying surface runoff and vulnerability to flooding. In addition, insufficient channeling of rivers and building houses on marshy land expose families to greater risks. Uncontrolled urbanization has modified ecosystems, intensified erosion and sedimentation, and generated little urban planning, which affects the natural landscape and biodiversity. This evaluation supports the idea that one-dimensional approaches focused mainly on urban infrastructure are usually prioritized in the post-disaster stages (Rinaldi & Bergamini, 2020).

In the socio-cultural dimension, 13.18% of the population lives in poverty, a structural problem intertwined with other social and economic factors. This high poverty rate profoundly impacts access to essential services such as health, education, and security, limiting individual and collective development opportunities. Poverty also reinforces the inhabitants' vulnerability to natural disasters and adverse environmental conditions. For example, 85.30% of the population is exposed to floods, which aggravates the risks to human life and local infrastructure. This exposure is linked to population density, since more than 200 inhabitants per block occupy high-risk areas, which shows the insufficiency of urban planning to mitigate these dangers. In addition, the average distance to emergency services, 4.8 km, hinders rapid access to medical care, especially in critical situations, reflecting a lack of investment in adequate health infrastructure. This reality is manifested in many overcrowded family nuclei and close households, where 81 families live in overcrowded conditions and 708 households are in vulnerable situations, which highlights the difficult living conditions. Under the approach of the phenomenon conceptualized as "Risk Reproduction Cycle," it is essential to consider people as active agents of recovery (Olivera & González, 2010).

In the political-economic dimension, the insufficiency of resources and the absence of adequate legislation that guarantees an equitable distribution of services are evident. Although access to security services has improved, the new police station's location in flood zones compromises its operability, highlighting the need for more strategic spatial planning. The lack of adequate legislation and public investment in critical infrastructure, such as water services and waste management, indicates a weakness in local governance. The existence of 21 rainwater evacuation projects, of which 16 have been built, is a step in the right direction, but the lack of integrated planning and adequate supervision limits their effectiveness. The lack of public responsibility in

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maintaining these works and low community participation in decision-making highlight the need for more inclusive and sustainable policies. In this sense, systematic resilience should replace the traditional vision of resistance focused on specific components, promoting a management that integrates human dynamics and natural phenomena (Larenas Salas, 2016).

In summary, the three dimensions analyzed are closely interrelated and show how problems in one dimension affect the others. Interventions on the river banks and urbanization problems in the physical-spatial dimension generate vulnerabilities aggravated by poverty and lack of access to basic services in the socio-cultural dimension, as well as insufficient planning and resources in the political-economic dimension. A comprehensive approach that addresses these challenges in a coordinated way, promotes sustainable urban development, and considers the territory's social needs and environmental conditions is necessary to improve the quality of life and reduce the community's vulnerability. Implementing public policies with these dimensions will promote a safer and more equitable environment for all inhabitants.

VII. CONCLUSIONS

The hypothesis is partially verified, since a comprehensive intervention in the analyzed dimensions could reduce the habitat's vulnerability. While the analysis shows that the interactions between the dimensions are complex and directly affect the population's well-being, limitations are also identified. For example, the sanitary and rainwater drainage infrastructure has improved, but significant deficiencies persist that limit the effectiveness of these interventions. The lack of adequate planning and supervision is a limitation in the improvement process that can compromise the sustainability of the progress achieved.

Additionally, some aspects, such as the mental health of the post-disaster population, were not addressed in depth, a critical issue that deserves to be investigated. This approach could have offered a more holistic view of vulnerability in the Nonguén Valley, given that the psychological consequences of living in a risky environment can have a lasting impact on quality of life.

The generalization of the findings of the Valle Nonguén case study presents challenges. Although the problems identified may represent other urban contexts in Chile and Latin America, each region's socio-cultural, economic, and environmental particularities must be considered. The factors contributing to vulnerability are often contextual and specific, implying that solutions must be adapted to local circumstances.

However, the analysis offers valuable lessons that could be applied to similar contexts. For example, the interrelationship between dimensions and their influence on vulnerability can be a conceptual framework for assessing other post-disaster urban habitats. The evidence that poverty and lack of access to services are critical factors that aggravate vulnerability could be generalized, as long as the specific context's particularities are considered.

In conclusion, the study of the Nonguén Valley highlights the need for a multidimensional approach to address vulnerability in post-disaster habitats. The interaction between the physical-spatial, socio-cultural, and political-economic dimensions highlights the importance of comprehensive urban planning that considers local realities and promotes community participation. Despite the limitations and the difficulty in generalizing the results, the conclusions drawn provide a solid basis for future research and the formulation of policies that seek to improve the quality of life and the safety of communities in similar contexts.

The analysis results of the physical-spatial, socio-cultural, and political-economic dimensions in the Nonguén Valley corroborate and enrich the concepts presented in the theoretical framework. The literature on urban vulnerability and resilience argues that natural disasters are not only environmental phenomena, but are profoundly influenced by social and economic factors. This is manifested in the Nonguén Valley, where, according to the data provided by the censuses in 2002 and 2017, 13.18% of the population lives in poverty, and an alarming 85.30% is exposed to floods. These data reflect the inherent vulnerability in the community's socio-economic structure, aligning with theories arguing that poverty and inequality amplify disaster risk. In addition, the theoretical framework emphasizes the need for comprehensive urban planning to mitigate risks. The results reinforce this approach, indicating that urbanization's interventions on the river's edge and backfills have exacerbated the area's physical vulnerability. The lack of adequate infrastructure for drainage and uncontrolled urbanization are also consistent with studies highlighting how urban development decisions can increase exposure to disasters.

VIII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization, D.S., I.B.; Data curation, D.S., I.B.; Formal analysis, D.S., J. P.; Acquisition of financing, D.S.; Research, D.S., I.B.; Methodology, D.S., I.B.; Project management, D.S.; Resources, D.S.; Software, D.S.; Supervision, I.B.; Validation, D.S., I.B.; Visualization, D.S., J. P.; Writing - original draft, D.S., I.B.; Writing - revision and editing, D.S., I.B.

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WHERE DO THE LITTLE ONES STUDY? SPATIAL INEQUALITY IN PRESCHOOL EDUCATION PROVISION IN THE METROPOLITAN AREA OF SANTIAGO, CHILE[1]

¿DÓNDE ESTUDIAN LOS MÁS PEQUEÑOS? DESIGUALDAD ESPACIAL EN LA OFERTA DE EDUCACIÓN PREESCOLAR EN EL ÁREA METROPOLITANA DE SANTIAGO, CHILE

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Este estudio examina la distribución de la oferta de educación preescolar en el Área Metropolitana de Santiago, evidenciando desigualdades en la relación entre la demanda infantil y la infraestructura educativa. Se utilizaron datos censales del año 2017 y registros del 2023, se aplicó un modelo de Regresión Geográficamente Ponderada (GWR) para analizar variaciones locales. Las covariantes incluyen matrículas disponibles, valor del suelo y proporción de mujeres, reflejándose dinámicas urbanas y socioeconómicas. Los resultados muestran una correlación positiva entre matrículas y presencia de infantes, y una relación negativa con el valor del suelo, lo que indica menor acceso en áreas de alto costo. El análisis espacial detectó clústeres de sobreestimación y subestimación de la oferta educativa, en que destaca la necesidad de políticas focalizadas. El estudio propone ajustar la planificación urbana para garantizar un acceso equitativo a la educación preescolar, subrayándose la relevancia de enfoques espaciales en la evaluación de servicios públicos.

Palabras clave: desigualdad, Santiago, patrones, infancia

This study examines the distribution of preschool education provided in the Metropolitan Area of Santiago, evidencing inequalities in the relationship between the demand and educational infrastructure. Census data from 2017 and records from 2023 were used, applying a Geographically Weighted Regression (GWR) model to analyze local variations. Covariates include available slots, land value, and proportion of females, reflecting urban and socioeconomic dynamics. The results show a positive correlation between enrollment and the presence of infants, and a negative relationship with land value, indicating less access in high-cost areas. The spatial analysis detected clusters of overestimating and underestimating educational availability, highlighting the need for targeted policies. The study proposes adjusting urban planning to ensure equitable access to preschool education, highlighting the relevance of spatial approaches in evaluating public services.

Keywords: inequality, Santiago, patterns, childhood

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I. INTRODUCTION

Preschool education plays a crucial role in shaping individual and collective well-being. It is widely recognized as one of the most effective social investments to reduce structural inequalities from the earliest stages of development (Findlay, Findlay, & Stewart, 2009; Romanillos & García-Palomares, 2018). In Chile, the preschool education system provides services to children aged 0 to 5. Although its coverage has increased in the last two decades, important gaps in access and quality persist, especially in the peripheral urban sectors (Alaníz Hernández, 2021; Muñoz-Oyarce, 2021; Rivera Flores & Orozco-Martínez, 2022). Despite the state's drive to expand the options through public and subsidized modalities, the infrastructure for early childhood education continues to reproduce historical patterns of territorial segregation, particularly in the Metropolitan Area of Santiago, a city marked by a deeply unequal urban morphology (Catalan Catalan, 2024; Ramond, 2025).

This study examines the spatial distribution of the preschool education infrastructure in Santiago, investigating how its location responds—or does not—to the real demand of urban communities. A Geographically Weighted Regression (GWR) model was used, which allowed capturing the local variability in the relationship between the child population (0 to 5 years old) and the availability of spots in kindergartens and daycares. Variables such as land value, an indicator of real estate dynamics, and the proportion of women, as a proxy for family care responsibilities and structures, are incorporated to highlight structural factors that affect equity of access. The findings of this research approach contribute to the empirical evidence applied based on GWR from similar studies in Latin America (Alonso-Pastor, Olaya Acosta & Calmet, 2024; Sassera, 2022).

From a theoretical perspective, this work is anchored in socio-spatial approaches that understand education as a right and that articulate the theory of spatial justice with territorial accessibility models (Cabannes & Lipietz, 2018; Kofman & Lebas, 1996; Marcuse et al., 2009). The central hypothesis suggests that urban planning perpetuates conditions of inequality that affect skill development from an early age by not comprehensively integrating educational services for children. Thus, it advocates for a territorial configuration that places children at the heart of urban planning decisions.

II. THEORETICAL FRAMEWORK

Early childhood has been central to care policies in Chile, where various public policies have tried to ensure access to quality preschool education. Different challenges in this area, on which urban studies can provide convergent views towards empirical and relevant solutions, are still pending. One of the leading causes of concern is school absenteeism, with children missing 14% of school days on average (Arbour et al., 2023). This situation is often explained by urban-type difficulties, especially mobility and proximity. Socioeconomic status is relevant to achieving educational outcomes, which affects low-income children the most (Espinoza et al., 2020; Gelber et al., 2021; Moraga-Aros et al., 2022; Otero, Carranza & Contreras, 2017). This not only impacts school performance, but also health. For example, care in educational centers has been associated with a lower body mass index in early childhood (Allel, Narea & Undurraga, 2020), where accessibility is also a relevant factor from an urbanistic perspective (Perez-Silva et al., 2023). The distance to preschool facilities affects attendance, albeit less than the child's age (Dussaillant, 2016). This is supported in the international literature. Access to quality early education is associated with better academic performance and behavioral outcomes in kindergarten and daycares (Fantuzzo et al., 2005; Jimenez et al., 2016). Urban planning should consider the proximity to these establishments, as this impacts creating more affordable cities, significantly affecting housing prices and parents' decisions (Bergantino et al., 2022; Bucaite-Vilke, 2021; Vergara-Perucich, Aguirre-Nuñez & Marmolejo-Duarte, 2023). The optimal distribution of these facilities can significantly reduce travel costs and improve accessibility (Ullauri-Ugalde et al., 2024; Xu et al., 2020). Urban environments with libraries and child care centers positively influence early development, particularly in the socio-emotional and literacy domains (Prado-Galbarro et al., 2021). Designing cities that reduce disparities requires clearly identifying where they occur or gaps in territories (Kim & Wang, 2019; Zurayk, Tawil & Gangarosa., 1982).

This is a multifactorial problem that requires integrating factors that go beyond mere localization and that also focus on other variables to understand their complexity. Socioeconomic factors significantly influence the access and quality of early childhood education, with children from low-income families being less likely to enroll in high-quality programs (Cloney et al., 2016; Crosnoe et al., 2016). This disparity contributes to achievement gaps in language, literacy, and socio-emotional development (Bassok et al., 2016; Hartas, 2011; Tran, Luchters, & Fisher, 2017). Theoretical models that explain these disparities include the accommodation or ubiquity model (Crosnoe et al., 2016) and concerted cultivation (Cheadle, 2008). Parents' educational investments mediate socioeconomic and racial/ethnic disparities in children's academic achievement. To address these issues,

strategies such as promoting children's participation in decision-making related to their initial education, which affects their social mobility in the future, are generated (Correia et al., 2023, p. 202; Wu, Li & Miao, 2024). In this regard, Chile has a knowledge gap regarding the spatial distribution patterns of preschool educational spaces, which should be a structural part of the models for new neighborhoods and even integrated as critical infrastructures.

The theoretical framework is a reference point for the article, which is located at the intersection between socio-spatial theory and applied territorial analysis. It articulates the spatial justice approach with geographic modeling tools to assess inequalities in access to initial education. It is assumed that the location of preschool services in Santiago reproduces socio-spatial segregation dynamics, which disproportionately affects vulnerable groups. The hypothesis suggests a structural misalignment between child demand and institutional supply, influenced by urban factors such as land value and gender structure as a proxy for care. The geographically weighted regression allows testing this hypothesis, which reveals local patterns of educational inequality.

Case Study

The Metropolitan Area of Santiago (AMS, in Spanish) is a paradigmatic case of urbanization under the neoliberal paradigm. It is characterized by market-oriented planning, institutional fragmentation, and marked socio-spatial segregation. After the structural reforms promoted during the Pinochet dictatorship, a subsidiary state model was consolidated, in which city production was largely in the hands of the private sector, without a metropolitan authority that integrally coordinated urban planning (Garreton, 2017). This situation has resulted in a functionally polycentric, but territorially and socially segmented city, where access to public goods such as education, housing, and transport varies drastically depending on the income level and location of the inhabitants (Truffello & Hidalgo, 2015). Despite important public investments, such as the expansion of the Metro, urban benefits tend to be captured in the areas with the highest real estate valuation, exacerbating the territorial exclusion of working-class sectors (Vergara-Perucich & Aguirre-Nuñez, 2020). Peripheral growth, driven by demand subsidy policies, encourages urban dispersion, aggravating the housing deficit and infrastructural disconnection (Correa-Parra et al., 2023). In this context, studying the localization and accessibility of preschool educational infrastructures is key to understanding how the city reproduces inequalities from the earliest ages.

III. METHODOLOGY

Geographically weighted regression (GWR) is an effective tool for analyzing spatial relationships, especially in studies on accessibility and educational inequality. It captures local variations better than the ordinary least squares regression (OLS). Its application has demonstrated significant improvements in modeling access to public hospitals (Martinez Bascunan & Rojas Quezada, 2016), public beaches (Kim & Nicholls, 2016), and recreational resources (Kim & Graefe, 2020). In addition, GWR has been instrumental in examining spatial relationships between environmental, socioeconomic, and health indicators (Saib et al., 2014), investigating long-term limiting diseases and deprivation at the territorial level (Duarte-Cunha et al., 2016; Morrissey, 2015), as well as modeling spatial variations in housing prices (Lu et al., 2017). These diverse applications highlight GWR's strength in addressing spatial heterogeneity and dependence.

This study uses census data from 2017 and educational records from 2023 to analyze the spatial distribution of preschool education supply and demand in the Metropolitan Area of Santiago. The timeframe was chosen considering that a 0-year-old infant in 2017 would have completed the kindergarten cycle in 2023, providing a complete window of analysis. Although this criterion limits itself to possible demographic changes, the method can be replicated with future public data, facilitating long-term comparisons. The data used come from the 2017 Census (National Institute of Statistics [INE], 2017), while validated methodologies by Correa-Parra, Vergara-Perucich & Aguirre-Nuñez (2020); Correa Parra, Vergara Perucich & Aguirre Núñez (2022); Encinas et al. (2022); Ulloa-León et al. (2023), and from the open data portal of the Ministry of Education of Chile (MINEDUC, 2025), were followed. This method combines key variables to analyze spatial inequalities in preschool education using GWR, which captures local effects in each census area. The data sample includes enrollment and educational establishments of all types of dependency: municipal (26,547 enrollments), private (24,671 enrollments), subsidized private (126,378 enrollments), and local education services (4,148 enrollments). In this case, only establishments located in urban areas and in an active state of operation were used as of 2023, the cut-off date of the Preschool Education Registry 2011-2023 of the Studies Center of the Ministry of Education (MINEDUC, 2025).

As a dependent variable, GWR modeling uses the number of children aged 0 to 5 per census area, interpreted as the potential demand for preschool education. This variable was calculated from census data disaggregated by block and added to census tracts, with a minimum variation

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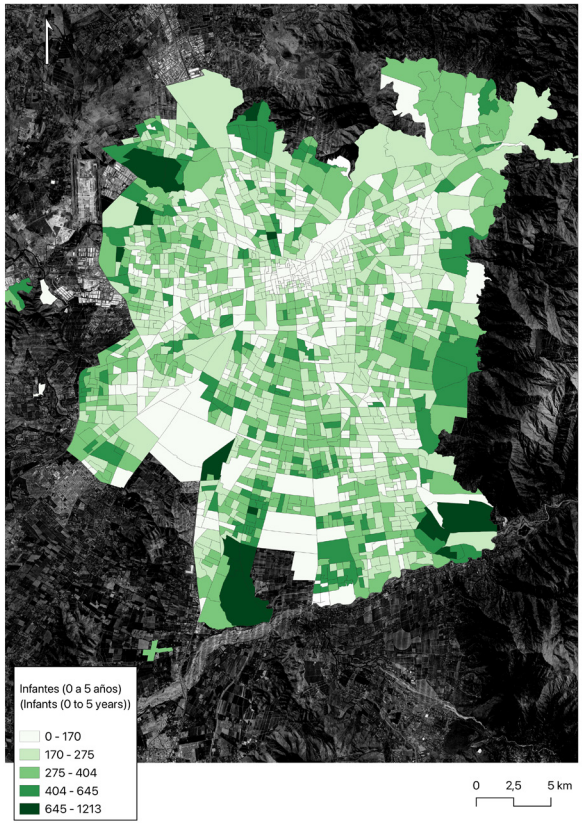

Figure 1. Children between 0 and 5 years of age by census areas in the Metropolitan Area of Santiago. Source: Preparation by the authors with data from the 2017 CENSUS (INE, 2017).

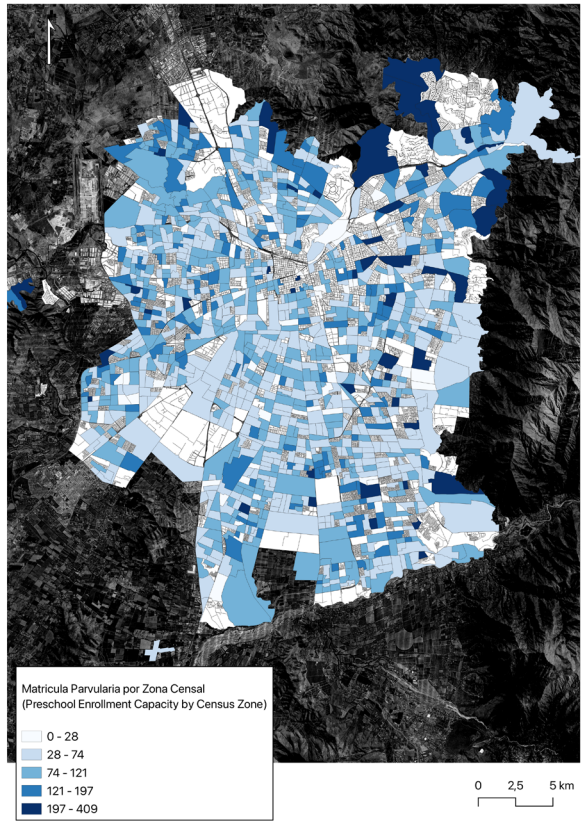

Figure 2. Preschool enrollments according to establishments by census areas. Source: Preparation by the authors with data from MINEDUC. (2025).

of 0.256%, validating the conversion. The covariates include available enrollments (educational offer), average land value (urban dynamics), and percentage of women (gender structure). A limitation of this study is that the estimation of the initial education available by census area is based on the geographical location of the establishments and does not consider the real routes of the families. This introduces a spatial bias associated with the ***Modifiable Areal Unit Problem*** [MAUP], particularly in bordering areas. The offer was treated as a structural proxy of the available facilities, without incorporating patterns of parental choice or daily commutes, which restricts the interpretative scope regarding the effective accessibility to these educational services.

One limitation of using census data is that it assumes that children should attend establishments close to their homes. However, including numerous establishments with part-time working hours reinforces the reasonableness of the residential approach.

Based on the model's residuals, a local spatial association analysis [LISA] identifies clusters of equity or inequity by categorizing the zones into High-High, Low-High, High-Low, and Low-Low patterns and offering a detailed view of spatial inequalities. The LISA analysis applied seeks to evaluate the presence of spatial autocorrelation in the model's errors. In other words, it makes it possible to detect whether the overestimations or underestimations are spatially concentrated, revealing a non-random structure of the residuals.

IV. RESULTS

The modeling is applied with four core variables: Child demand (dependent variable) measured in the number of children aged 0 to 5 by census area (INE, 2017); educational offer measured in effective enrollments in active kindergartens as of 2023, geo-referenced and added to the census area where each establishment is located; urban

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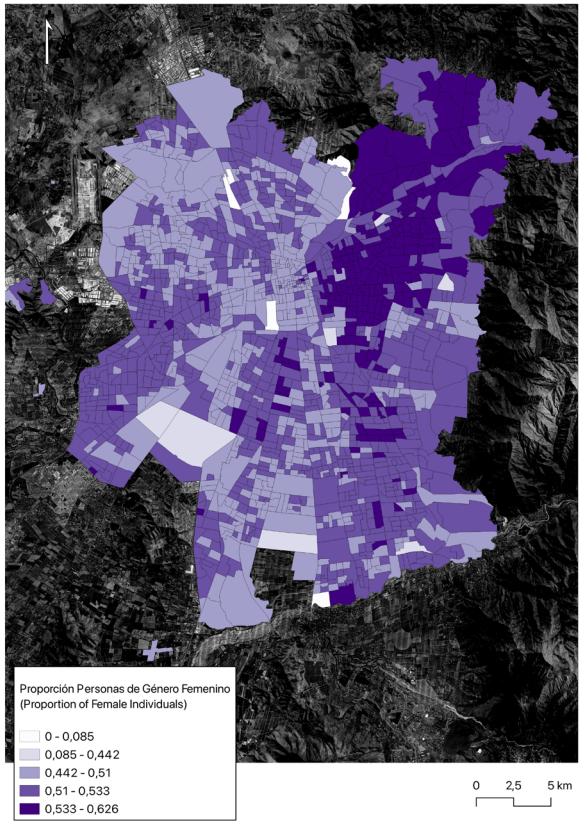

Figure 3. Distribution by census areas of people of the female gender. Source: Preparation by the authors with data from the 2017 CENSUS (INE, 2017).

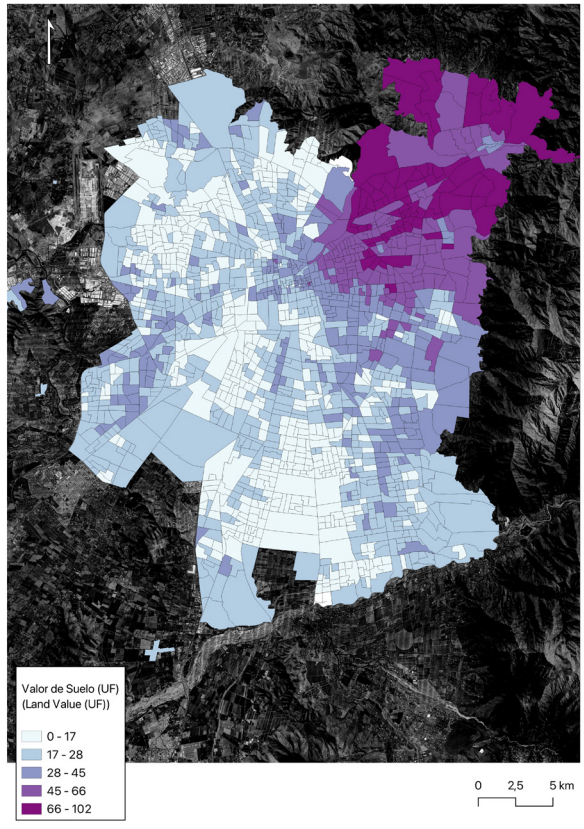

Figure 4. Average land value in UF by census tract. Source: Prepared by the authors with INE data (2025).

Residual sum of squares	1106.782
Log of verisimilitude	-1610.653
Akaike's Information Criterion	3229.306
Corrected Akaike Information Criterion	3231.359
R2	0.038
Adjusted R2	0.036

Table 1. Diagnostics of global regression fit. Source: Preparation by the authors.

Variable	Coefficient	SE	t(Est/SE)	p-value
Interception	0	0.029	0	1
Kindergarten and daycare enrollment by census area	0.109	0.029	3.711	0
Land Value in UF	-0.19	0.031	-6.077	0
Proportion of women by census area	0.026	0.031	0.853	0.394

Table 2. Global regression results. Source: Preparation by the authors.

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Residual sum of squares	601.968
Effective number of parameters (tract(S))	225.399
Degrees of freedom	925.601
Estimation of sigma	0.806
Log of verisimilitude	-1260.169
Degree of dependence	0.428
Akaike's Information Criterion	2973.136
Corrected Akaike Information Criterion	3084.619
Bayesian Information Criterion (BIC)	4116.083
R2	0.477
Adjusted R2	0.35
Adjusted Alpha (95%)	0.001
Adjusted critical t-value (95%)	3.333

Table 3. Diagnostics of the fit of the geographically weighted regression (GWR).Source: Preparation by the authors.

Variable	Mean Coefficient	STD	Min	Median	Max
Interception	-0.011	0.495	-1.353	-0.114	2.645
Kindergarten enrollment by census area	0,068	0.24	-0.554	0.06	2.101
Land value by census area in UF	-0,099	0.544	-1.811	-0.094	1.981
Proportion of women by census area	-0.077	0.518	-1.978	-0.054	2.423

Table 4. Synthetic results of the geographically weighted regression. Source: Preparation by the authors

condition, measured according to the average land value (UF/m^2) declared in fiscal cadasters; it is used as a proxy for real estate pressures and residential access barriers; and gender dimension measured by the proportion of women over the total population; it operates as a proxy for care structures and possible residence patterns of families with children. Figures 1 and 2 show clear north-south gradients: child demand is concentrated in south-west peripheral communes, while the educational offer appears denser in the intermediate ring. Figures 3 and 4 confirm the well-known axis of socio-economic segregation: high land values and low relative presence of women in the north-east, while the inverse pattern dominates the south-west.

Table 1 presents the global regression adjustment diagnostics, and Table 2 presents the estimated coefficients. This begins with a linear model where the variable to be predicted is the child population; three explanatory variables are contrasted (supply, land price, and proportion of women). The low R^2 (0.038) and the elevated Akaike (3231) indicate a limited explanatory capacity. However, two coefficients are statistically significant: (i) the educational offer ($\beta = 0.109$; $p < 0.001$) is positively associated with child demand: more enrolments coincide, on average, with a greater presence of children; and the land value ($\beta = -0.190$; $p < 0.001$) shows an adverse effect, which demonstrates that families with children are preferably located in areas with cheaper land. The proportion of women lacks global significance ($p = 0.394$). The contrast between the magnitude of the errors and their significance suggests that the relationship between child demand and facilities is heterogeneous. This premise justifies the introduction of geographically weighted regression to increase the accuracy and achieve greater explanatory capacity of the model.

Table 3 summarizes the GWR fit diagnostics, and Table 4 summarizes the statistics of the local coefficients. The model incorporates Kernel adaptive and Euclidean distance,

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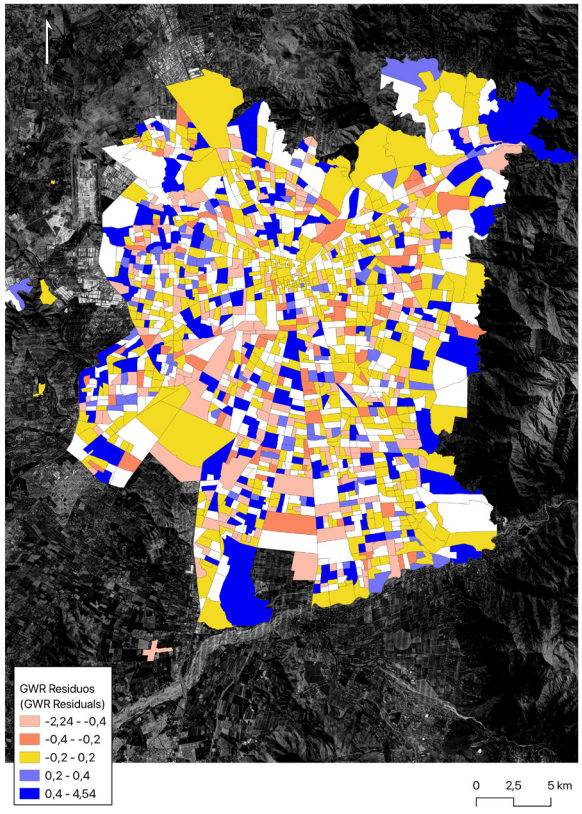

Figure 5. Residuals of the geographically weighted regression. Source: Preparation by the authors.

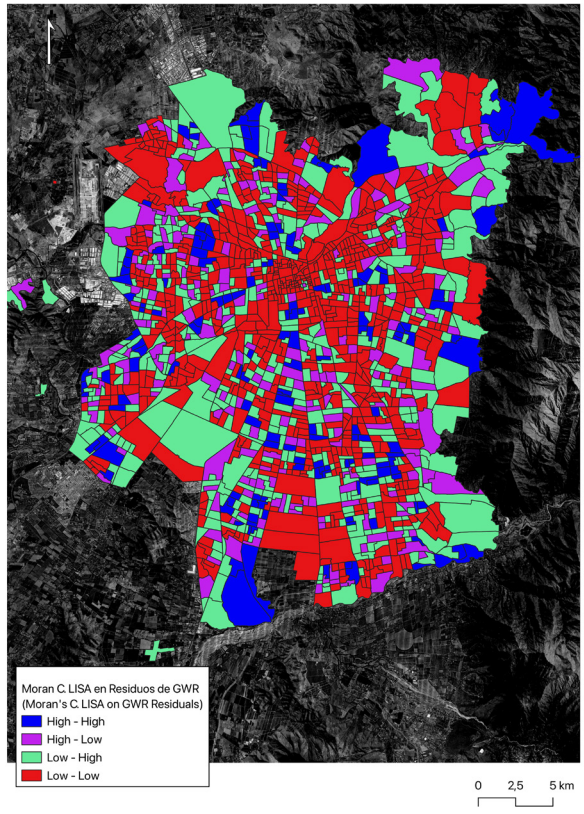

Figure 6. LISA by Moran with geographically weighted residuals. Source: Preparation by the authors.

optimized via AICc. The improvement is substantial: the R^2 rises to 0.477, and the sum of residual squares is reduced by almost half. The average coefficient for the variable "educational offer" is 0.068; however, its range is -0.554 to 2.101.

The average land value is -0.099, but the range (-1.811 to 1.981) shows sign inversions. Although the proportion of women is not significant globally, it acquires relevance locally.

Figure 5 shows the residuals of the geographically weighted regression (GWR) applied to the analysis of the distribution of children and educational offer in the study area. The colors represent different ranges of residuals, where yellow indicates residuals close to zero (between -0.2 and 0.2), suggesting a good fit of the model in those zones. The red and orange tones represent negative residuals, with values ranging from -0.2 to -2.24, indicating the areas where the model underestimated the observed value of the dependent variable. On the other hand, the blue areas, with residuals between 0.4 and 4.54, show areas where the model overestimated the observed values. The spatial distribution of these residuals reveals patterns that suggest local variations in the model's accuracy, possibly associated with factors not fully captured by the selected covariants. This spatial variability in the residuals highlights the importance of adjusting educational infrastructure distribution policies according to each area's local characteristics. To draw more irrefutable conclusions, a spatial autocorrelation analysis of the residuals is applied using a categorical Moran Index.

Figure 6 presents a local spatial association analysis [LISA] on the residuals of the geographically weighted regression [GWR] in the study area, using the Moran index to detect spatial autocorrelation clusters between nearby census tracts. The clusters in blue represent High-High areas, where the residuals are consistently high in neighboring areas. This pattern suggests a systematic overestimation in the model for these areas, possibly due to local factors that increase the discrepancy between educational supply and child

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demand. The clusters in red represent Low-Low areas, where residuals are consistently low in neighboring areas, indicating a homogeneous underestimation. This could reflect local characteristics where the educational offer is insufficient compared to the demand. On the other hand, the purple (High-Low) and green (Low-High) zones represent areas of spatial heterogeneity, where the residuals of one area contrast with its neighbors. In the High-Low areas (purple), the areas with high overestimation are surrounded by zones of underestimation. In contrast, the Low-High (green) areas present underestimation in areas surrounded by overestimation. These heterogeneous patterns reveal local variations that the GWR model fails to explain fully, suggesting the presence of additional or specific contextual factors to be considered.

V. DISCUSSION

The reviewed literature suggests that proximity to educational centers can influence children's attendance and academic and socio-emotional development, an argument supported by Dussaillant (2016) and Fantuzzo et al. (2005). However, the GWR model's results indicate that tuition fees are not evenly distributed, creating gaps in areas with high child demand and low service supply. This evidences patterns of territorial inequality similar to those described by Kim and Wang (2019). On the other hand, the land value shows a negative correlation with the presence of children, which suggests that areas of high real estate value are less accessible to families with small children. This finding aligns with Bergantino et al.'s (2022) and Bucaite-Vilke's (2021) studies. This exclusionary dynamic also highlights the need for public policies integrating access to critical infrastructure in areas of high real estate cost.

The Moran index allows a more nuanced understanding of spatial inequity in the distribution of educational services by overcoming traditional approaches that do not consider local specificities, as Kim and Nicholls (2016) point out in their application of GWR to assess access to public spaces. Operationally, this indicates a lack of preschool availability in the Metropolitan Area of Santiago.

The results suggest that disparities in the distribution of educational services linked to gender factors exist, an aspect less developed in urban literature. Although the proportion of women did not show a consistent pattern, their inclusion opens the discussion on how gender structures can influence educational planning and the spatial organization of urban services, which is relevant for future studies.

This modeling allows detecting some limitations that appear with the evidence. The first is that using urban variables such as facilities and land value to explain a demographic phenomenon implies an indirect relationship: families choose to reside where affordable prices and the availability of services converge. The model captures that structural nexus, but does not include specific family motivations or housing attributes. This could require a specific survey and qualitative analysis in sectors that this study finds interesting. Then, the educational offer was assigned to the census tract where each preschool facility is located. In bordering areas, this can explain some mismatches of the model in terms of seeking to increase its explanatory capacity. A structural proxy was considered, but daily mobility was not modeled. An analysis of isochrons or transport networks would improve the accessibility metric.

VI. CONCLUSIONS

This study shows that the supply of preschool education in the Metropolitan Area of Santiago has an unequal spatial distribution. Areas with a high concentration of children lack sufficient enrollment, while in neighborhoods with higher real estate values, the infrastructure exceeds the local demand. The application of a geographically weighted regression [GWR] revealed that the availability of places partly explains the location of early childhood. However, that land value acts as an economic barrier, moving young families to more accessible urban perimeters. In addition, the spatial variability of the coefficients and the autocorrelation of the residuals show omitted factors, such as housing typologies and mobility patterns, that influence actual access to preschool services.

The findings underline the need to integrate educational planning with housing and transportation policies, so that future interventions specifically identify points of insufficient supply, where demand is most critical. It is recommended that the model be enhanced by incorporating variables related to family life cycles and real accessibility based on travel times. Likewise, a mixed approach that includes interviews with families could clarify the motivations of choice and qualitative barriers.

VII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization.; Data curation, F.V.-P.; Formal analysis, F.V.-P.; Acquisition of financing, F.V.-P.; Research, F.V.-P.; Methodology, F.V.-P.; Project management, F.V.-P.; Resources, F.V.-P.; Software, F.V.-P.; Supervision, F.V.-P.; Validation, F.V.-P.; Visualization, F.V.-P.; Writing – original draft, F.V.-P.; Writing – revision and editing, F.V.-P.

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USING FUZZY INFERENCE SYSTEMS TO EVALUATE SIDEWALK QUALITY IN AHVAZ, IRAN[1]

USO DE SISTEMAS DE INFERENCIA DIFUSA PARA EVALUAR LA CALIDAD DE LAS VEREDAS EN AHVAZ, IRÁN

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Las veredas y los peatones son componentes vitales de la vida urbana y desempeñan un papel crucial para mantener la sustentabilidad y habitabilidad de las ciudades. Las veredas de alta calidad contribuyen a crear espacios urbanos más seguros y vibrantes. Dados los importantes beneficios sociales, económicos y culturales de caminar, los esfuerzos para mejorar las condiciones de las veredas han atraído una atención considerable en los últimos años. Este estudio busca evaluar el estado y la calidad de las veredas urbanas en Ahvaz, una ciudad en el suroeste de Irán. La evaluación se basa en datos recopilados a través de cuestionarios completados por expertos en geografía y planificación urbana. Se empleó un sistema de inferencia difusa implementado en el software MATLAB para identificar las reglas subyacentes a la evaluación de la calidad de las veredas. Posteriormente, los datos del cuestionario se analizaron mediante métodos de Entropy, WASPAS e interpolación IDW. El análisis resultó en la identificación de 18 reglas distintas para evaluar la calidad de las veredas. Los hallazgos indican que las veredas en la región tres exhiben la más alta calidad, mientras que las de la región siete ocupan el lugar más bajo. En general, el estudio revela que la mayoría de las veredas en Ahvaz son de muy mala calidad, y problemas como pendientes inadecuadas son factores contribuyentes importantes.

Palabras clave: sistemas de inferencia difusa, MATLAB, calidad de veredas, peatones, Ahvaz

Sidewalks and pedestrians are vital components of urban life, playing a crucial role in sustaining the sustainability and livability of cities. High-quality sidewalks contribute to creating safer and more vibrant urban spaces. Given the significant social, economic, and cultural benefits of walking, efforts to improve sidewalk conditions have attracted considerable attention in recent years. This study seeks to evaluate the condition and quality of urban sidewalks in Ahvaz, a city in southwestern Iran. The assessment is based on data collected through questionnaires completed by geography and urban planning experts. A fuzzy inference system implemented in MATLAB software was employed to identify the rules underlying the evaluation of sidewalk quality. Subsequently, the questionnaire data were analyzed using Entropy, WASPAS, and IDW interpolation methods. The analysis resulted in the identification of 18 distinct rules for assessing sidewalk quality. The findings indicate that sidewalks in Region Three exhibit the highest quality, while those in Region Seven rank the lowest. Overall, the study reveals that most sidewalks in Ahvaz are of very poor quality, with issues such as unsuitable slopes being significant contributing factors.

Keywords: fuzzy Inference Systems, MATLAB, Sidewalk Quality, Pedestrians, Ahvaz

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I. INTRODUCTION

Historically, cities were highly pedestrian-friendly, with walking as the primary mode of transportation due to its universal accessibility and affordability. However, a significant modern challenge in urban development is the increasing dependence on motor vehicles, accompanied by the neglect of pedestrian infrastructure and walkways. This shift has been identified as a significant factor in the degradation of urban quality and the erosion of social, cultural, and aesthetic values in public spaces, particularly following the industrial revolution and the advent of car-oriented urban design (Moradpour et al., 2018, p. 212).

Walking remains an economical, healthy, and sustainable mode of transport, profoundly impacting urban life. As the most prevalent form of recreational physical activity, walking improves public health, fosters social connections, and generates significant socioeconomic advantages (Stefanidis & Bartzokas-Tsiompras, 2024, p. 1). Cities that prioritize pedestrianization not only encourage daily physical activity but also reduce public health costs associated with sedentary lifestyles, obesity, and respiratory illnesses (Yussif et al., 2024, p. 1; Zapata-Diomedi et al., 2019; Rundle & Heymsfield, 2016). Walkable neighborhoods are associated with lower obesity prevalence (Kowaleski-Jones et al., 2018, p. 14). Furthermore, pedestrian-friendly urban environments promote mental well-being and environmental sustainability by offering alternatives to car-based commuting (Yussif et al., 2024, p. 1). Many vibrant qualities associated with urban life, such as dynamic street activity, cultural diversity, and opportunities for unexpected interactions, are rooted in high-quality, walkable urban design (Norton, 2011).

With the rise of private cars in the 20th century, cities worldwide began reallocating public urban spaces to accommodate vehicles. This car-centric development has led to widespread "car dependency," contributing to problems such as traffic congestion, fatalities from car accidents, and environmental pollution from noise and emissions (Rhoads et al., 2023, p. 1).

Modern urban design increasingly emphasizes human-centered transportation systems that prioritize public transit, bike lanes, and extensive sidewalk networks over vehicle-oriented infrastructure (Lin et al., 2021, p. 1). In this context, sidewalks should be recognized as foundational elements of urban planning, given their influence on the quality of life, mobility, air quality, and urban design (Da Rocha et al., 2019, p. 42). Beyond facilitating movement, sidewalks serve as spaces for planned and spontaneous social interactions, as well as venues for cultural and commercial activities, including art, music, and business ventures. This multifunctionality highlights their significance in contemporary urban life (Motahari Tabar & Hosseininia, 2022, p. 71).

As vital public spaces, sidewalks foster social connections by shaping the landscapes where meaningful interactions occur. Recognizing the needs of modern society and the intrinsic values of these spaces has driven efforts to design sidewalks that are not only functional but also foster a sense of place and belonging (Ghadami, 2019, p. 950). Sidewalks are purposefully designed for pedestrians and are typically situated alongside streets. Unlike streets or roads, sidewalks are user-centric, designed exclusively to improve pedestrian experiences. They provide safe, accessible pathways while humanizing the streetscape (Li et al., 2024, p. 961). Additionally, sidewalks act as socio-cultural spaces, allowing informal interactions that contribute to preserving cultural identity (Janpathompong & Murakami, 2021, p. 4). High-quality sidewalks encourage pedestrians to walk more, enhancing mobility and sociability (Rachmanto, 2021, p. 6).

As the administrative center of Khuzestan Province and a key industrial hub in southern Iran, Ahvaz experiences high pedestrian density, particularly in its downtown and commercial districts during peak hours. This consistent activity underscores the critical need to assess the quality of the city's sidewalks to support effective urban planning. The present study aims to evaluate the condition and quality of sidewalks in Ahvaz.

II. LITERATURE REVIEW

Zarghami et al. (2015), in their study ***Investigating the Relationship between Urban Pedestrian Pathway Design and Psychological Sense of Security (Case Study: Tehran),*** explored the connection between pedestrians' sense of security and their use of sidewalks.

The results of this study indicated differences between individuals over 40 and under 40 in terms of the extent and reasons for using or not using urban sidewalks. Using a mixed-methods approach, the study revealed that individuals over 40 were more inclined to take short walks than those under 40, who favored vehicles. This disparity underscores a notable behavioral divergence between the two age groups. For both groups, the aesthetic appeal of sidewalks was a key priority. However, older individuals prioritized addressing uneven surfaces, while younger participants expressed greater concern for sidewalk width.

Ekra Sardashti & Sajadzadeh (2021), in their work ***Measuring and Evaluating the Quality of Urban Walkways from the Perspective of the Creative Urban Space: Case Study of Central Urban Walkways in Rasht City of Iran***, assessed the quality of urban sidewalks in Rasht through the lens of creative urban spaces. The study developed a conceptual model of creative urban space and evaluated specific indicators and criteria within this framework. Their findings highlighted that integrating creative city indicators into urban spaces significantly increases citizen satisfaction. Achieving sidewalks that reflect the principles of a creative city necessitates prioritizing the development of these indicators.

Da Rocha et al. (2019), in their article ***Quality of Sidewalks in a Brazilian City: A Broad Vision***, analyzed the quality of sidewalks in a medium-sized Brazilian city by combining pedestrian perceptions with technical evaluations. Their findings revealed that sidewalks in Passo Fundo, similar to those in many Brazilian cities, scored poorly on the Sidewalk Quality Index (SQI). The study emphasized that a high SQI can improve urban mobility and quality of life while positively impacting various urban indicators.

Lee et al. (2009), in their study ***Design Criteria for an Urban Sidewalk Landscape Considering Emotional Perception***, investigated preferences for sidewalk design using affective engineering principles. By modeling the relationships between design elements and their proportions in sidewalk landscapes, the study proposed criteria for designing comfortable and aesthetically pleasing sidewalks. Their results underscored the importance of affective engineering in creating emotionally engaging and visually appealing sidewalk environments.

III. THEORETICAL REVIEW

Roads are a fundamental component of urban outdoor spaces. They serve not only as transportation corridors but also as venues for social interactions and commercial activities. However, with the widespread adoption of personal vehicles and the expansion of urban areas, road design has become increasingly vehicle-centric. Wider lanes and denser road networks have improved traffic flow and efficiency, but this shift has also degraded the quality of urban outdoor environments. Consequently, once vibrant spaces for social and commercial engagement, sidewalks have become constrained by challenges such as air pollution, noise, and thermal stress (Lin et al., 2021, p. 1). Streets are the most extensive public spaces in cities, and sidewalks, as the most frequented areas by pedestrians, play a crucial role in shaping their psychological perceptions (Li et al., 2024, p. 961).

Classic urban theorists such as Jan Gehl and Jane Jacobs have underscored the importance of social, psychological, cultural, and environmental elements in designing walkable spaces. Gehl advocated for cities designed with people, rather than cars, in mind. He emphasized that vibrant urban life relies on fostering meaningful social interactions, creating a sense of safety, and offering an aesthetically pleasing experience through architecture, greenery, and art. Gehl believed that the potential for a lively city is strengthened when more people are invited to walk, bike, and stay in the city's public spaces (Gehl, 2010, p. 6). Jacobs, on the other hand, highlighted the vitality of streets bustling with diverse groups of people throughout the day. Her concept of "eyes on the street" emphasized that active street life naturally increases safety. Jacobs also stressed the significance of mixed land uses, which bring energy and unpredictability to streets, enriching cultural and social interactions while encouraging more pedestrian activity. She contended that sidewalks must sustain consistent foot traffic to not only multiply surveillance but also prompt residents in adjacent buildings to observe street life. As Jacobs (1989, p. 54) noted, "Large numbers of people entertain themselves, off and on, by watching street activity."

In addition to these theoretical contributions, a growing body of research over the past few decades has emphasized the importance of designing pedestrian-friendly streets (Forsyth et al., 2009). The quality of pedestrian networks is increasingly recognized as essential for sustainable urban development and mobility (Forsyth et al., 2009). This involves addressing both tangible and intangible factors, including the physical and built environment (e.g., sidewalk and street widths, tree canopies, population density, building heights, and traffic volumes), urban design attributes (e.g., imageability, legibility, human scale, enclosure, transparency, linkage, and coherence), and human responses (e.g., fear of crime, comfort, and engagement). These factors collectively shape the appeal and functionality of pedestrian spaces but are often overlooked in urban planning and pedestrian accessibility strategies (Stefanidis & Bartzokas-Tsiompras, 2024, p. 1).

Sidewalks are integral elements of streets and serve as dynamic spaces for diverse activities. From a planning perspective, well-designed and integrated sidewalks reflect the city's image. Engaging and thoughtfully planned sidewalks contribute to the perception of a

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well-organized city, while poorly designed sidewalks can project an image of disarray (Abdallah, 2020, p. 49).

Deficiencies in sidewalks and restrictions on pedestrian mobility often stem from shortcomings in planning, design, construction, and maintenance (Jia et al., 2022, p. 3). In developing countries, it is common to encounter issues such as poorly designed intersections, missing sidewalk segments, inadequate crossings, limited accessibility for vulnerable users, and deliberate barriers on major roads. Maintenance challenges are also prevalent, with sidewalks frequently overgrown with vegetation, obstructed by debris, or encroached upon by street vendors, parked vehicles, and loading activities. These issues often force pedestrians to engage in risky behaviors, such as walking in traffic lanes or crossing streets at unsafe locations. While road safety initiatives tend to focus on roads and intersections, sidewalk conditions and walkability assessments are often neglected (Jia et al., 2022, p. 3). Similarly, sidewalk maintenance has not received sufficient attention in urban planning and policy discussions, despite its critical role in securing pedestrian safety and comfort (Khalak et al., 2024, p. 455). Pedestrian-oriented design contributes significantly to revitalizing urban centers by creating collective spaces that foster social interactions and solidarity among citizens. Pedestrian areas, as defined by Ghadami (2019, p. 950), are urban spaces where pedestrian movement is prioritized, often by restricting or completely excluding vehicular traffic during specific hours.

Sidewalks are expected to provide six essential benefits for pedestrians: (1) strong connectivity within the path network, (2) integration with public transportation, (3) appealing aesthetics, (4) sufficient safety, (5) fine-grained land use, and (6) high-quality pedestrian paths (Yencha, 2019, p. 690). These factors are evaluated through two primary categories: neighborhood-level (macroscale) and sidewalk-level (microscale) features. Neighborhood-level features include environmental elements such as land-use diversity, aesthetics, dwelling and intersection density, and street connectivity. In contrast, sidewalk-level features focus on infrastructure-specific characteristics, including surface conditions, width, furniture, and curbs. These microscale features directly impact pedestrian comfort and satisfaction. However, continuous use and adverse environmental conditions often deteriorate infrastructure, making timely maintenance crucial for optimal functionality (Yussif et al., 2024; p. 2).

The "Five Cs" approach is a comprehensive framework for improving streets and sidewalks by prioritizing walkability and accommodating diverse activities. This approach emphasizes meeting pedestrians' needs, both for formal and informal activities, and outlines five critical principles for enhancing the walking experience:

- Connected: Establishing a complete network of routes and sidewalks, both at a macroscale (street connectivity) and microscale (physically or visually linked sidewalks).
- Convivial: Structuring sidewalks to facilitate social interactions by meeting users' needs in an organized and inclusive way, creating safer, more pleasant, and comfortable spaces.
- Conspicuous: Providing clear signage for streets, shops, and sidewalk activities to facilitate accessible, smooth, and enjoyable walking experiences.
- Comfortable: Incorporating amenities like seating, shading devices, and regular pavement maintenance to increase comfort.
- Convenient: Designing sidewalks and streets to be efficient, cost-effective, and user-friendly, catering to pedestrians' functional and aesthetic needs.

By applying these principles, sidewalks can support a diverse range of activities while protecting pedestrian safety and comfort. Achieving this requires aligning activity patterns with these principles and understanding the relationship between usage patterns and walkability (Abdallah, 2020, p. 59).

The focus on improving sidewalks is not new, but has evolved significantly in recent decades. Jane Jacobs, in her influential work since the 1960s, introduced the concept of "eyes on the street," emphasizing the role of diverse street users in providing natural surveillance and enhancing safety. Jacobs (1989, p. 56) articulated this concept with particular insight regarding sidewalk security, noting the necessity for "an almost unconscious assumption of general street support when the chips are down" among those providing this surveillance. She succinctly encapsulated this phenomenon as "trust" - a social construct that emerges gradually through countless minor interactions in public sidewalk spaces. This concept highlights how homemakers, shopkeepers, pedestrians, street vendors, and office workers collectively create a sense of security for all users. Subsequent theories by urban designers and architects have underscored the benefits of walking and sidewalk use, including reduced reliance on motor vehicles, lower transport emissions, and improved public health (Mozingo, 1989; Smith & dos Santos, 2019). Increased pedestrian activity also leads to safer streets, greater urban vibrancy, and improved social cohesion.

Index	Indicator	Index	Indicator	Index	Indicator
I1	Safety	I6	Vitality	I11	Maintenance
I2	Security	I7	Flooring	I12	Cleanliness
I3	Lighting	I8	Accessibility	I13	Proper slope
I4	Green space	I9	Cohesiveness	I14	Proper width
I5	Mobility	I10	Social interaction	I15	Suitable for all groups of life

Table 1. Sidewalk Quality Indicators. Source: Preparation by the Authors.

The importance of sidewalks has gained renewed attention in urban design, particularly in the post-pandemic era. Many cities have developed guidelines and principles to improve sidewalk livability and sustainability, focusing on factors such as universal accessibility, safe connections, signage, aesthetics, security, quality surfaces, and proper drainage. Sidewalks must extend their functions beyond providing circulation spaces to fostering direct contact between citizens and their social environments.

Accordingly, five basic criteria have been identified for effective sidewalk design:

a. Accessibility: Guaranteeing all individuals, including those with mobility challenges, can use sidewalks safely and independently. This includes providing comfort, shelter, and protection while adhering to principles of broad access and ease of movement.
b. Maintenance: Addressing the physical condition of pavement, covering materials, and floor adhesion to guarantee pedestrian comfort and safety.
c. Connectivity: Establishing continuous routes free from obstacles, with level crossings, appropriate signage, and accessibility features that accommodate diverse needs.
d. Security: Improving both real and perceived safety through adequate lighting, the presence of other pedestrians, and urban infrastructure designed to minimize risks.
e. Ambience: Integrating landscaping elements and design features that enhance sidewalks' usability and visual appeal (Almeida et al., 2024, p. 729).

A well-connected sidewalk network is essential for promoting pedestrian mobility, improving accessibility, and fostering sustainable, pedestrian-friendly urban environments (Quijada-Alarcón et al., 2024; p. 2).

IV. MATERIALS AND METHODS

This research employed a descriptive-analytical and applied approach regarding content and methodology. Data and information were collected using a documentary field survey method. Indicators for assessing urban sidewalk quality were derived from a comprehensive review of the theoretical literature (Table 1).

The statistical population consisted of geography and urban planning experts. A sample of 10 experts participated in a questionnaire-based survey to evaluate the quality of sidewalks in various regions of Ahvaz. Their responses formed the foundation for the research analysis.

To analyze the data, several methodologies were employed:

- The fuzzy inference system in MATLAB software was used to establish the rules for measuring sidewalk quality.
- The Entropy method was applied to weigh the indicators.
- The WASPAS model was employed to rank the regions of Ahvaz based on sidewalk quality.
- The Inverse Distance Weighting (IDW) interpolation method was employed to visualize the condition of sidewalks in Ahvaz.

Research study area

Ahvaz is one of the largest cities in Iran and serves as the country's primary financial hub (Pakbaz et al., 2013, p. 109). It is the capital city of Khuzestan province and is strategically located along the Karun River, one of the country's major rivers. Situated in an oil-rich province bordering Iraq and Kuwait, Ahvaz holds a significant geopolitical position (Alizadeh & Sharifi, 2020, p. 7). The city is surrounded by

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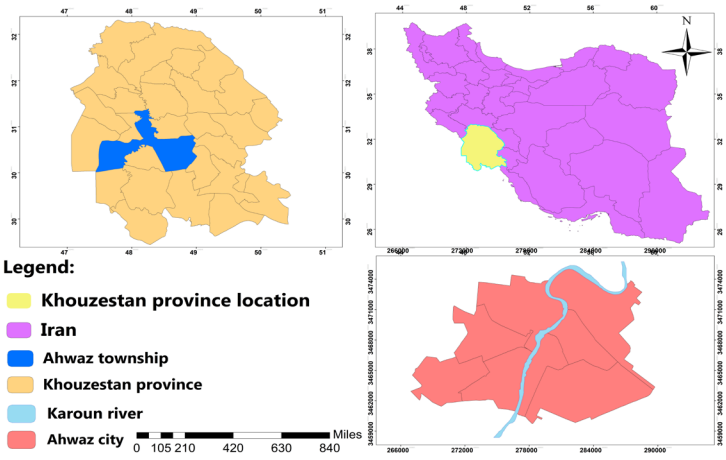

Figure 1. Study area. Source: Preparation by the Authors.

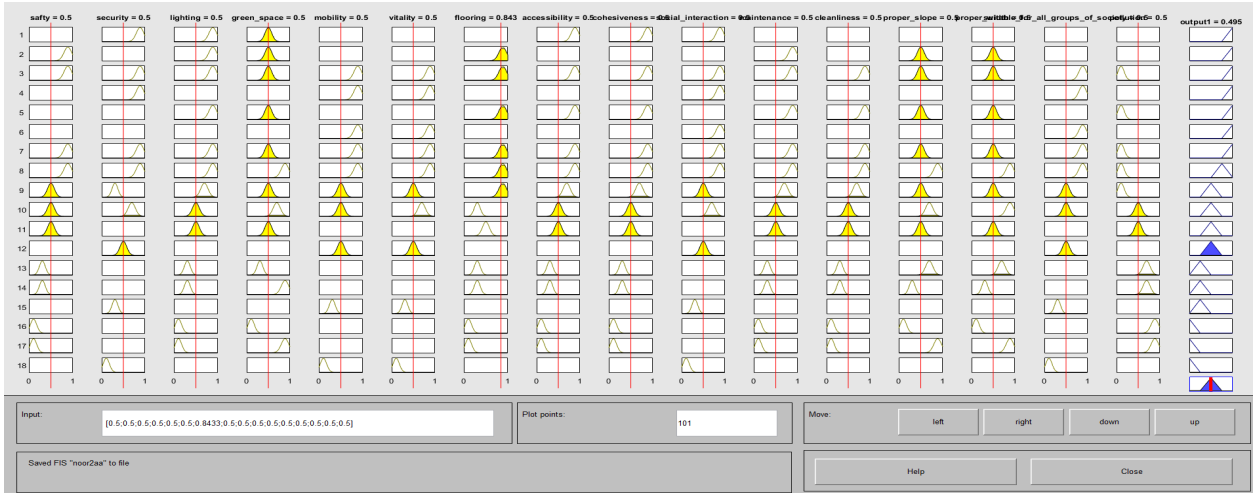

Figure 2. Fuzzy inference system output rules. Source: Preparation by the Authors.

Sheiban, Veis, Mollasani, Shooshtar, Dezful, and Shoosh to the north, Ramhormoz to the east, Hamidieh to the west, and Shadegan, Mahshahr, Khoramshahr, and Abadan to the south.

Ahvaz is divided into eight urban regions, each consisting of three or four districts (Safaeepour et al., 2017, p. 6). The geographical coordinates of Ahvaz are 31°20′N and 48°40′E (Figure 1), with an elevation of 18 meters above sea level. The city's industrial sector, including numerous large industrial plants, has made Ahvaz one of Iran's key industrial centers, attracting many immigrants to the area (Alavi et al., 2015, p. 299). Covering an area of approximately 220 km^2, Ahvaz has a population of nearly 1.2 million people.

V. ANALYSIS OF FINDINGS

Initially, the fuzzy inference system model was implemented, and 18 rules were extracted to measure the quality of urban sidewalks based on the research indicators. The rules are as follows (Figure 2):

- Rule 1: If security, lighting, accessibility, cohesiveness, and social interaction are very high, and green space is average, then the quality of sidewalks will be very high.
- Rule 2: If safety, lighting, flooring quality, and social interaction are very high, and green space, proper

width, and proper slope are average, then the quality of sidewalks will be very high.

- Rule 3: If safety, security, lighting, mobility, vitality, suitable flooring, accessibility, cohesiveness, and social interaction are very high, and green space, proper width, and proper slope are average, then the quality of sidewalks will be very high.
- Rule 4: If security, lighting, mobility, vitality, social interaction, and suitability for all groups of society are very high, then the quality of sidewalks will be very high.
- Rule 5: If lighting, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are very high, and green space is average, then the quality of sidewalks will be very high.
- Rule 6: If mobility, vitality, social interaction, and suitability for all sections of society are very high, then the quality of sidewalks will be very high.
- Rule 7: If safety, security, lighting, mobility, vitality, appropriate flooring, accessibility, cohesiveness, social interaction, maintenance, cleanliness, and suitability for all sections of society are very high, and green space, proper slope, and proper width are average, then the quality of sidewalks will be very high.
- Rule 8: If safety, security, lighting, mobility, vitality, suitable flooring, accessibility, cohesiveness, social interaction, maintenance, cleanliness, and suitability for all sections of society are very high, and green space, and proper width and slope are high, then the quality of sidewalks will be relatively high.
- Rule 9: If lighting, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are very high, and safety, green space, mobility, vitality, social interaction, proper slope, proper width, and suitability for all sections of society are average, and security is low, then the quality of sidewalks will be average.
- Rule 10: If safety, mobility, accessibility, cohesiveness, maintenance, cleanliness, and suitability for various groups of society are high, and security, green space, vitality, social interaction, proper slope, and proper width are high, and the quality of flooring is low, then the quality of sidewalks will be average.
- Rule 11: If safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, cleanliness, proper slope, and proper width are average, then the quality of sidewalks will be almost average.
- Rule 12: If security, mobility, vitality, social interaction, and suitability for all groups of society are average, then the quality of sidewalks will be almost average.
- Rule 13: If proper slope and width are high, and safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are low, then the quality of sidewalks will be low.

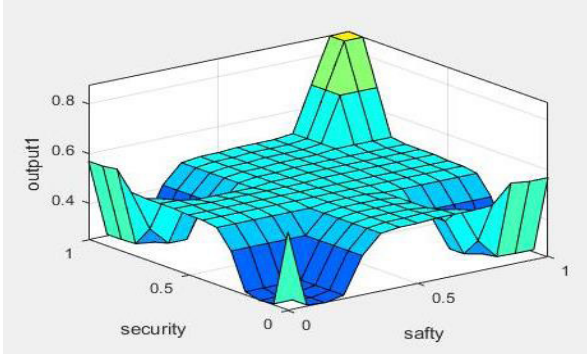

Figure 3. Output diagram of the rules of the fuzzy inference system. Source: Preparation by the Authors.

- Rule 14: If green space is too high, and safety, lighting, suitable flooring, accessibility, cohesiveness, maintenance, cleanliness, proper slope, and proper width are low, then the quality of sidewalks will be low.
- Rule 15: If green space is too high, and security, mobility, vitality, appropriate flooring, social interaction, and suitability for all groups of society are low, then the quality of sidewalks will be low.
- Rule 16: If safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, cleanliness, proper slope, and proper width are too low, then the quality of sidewalks will be too low.
- Rule 17: If green space, proper slope, and proper width are too high, and safety, lighting, green space, suitable flooring, accessibility, cohesiveness, maintenance, and cleanliness are too low, then the quality of sidewalks will be too low.
- Rule 18: If safety, mobility, vitality, social interaction, and suitability for all groups of society are too low, then the quality of sidewalks will be too low.

Eventually, the following figure illustrates the output diagram generated by the fuzzy inference system, showing the rules' results. (Figure 3)

Subsequently, the condition of urban sidewalks in various regions of Ahvaz was assessed. A questionnaire was distributed to experts, who provided their evaluations of sidewalk quality based on the city's zoning. The average of their responses was then calculated and analyzed. Shannon's Entropy Model was applied to determine the weight of the indicators. The results of this model, showing the weights assigned to each indicator, are presented in Table 2 below for further analysis in the subsequent stages.

index	Safety	Security	Lighting	Green space	Mobility
w	0.0666	0.0668	0.0673	0.0665	0.0670
index	Vitality	Flooring	Accessibility	Cohesiveness	Social interaction
w	0.0669	0.0664	0.0671	0.0665	0.0673
index	Maintenance	Cleanliness	Proper slope	Proper width	Suitable for all groups of life
w	0.0655	0.0665	0.0662	0.0664	0.0671

Table 2. Weights of Indexes. Source: Preparation by the Authors.

Then, the results of the experts' questionnaire, along with the weights of the indicators obtained in the previous step, were entered into Excel software to determine the regions' ranking according to the quality of the sidewalks using the WASPAS model. A numerical value was obtained for each region, and its corresponding rank was determined, as shown in Table 3.

This table illustrates the regions' ranking, with Region Three having the highest sidewalk quality score (0.929) and Region 7 having the lowest (0.454).

The outcomes of the previous steps were entered into the GIS software to illustrate the current situation clearly. Using the IDW interpolation model, the general outline of sidewalk quality across the regions was depicted (Figure 4).

By analyzing the results of the WASPAS and IDW models, it was found that Region Three has the highest quality of urban sidewalks compared to other regions (Figure 5). The sidewalks in this area stand out for their superior safety levels. Security is consistently high across most sidewalks in the region. Additionally, Region Three boasts ample green space, well-maintained flooring, appropriate slope, and a high degree of cohesiveness. Regular maintenance guarantees the sidewalks are well-kept. These factors make the sidewalks in this region accessible to diverse social groups and promote social interactions. However, accessibility remains a challenge in some neighborhoods within the region.

Región	Q2	Rank
1	0,608	4
2	0,820	2
3	0,929	1
4	0,738	3
5	0,575	5
6	0,460	7
7	0,454	8
8	0,558	6

Table 3. Rankings of regions based on sidewalk quality. Source: Preparation by the Authors.

Region Two ranks second (Figure 6). The vitality and mobility of the sidewalks here are higher than those in other regions. Safety is also a strong feature in most areas, with well-maintained sidewalks that cater to a wide range of users. These elements together boost social interaction. However, security is a notable concern, as certain sidewalks in this region suffer from lower security levels.

Region Four ranks third (Figure 7). The sidewalks in this region are particularly distinguished by their high accessibility, which is the best in the city. Additionally, most sidewalks here have optimal width. Social interaction is prevalent along many of these sidewalks, and mobility and safety levels are relatively high. However, there are two significant issues: the severe lack of lighting and the pressing need for improved green spaces. Moreover, maintenance is inadequate in some parts of the region, further affecting sidewalk quality.

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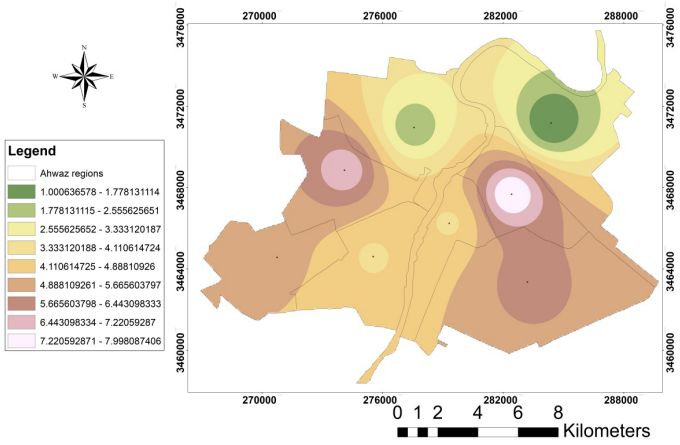

Figure 4: Sidewalk quality IDW. Source: Preparation by the Authors.

Figure 5: Sidewalk in Region Three. Source: Photo taken by the Authors.

Figure 6: Sidewalk in Region Two. Source: Photo taken by the Authors.

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Region One ranks next in the overall ranking (Figure 8). The sidewalks exhibit exceptionally high mobility and vitality, significantly improving social interactions. These sidewalks are generally suitable for use by diverse social groups. However, they lack proper slope and width, and the flooring is often inadequate. Insufficient lighting is another issue in this region. There is a pressing need for increased green space and more frequent maintenance to improve the quality of the sidewalks.

Region Five is ranked fifth (Figure 9). The sidewalks in this region score poorly across several indicators. While some sidewalks have nearly adequate width, the overall quality remains low. Social interaction is relatively high in certain areas, but security is a significant concern, as most sidewalks in this region have very low security. The flooring is frequently unsuitable, and maintenance is irregular.

Figure 7: Sidewalk in Region Four. Source: Photo taken by the Authors

Figure 8: Sidewalk in Region One. Source: Photo taken by the Authors

Furthermore, the sidewalks suffer from poor lighting and a lack of green space. Vitality and accessibility are low, and many areas are plagued by improper slope and weak cohesiveness.

Region Eight follows closely behind (Figure 10). While certain sidewalks in this region demonstrate high social interaction, overall, the quality is low. Cleanliness is only moderately acceptable, and cohesiveness is lacking. Accessibility is low, and the sidewalks do not cater well to the needs of different social groups, which limits social interaction. As a result, vitality and mobility are also low. Many of the sidewalks here are hindered by improper width, slope, lighting, and insufficient green space. Safety and security are significant concerns, and maintenance is insufficient.

Region Six is next in the ranking (Figure 11). The sidewalks here perform well only in terms of social interaction, which slightly boosts the area's vitality. However, they are lacking in many other key indicators. The sidewalks are too narrow and have improper slopes, leading to poor accessibility. Safety and security are minimal, and green space is extremely limited. Cleanliness and maintenance are largely neglected, making the sidewalks unsuitable for the community.

Region Seven is ranked lowest (Figure 12). The sidewalks here perform poorly in all the indicators studied. They are notably lacking in safety, with issues such as unsuitable slopes, insufficient width, and inadequate green space being particularly problematic. Lighting and flooring are also substandard. Security is low across the region, making

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Figure 9: Sidewalk in Region Five. Source: Photo taken by the Authors

Figure 10: Sidewalk in Region Eight. Source: Photo taken by the Authors

Figure 11: Sidewalk in Region Six. Source: Photo taken by the Authors

Figure 12: Sidewalk in Region Seven. Source: Photo taken by the Authors

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the sidewalks unsuitable for a wide range of users. The vitality and mobility of these sidewalks are consistently low, and maintenance and cleanliness are neglected, further diminishing their quality.

VI. CONCLUSION

Sidewalks are undeniably one of the most critical components of urban infrastructure. They not only facilitate pedestrian movement but also contribute significantly to the vitality of public spaces, symbolizing a city's identity, civility, and quality of life. Although the importance of improving sidewalks is not new, it has gained heightened attention in recent decades, particularly in the wake of the COVID-19 pandemic. The post-pandemic period witnessed heightened attention to urban infrastructure modifications, particularly the widening of walkways and pedestrian paths to improve pedestrian safety and comfort. Furthermore, the increased preference for sidewalk usage over public transportation, driven by their open-air nature and reduced interpersonal contact, has significantly amplified the focus on improving pedestrian infrastructure quality during this era.

This shift has led many cities to adopt guidelines and principles to create more livable and sustainable pedestrian areas, fostering vibrant and active urban spaces.

In Ahvaz, particularly within its administrative and commercial centers, high population densities during peak hours underscore the need for comprehensive research to evaluate and improve sidewalk quality. This study sought to assess the condition of sidewalks across the city's regions using a combination of documentary and field survey methods. Data were gathered through a structured questionnaire distributed to geography and urban planning experts, providing the basis for measuring sidewalk quality.

The study employed a fuzzy inference system in MATLAB software to analyze the data and create quality measurement rules. Shannon's Entropy was used to assign weights to different indicators, and the WASPAS model was used to rank the city's regions based on sidewalk quality. The findings reveal several critical issues with Ahvaz's sidewalks. A prominent weakness is the prevalence of improper slopes, which frequently renders sidewalks impassable during the rainy season. Additionally, inadequate flooring poses challenges for pedestrians, particularly for individuals with disabilities. Many sidewalks lack sufficient lighting and green spaces, while safety and security remain pressing concerns.

Despite these challenges, the study highlights a notable strength: Ahvaz's sidewalks support relatively high levels of social interaction, which boosts their vitality and mobility to some extent. However, this strength is overshadowed by the need for significant improvements in maintenance, cleanliness, and overall accessibility. Addressing these deficiencies through strategic urban planning and targeted interventions will not only improve the quality of Ahvaz's sidewalks but also enhance the livability and functionality of its urban spaces for all residents. To improve the quality of sidewalks in Ahvaz, urban planning efforts must prioritize specific issues that are currently inadequate across most areas of the city. One critical measure is expanding green spaces and vegetation along sidewalks, using native plant species to guarantee sustainability. Additionally, waste management must be prioritized citywide, as environmental pollution significantly disrupts the usability of these spaces. Attention to urban street furniture, such as benches and shade structures, can further improve pedestrian comfort by providing resting areas. Moreover, revitalizing Ahvaz's streetscapes through aesthetic improvements and promoting group activities, including cultural and artistic events, would inject much-needed vibrancy into the city. Despite being essential for urban vitality, such activities are currently scarce in Ahvaz. Finally, practical concerns, such as proper slope adjustments, durable pavement materials, and adequate lighting, must be implemented consistently across all districts. Adopting these measures would substantially elevate the quality of sidewalks throughout Ahvaz.

VII. CONTRIBUTION OF AUTHORS CRediT.

Conceptualization, M.G.; Data curation, M.G.; Formal analysis, M.G. & Z.S.; Acquisition of financing, N.A. & Z.S.; Research, M.G., Z.S. & N.A.; Methodology, M.G. & N.A.; Project management, M.G.; Resources, Z.S. & N.A.; Software, M.G.; Supervision, M.G.; Validation, Z.S. & N.A.; Visualization, N.A.; Writing – original draft, M.G. & N.A; Writing – revision and editing, M.G. & Z.S.

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ANALYSIS OF PEDESTRIAN MOBILITY IN THE COMMERCIAL AREA OF IBAGUÉ, COLOMBIA [1]

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La caminabilidad describe la facilidad y comodidad con la que las personas pueden desplazarse a pie en un entorno urbano de manera ágil y fluida. Para analizar este aspecto, se utiliza el índice de caminabilidad, un indicador que relaciona el espacio público con la infraestructura y las condiciones que la ciudad ofrece para que los peatones puedan desplazarse de un lugar a otro de manera segura, cómoda y eficiente. Planificar ciudades caminables ofrece beneficios en salud, bienestar, eficiencia e inclusión para sus habitantes. Este trabajo construye un índice de caminabilidad en la Carrera Tercera entre calles 10 y 19 en Ibagué, Colombia. Se utilizó una metodología de 4 fases: contextualización de la zona, recolección y categorización de datos, construcción del indicador y aplicación del índice. Se obtuvo un puntaje de 3.27 en una escala de 1 a 5. Aunque la infraestructura tuvo puntajes altos, las variables socioambientales impactaron el resultado final, subrayando la necesidad de crear espacios que fomenten la interacción social y la convivencia comunitaria.

Palabras clave: caminabilidad, infraestructura, índice, espacio público.

Walkability refers to the ease and comfort with which people can move around on foot quickly and fluidly in an urban environment. To analyze this aspect, the walkability index is used, an indicator that relates public space to the infrastructure and conditions that the city offers for pedestrians to move from one place to another in a safe, comfortable, and efficient manner. Planning walkable cities provides benefits for their inhabitants, including improved health, well-being, efficiency, and inclusion. This work constructs a walkability index for Carrera Tercera between Calles 10 and 19 in Ibagué, Colombia. A four-phase methodology was used: contextualization of the area, data collection and categorization, construction of the indicator, and application of the index. A score of 3.27 was obtained on a scale of 1 to 5. Although the infrastructure received high scores, the socio-environmental variables influenced the final result, underscoring the need to create spaces that promote social interaction and community living.

Keywords: walkability, infrastructure, index, public space.

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I. INTRODUCTION

Walkability indices objectively evaluate the characteristics that influence the pedestrian experience and generate a numerical score. These results identify components of the environment that have shortcomings and allow monitoring improvement projects or prioritizing interventions during the infrastructure's useful life. Historically, walkability was quantified only as the extent to which a physical environment allows walking, based on geometric characteristics of design or condition and the quality of the surfaces. However, it is currently known that infrastructure should not be measured in isolation, as it might not adequately reflect walkability (Stockton et al., 2016). Paulo dos Anjos Souza Barbosa et al. (2019) confirm that factors such as population density and land use are key for walking, both for pedestrians and people with reduced mobility. In addition, the interaction between land use, transport systems, and urban design affects pedestrian behavior and generates significant environmental consequences (Larranaga et al., 2019).

The objective of this work is to develop a specific walkability index for the study area, combining qualitative and quantitative variables, to identify areas with a high potential for improvement. This research was carried out in the city of Ibagué, in central-western Colombia, specifically in the historic center, along Carrera Tercera between 10th and 19th streets (Figure 1).

II. THEORETICAL FRAMEWORK

The literature suggests that more walkable environments are associated with increased physical activity, lower obesity rates, and better cardiovascular health. Ewing and Handy (2009) mention that important factors for walkability include considering the population density of the area, the mix of land uses, the connection of the streets, safety (both personal and road), and the quality of the pedestrian environment. Additionally, Sallis and Glanz (2006) in their research showed that the design of the built environment can influence and change people's behavior, in terms of health and physical activity.

In recent decades, there has been a growing interest in investigating the relationship between urban space and movement, divided into two main lines: one on the spatial behavior of people and their interaction with the environment, and the other on the application of this knowledge in infrastructure planning, natural area management and non-motorized mobility (Orellana et al., 2017). In cities not designed for walking, pedestrians face dangers such as unsafe roads, pollution, and stress, which affect physical and mental health. According to the Institute for Transportation & Development Policy [ITDP], the most vulnerable sectors of the population tend to walk due to a lack of alternatives, while walkable cities, with dense and mixed-use neighborhoods, allow saving on transportation and reducing stress (ITDP, 2020).

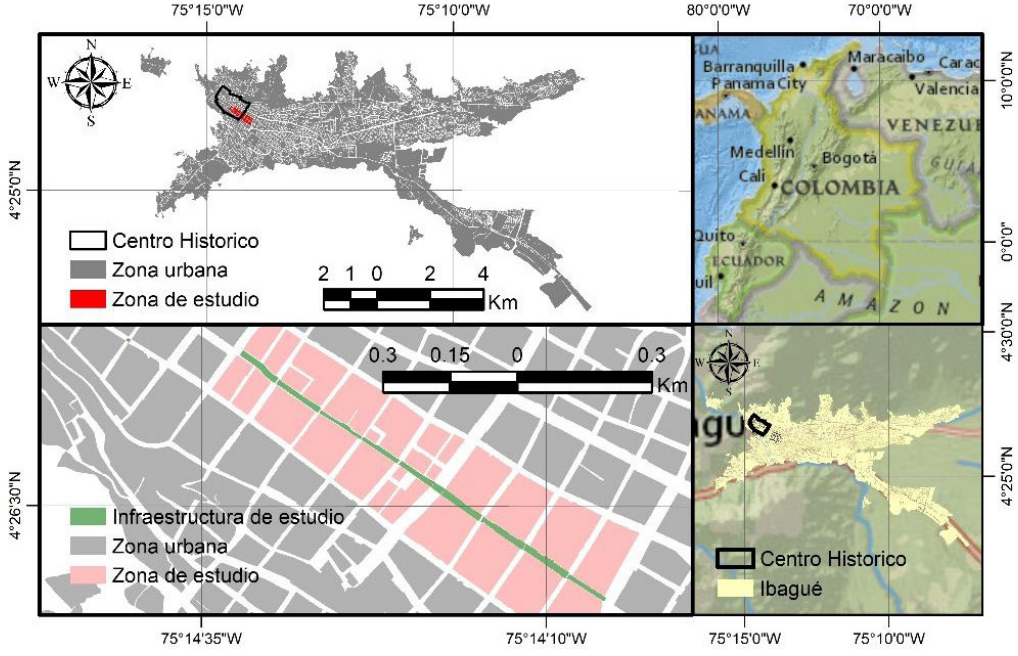

Figure 1. Geographical location of the city of Ibague and the study area. Source: Preparation by the Authors.

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Authors	Place	Categories
Gutiérrez-López et al. (2019).	Bogota, Colombia	Environmental quality, density, proximity, comfort, and entropy
Castro (2021).	Bogota, Colombia	Infrastructure, road safety, citizen safety, access to the destination, and comfort
Wibowo et al. (2015).	Bandung, Indonesia	Safety, security, comfort, attractiveness, and support policies
Pulla & Hermida (2021).	Cuenca, Ecuador	Mixticity of uses, environmental comfort, safety, and road infrastructure
Ewing & Handy (2009).	USA	Population density, mix of land uses, street connectivity, safety, and quality of pedestrian environment
Sallis & Glanz (2006).	USA	Environmental design, public health

Table 1. International and domestic benchmarks in the choice of variables for walkability measurements. Source: Preparation by the Authors.

Walking is an essential component to fostering healthier, more ecologically and socially active communities, and in many cases, it is the only way many people can access their daily activities. However, the decline of pedestrian access in most cities over the last century has created significant challenges for urban design, especially in terms of safety, accessibility, and social inclusion (Moura et al., 2017).

Quality of life covers multiple dimensions, from the physical and mental health of citizens to access to basic services, safety, and employment and recreation opportunities. Although it is not always easy to measure, it is an indicator that reflects diverse factors that directly affect urban well-being. In this sense, the case of Pontevedra, a city located in the northwest of Spain, specifically in the autonomous community of Galicia, is an example, since the improvement of the quality of life was achieved through the creation of safer public spaces, better pedestrian mobility, and the reduction of pollution, which has made the city more livable and attractive for its inhabitants (Pazos-Otón et al., 2024).

It is the responsibility of society and the authorities to guarantee an accessible environment for all citizens on equal terms (Hernández Galán, 2011). Planning for sustainable mobility is a key goal for governments. Improving the conditions for pedestrians and cyclists facilitates movement, reduces pollution and congestion, and offers social benefits (Guzman et al., 2020). Cities where walking is a predominant means of transport benefit both privileged and marginalized groups. In the United States, people with the lowest incomes allocate almost a third of their income to transportation. In Nairobi, Kenya, more than half of low-income residents walk to work because public transport is not economically accessible. However, this high level of walking is not due to an urban design for pedestrians, but to the lack of alternatives (ITDP, 2020).

Therefore, pedestrian infrastructure must prioritize accessibility for all users, especially the most disadvantaged. In addition, the public space must be designed not only to offer adequate conditions for pedestrians, but also to promote social integration, the inclusion of marginalized groups, and improve mental and emotional well-being during commuting. This vision implies adopting an urban design with a focus on the human dimension, which considers factors such as accessibility, scale, safety, furniture, and vegetation (Cevallos & Parrado, 2018).

Urban mobility is a key component of well-being, and its analysis allows evaluating the applicability of different measurement approaches and methodologies (Oviedo & Guzman, 2020). In this context, the development of a walkability index offers a solution to overcome these limitations, providing a standardized and objective measure of the quality of the pedestrian environment. This index can combine multiple criteria and factors to offer a more complete assessment and be used by urban planners to identify areas in need of improvement and measure the impact of interventions on walkability (Giles-Corti et al., 2016).

Despite the importance of walkability, measuring this concept remains a challenge for urban planners and researchers. There are different tools and methods, each with strengths and weaknesses. Some focus on the subjective perception of walkability (Wibowo et al., 2015; Gutiérrez-López et al., 2019; Pulla & Hermida, 2021), while others use geospatial data to evaluate the pedestrian environment (Castro, 2021; Ewing & Handy, 2009; Sallis & Glanz, 2006). Each method has limitations, such as the subjectivity of the evaluators or the lack of standardization.

In recent years, the pedestrian mode of transport has gained significant relevance in the planning and growth of cities around the world, so several investigations have been carried out that generate a theoretical basis to understand and research this

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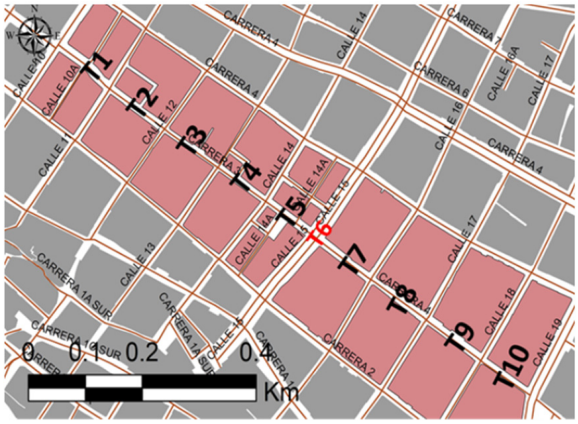

Figure 2. Sections of the study area. Source: Preparation by the Authors.

topic (Pulla & Hermida, 2021). However, studies estimating walkability have not yet been carried out in the city of Ibagué. This is the basis for building a walkability index for the study area. The categories used by the reference articles of the research were considered for this (Table 1).

III. CASE STUDY

Historically, Ibagué has expanded from its original core to the west, east, and southeast, developing a monocentric model where the provision of trade and services is mainly concentrated in the center, which generates center-periphery mobility patterns (National Council of Economic and Social Policy [CONPES], 2020). Carrera Tercera, located in the city's central core, has been a key intersection since the city's early days. This corridor is home to shops, urban facilities, public spaces, government offices, and cultural centers (Francel, 2015), attracting journeys as it concentrates most of the city's economic and social activity. One of its most relevant transformations was its pedestrianization, from 10th to 15th Street (Sections T1 to T5) in 2003, becoming the city's only pedestrian section.

The study focuses on Carrera Tercera (Figure 2) between 10th and 19th Streets (Sections T7 to T10), Ibagué's main pedestrian section. This section has undergone a significant urban transformation since its partial pedestrianization in 2003. This road concentrates a high density of commercial, cultural, and governmental activities, which represent typical patterns of pedestrian mobility in historical centers of intermediate Latin American cities. The selection of the case study seeks to highlight an everyday urban context in the region, where

Figure 3. Comparison between the exclusive pedestrian section and the shared section in Ibague's Carrera Tercera. Source: Preparation by the Authors.

the processes of revitalization of public space face similar challenges in terms of accessibility, informality, and shared use of urban space.

This study seeks to provide a basis for decisions in public policy and urban planning for this pedestrian area, considering that the section from 15th to 19th Streets is not yet pedestrianized. The municipal administration, through the Strategic Public Transport System [SETP, in Spanish], seeks to transform the center with the "Camina La Tercera (Walk La Tercera)" pedestrianization project, which promotes active and sustainable mobility. By improving walkability, it is hoped to encourage physical activity, reduce congestion, and create a more pleasant urban environment, improving the quality of life for residents (Enfoque Teve, 2023).

Two characteristic road sections were identified within the study area (Figure 3). The first (sections T1 to T5) is a road for exclusive pedestrian use, with a central space of 4.20 meters for pedestrian circulation, flanked by lateral sidewalks with varying widths between 3.75 and 5.40 meters, which configures a total cross-section of between 11.7 and 15

meters. The second section (T6 to T10) is a shared road that combines a 6-meter vehicle lane with pedestrian strips on both sides, whose widths range between 2.25 and 4.20 meters. This mixed configuration, with an estimated total width of 10.5 and 14.4 meters, reflects a coexistence between vehicle and pedestrian traffic, conditioned by the space available and the commercial pressure in the area. According to the recommendations of the Institute for Transportation and Development Policy (ITDP, 2020), the minimum accessible width for a sidewalk should be 1.80 meters, enough to allow the simultaneous passing of two wheelchairs. This reference was taken as a parameter to assess the sufficiency of pedestrian infrastructure in each section.

IV. METHODOLOGY

The research was based on the articles: ***Índice de caminabilidad para la ciudad de Bogotá*** (Gutiérrez-López et al., 2019), ***Metodología para la estimación del índice de caminabilidad a nivel ciudad y su aplicación al caso de estudio de Bogotá*** (Castro, 2021), Walkability Measures for City Area in Indonesia (Case Study of Bandung) (Wibowo et al., 2015) and ***Índice de Caminabilidad en el eje tranviario dentro del Centro Histórico de Cuenca*** (Pulla & Hermida, 2021). This bibliography was considered valuable as a precedent of indexes created in similar contexts to that of Ibagué, with the Cuenca index in Ecuador, standing out for its similarity in inhabitants and its focus on the walkability of the historic center. Based on this, four stages were considered.

Stage 1: Exploratory analysis of the environment and relevant actors

Stage 1 of the methodology focused on the exploratory analysis of the environment and the key social actors for the study. This phase was fundamental to understanding the context of the research and establishing a solid foundation. Information gathering techniques were used to become familiar with the area. This included a documentary and historical review of Carrera Tercera in academic, government, and press sources, as well as direct observation. The criteria for data collection were defined based on this and the literature review.

Stage 2: Data collection and cleansing

The data collection was carried out on Saturday, June 5th, Monday, June 7th, and Wednesday, June 9th, 2022, from 4 to 6 pm. Two typical days (Monday and Wednesday) and an atypical one (Saturday) were chosen to ensure the results are representative according to the sector's commercial dynamics. During the day, passers-by were interviewed using convenience sampling to identify key aspects of the pedestrian experience. Direct measurement, urban furniture inventory, and photographic registration were also carried out. This phase included the data cleansing and categorization, describing the most relevant qualitative and quantitative aspects of the walkability in the area.

The categories found were also hierarchized, assigning a value of their importance when calculating the walkability index. This made it possible to establish a more accurate and appropriate assessment of the area's situation regarding walkability.

Stage 3: Construction of the walkability indicator

Based on the literature review and the categories identified in stage 2, an indicator was constructed to calculate the area's walkability index. These categories were weighted to generate an average that adequately reflected the characteristics of the area. The indicator's construction required a careful analysis of the collected data, considering the perception of the people who live or pass through the area, providing a more complete and accurate view of the situation.

Stage 4: Implementation of the indicator for the study area

The last stage of the research focused on the application of the indicator built for the study area. Once the formula for calculating the walkability index was developed and applied to the data collected in stage 2, the indicator for the study area was calculated. Subsequently, relevant observations were made regarding the results obtained. It was important to analyze the results in detail and compare them with the data obtained in the previous phases. In addition, the areas with higher or lower walkability quality were identified, which allowed evaluating and diagnosing the area satisfactorily.

It is important to emphasize that the application of the indicator for the study area was a continuous process and required periodic measurements and evaluations to monitor the progress and effectiveness of the measures taken.
The researchers provided all the tools and resources used, and also applied the methodological process used. All the measurement tools used to carry out the research are attached in the appendices.

V. RESULTS

An exploratory analysis of the environment was conducted, and key actors were identified: passers-by, merchants, and government authorities. According to the National Census of Projection and Housing 2023 of the DANE [National Administrative Department of Statistics], Ibagué has 541,101 inhabitants (DANE, 2023). On this basis, a sample of 385 people was selected with a confidence level of 95% and a margin of error of 5%. Through semi-structured interviews, the essential characteristics for a satisfactory pedestrian experience and aspects to improve were investigated.

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To classify the responses, categories used in previous research were taken as references (Table 1), where the categories of safety, road infrastructure, and comfort-environment were defined. In addition, a new category was added, sidewalk obstruction, identified as a frequent problem in the area. On the other hand, the mix of uses, proximity, and density categories were discarded due to their low relevance in this context.

The interview responses were organized into four categories (Figure 4). Some categories were more recurrent, so weights were assigned according to the frequency of responses and the actors' perception of what was relevant for a satisfactory pedestrian experience.

Walkability will be evaluated in the 10 sections mentioned, excluding section 6, using four of the categories identified in

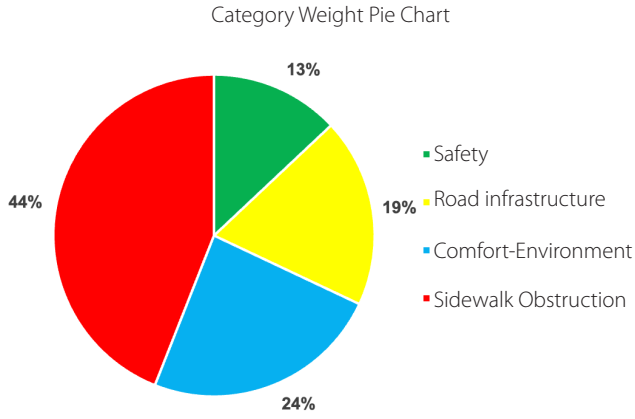

Figure 4. Corresponding weights for each of the walkability index categories. Source: Preparation by the Authors.

Category	Components	Qualification criteria
Safety	Lighting pedestrian spaces Pedestrian volume Openings to the sidewalk Perception of safety Speed signposts Presence of speed reducers Vehicle invasion on the sidewalk Conflicts between motorized and pedestrian means Safety when passing intersections Presence of a traffic light Presence of a zebra crossing Presence of a single platform Vehicle doors opening to the sidewalk	1. It is perceived to be dangerous. Pedestrians are susceptible to crime, traffic accidents, etc. 5. It feels safe. The street is well used, there is good lighting, and reduced vehicle speed.
Infrastructure	Presence of sidewalk Continuity of sidewalk Sidewalk width Condition of the sidewalk Non-slip sidewalk Slope of the section Presence of tactile paving Presence of a ramp Quality and condition of the ramps	1. There are risks and difficulties to walk on the sidewalk, or otherwise, there is no sidewalk available. 5. A walking surface without cracks or one that provides functional and well-maintained infrastructure for people with reduced mobility.
Comfort-Environment	State of trash cans [check] State of benches State of bicycle racks Lighting Condition of the surrounding buildings Presence of graffiti Cleanliness Green areas Covered sidewalk area for the weather	1. Absence of urban furniture or in a decadent state. A smelly and dirty environment that significantly reduces comfort. 5. The path is clean. It has urban furniture and green areas.
Obstruction of the sidewalk	Mobile obstacles Fixed obstacles Presence of informal vendors on the sidewalk	1. Street furniture, signs, vehicles, and informal vendors constantly block pedestrian traffic. 5. Pedestrian traffic is uninterrupted by permanent or moving obstacles.

Table 2. Rating components of each category. Source: Preparation by the Authors.

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the surveys (Figure 4). The first, safety, will analyze personal and road safety. The second, infrastructure, will examine sidewalks and streets in terms of paving, accessibility, and signage. The third, comfort-environment, will evaluate aspects such as noise, shade, vegetation, and cleanliness. The last one, obstruction of the sidewalk, will identify elements that hinder pedestrian traffic, such as vehicles, urban furniture, and informal commerce (Table 2).

Section 6, on being an intersection with traffic signals, requires a particular analysis because it does not conform to the criteria of the other sections. This will include the safety perceived by pedestrians regarding crossing times, sidewalks, zebra crossings, and compliance with rules by drivers. Intersections, critical points of road safety, are especially relevant, since according to the National Road Safety Observatory (ONSV, 2024), pedestrians come second in road users with the most fatalities in Ibagué.

Each of the sections is scored individually in the four categories. The scores of the 10 sections were then averaged for each category. Finally, the weighted average of the results of each category was calculated, considering the previously determined weights. The mathematical model below, Equation 1, was based on the one applied from the article Walkability Measures for City Area in Indonesia (Case Study of Bandung) written by Wibowo et al. (2015).

$$\textit{Walkability Index} = \frac{\sum_{i=1}^{n} n\, w_j P_j}{\sum_{i=1}^{n} n\, w_j} \quad \text{Equation (1)}$$

Where:
n: Number of sections.
w_j: Weight applied to category j.
P_j: Section score for category j.

Tramo	Calificación
T1	3.75
T2	3.58
T3	3.08
T4	3
T5	2.83
T6	-
T7	3.36
T8	2.64
T9	2.5
T10	2.64
Promedio	3.04

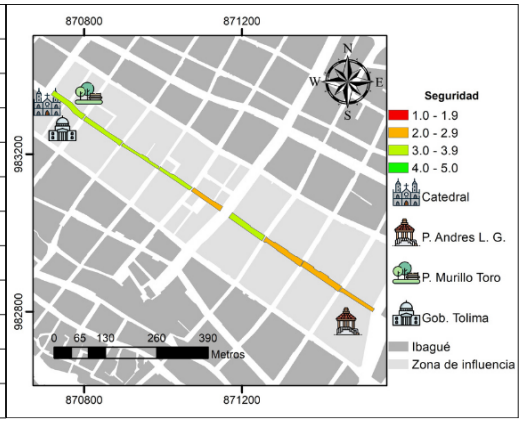

Figure 5. Safety score. Source: Preparation by the Authors.

Tramo	Calificación
T1	3.67
T2	3.67
T3	3.67
T4	3.67
T5	3
T6	-
T7	3
T8	3
T9	3
T10	2.33
Promedio	3.22

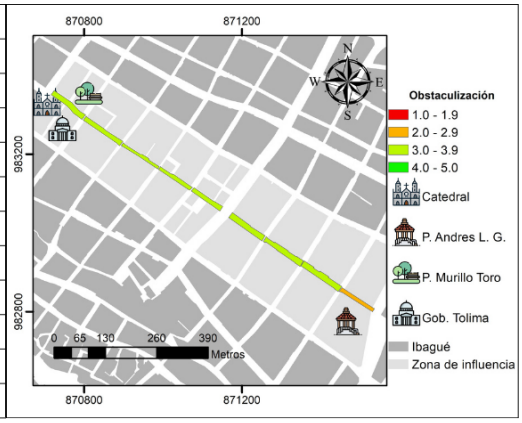

Figure 6. Sidewalk obstruction score. Source: Preparation by the Authors.

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Tramo	Calificación
T1	2.78
T2	2.67
T3	2.56
T4	2.33
T5	2.11
T6	-
T7	2.67
T8	2.86
T9	3.22
T10	2.11
Promedio	2.59

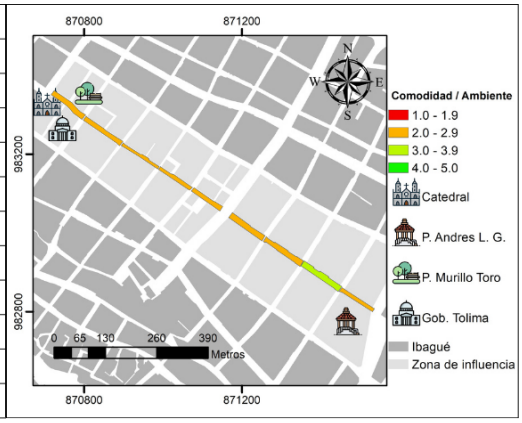

Figure 7. Comfort/environment score. Source: Preparation by the Authors.

Tramo	Calificación
T1	4.5
T2	4.13
T3	4
T4	4
T5	3.88
T6	-
T7	4.79
T8	4.71
T9	4.79
T10	4.88
Promedio	4.41

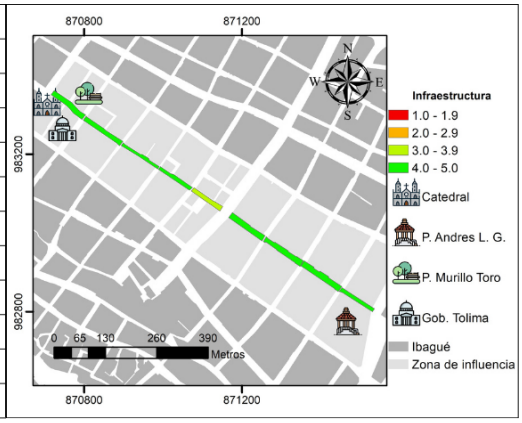

Figure 8. Infrastructure score. Source: Preparation by the Authors.

Tramo	Calificación
T1	3.62
T2	3.50
T3	3.39
T4	3.32
T5	2.93
T6	-
T7	3.31
T8	3.25
T9	3.33
T10	2.80
Promedio	3.27

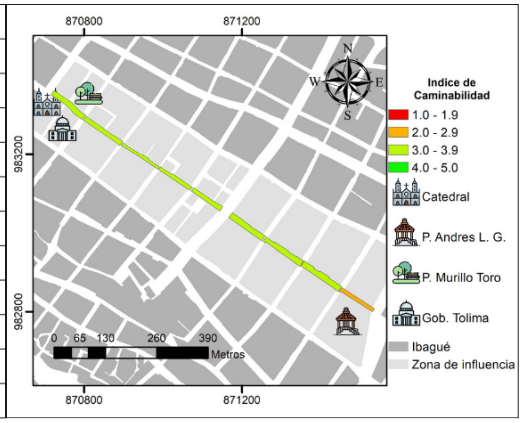

Figure 9. Overall score of the walkability index. Source: Preparation by the Authors.

The score of each category considers the criteria in the appendices, estimated through interviews with relevant actors. Criteria from the reference articles considered relevant to the case study were also taken into account. Sections 7, 8, 9, and 10 are not yet pedestrianized; however, the local administration expressed the intention to do so.

The results of each section in each of the categories (Figures 5, 6, 7, and 8) and the general walkability index (Figure 9) are shown below.

VI. DISCUSSION

The general walkability index had a score of 3.27, which indicates that the streets evaluated have a moderate/regular quality on a scale of 1 to 5, suggesting that although the current space meets acceptable physical conditions for pedestrians, there are aspects that could be improved to offer a more positive experience for pedestrians.

As previously mentioned, infrastructure stands out as the factor with the best score in all sections (4.41). Historically, physical attributes were quantified as the sole factor in determining the walkability indicator. However, the current consensus considers that measuring the attributes of the physical environment in isolation may be insufficient, since it reflects the different urban dynamics that affect walkability (Stockton et al., 2016).

It can be seen that the comfort/environment and the safety categories have the worst results, 2.59 and 3.04, respectively. It is coherent that people negatively perceive these aspects, since the two are closely related. When a pedestrian environment lacks elements that ensure comfort, such as wide sidewalks, suitable lighting, and noise control, this not only affects the overall pedestrian experience but also decreases the feeling of safety. An uncomfortable and poorly maintained environment can generate a greater perception of risk, which makes people feel more vulnerable to possible dangers.

Birche's study (2021), carried out in the city of La Plata, Argentina, offers a relevant perspective on the valuation of pedestrian space from a landscape and functional perspective. Her approach combines the diagnosis of the design, state, and accessibility of pedestrian road space with a critical reading of the urban car-centered model. The importance of considering variables such as the verified walkable width, vegetation, the quality of urban furniture, and the presence of obstacles is highlighted. Incorporating these criteria into the analysis of walkability in Ibagué allows enriching the study with an integrated vision that goes beyond the merely functional and reinforces the idea of the street as a public space for meeting, enjoyment, and urban landscape.

Pedestrians require a comprehensive comfort and safety experience that encompasses all their senses: from the ease of movement to the visual, sound, and thermal quality of the environment (Salem et al., 2022). The way elements are arranged in the urban landscape has a significant impact on how people perceive their surroundings and, therefore, on their general well-being. Comfort is closely linked to the perception of safety. A clean and well-maintained pedestrian environment, with obstacle-free sidewalks, not only facilitates pedestrian traffic but also reinforces the feeling of safety and accessibility (Arellana et al., 2019).

According to Irafany et al. (2020), continuity and mobility are key factors affecting urban walkability. This is reflected in the results, where the category of sidewalk obstruction scored 3 out of 5, indicating a significant presence of obstacles. The invasion of streets by informal vendors reduces the available space and creates barriers that hinder safe transit, especially for older or disabled people. In addition, uneven surfaces and the accumulation of trash worsen the pedestrian experience. The occupation fragments the pedestrian flow, forcing detours to the street, which increases risks and hinders efficient movement.

These findings support the findings of Arellana et al. (2019) and Stockton et al. (2016), who point out that the state of urban furniture, cleanliness, and continuity of pedestrian space directly influences perceptions of safety and comfort.

It is important to analyze the results of each category (infrastructure, comfort, environment, safety, and obstacles) individually, since, according to the methodology, some are more relevant for citizens. This will allow identifying the strengths of the study area and specific improvements in each section. The overall index of 3.27 can serve as a basis for diagnosing streets and provide key information for designing interventions that improve pedestrian mobility. From this point, specific actions can be developed to raise the quality of the streets and promote a better pedestrian experience.

VII. CONCLUSIONS

Carrera Tercera between 10th and 19th streets is the most important pedestrian corridor in the city of Ibague. It also provides a good atmosphere for pedestrians, according to the score of 3.27 obtained in the walkability index. It can be seen that the evaluated sections mostly obtained very good scores (between 4 and 5) in the infrastructure category, but the idea

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of Stockton et al. (2016) is reiterated, that walkability not only depends on the built space, but is influenced by many more variables. One of the most notable characteristics of the study area is its commercial nature, which encourages the invasion of pedestrian space by informal vendors and other actors (street artists, workers, among others). This invasion of the sidewalk is the main reason why walkability is punished in the area. The presence of informal vendors and street artists not only obstructs the sidewalk (Figure 6), but also brings with it more effects to walkability, such as: solid waste pollution, noise pollution, insecurity, invasion of urban furniture, among other factors that adversely impact the scores of other categories such as safety and comfort-environment.

On the other hand, it was observed that the score of each stage decreases as one moves along Carrera Tercera, from Section 1 to Section 10. Section 1, with the best rating of 3.62, stands out for its privileged location near parks, green areas, government buildings, and historical places of the city, which contribute to its optimal comfort, clean environment, and well-maintained infrastructure, as well as a reduced presence of informal vendors. In contrast, Sections 5 and 10 get the lowest scores, of 2.93 and 2.80, respectively. Section 5 poses a challenge for pedestrians, as it marks the end of the pedestrian section and is located near a busy vehicle crossing. Section 10 (between 18th and 19th Streets) is located in a tolerance zone in Ibagué, and both sections face similar problems, such as steep slopes, infrastructure deterioration, high concentration of informal vendors, and poor solid waste management.

The study of pedestrian zones using the walkability index allows detecting areas with limited pedestrian space, which is key to achieving greater equity in access to pedestrian infrastructure. This approach balances the use of urban space by identifying where investment is required in sidewalks, pedestrian streets, and other elements that promote walkability. In addition, this analysis offers decision makers valuable information to improve pedestrian cohesion in historic centers, favoring an inclusive and accessible environment for all (Navarro-Franco & Foronda-Robles, 2024).

One of the main strengths of this study is its comprehensive methodological approach, which combines data from the built environment with citizen perceptions collected through fieldwork. This methodology not only allows a more complete understanding of the urban phenomenon, but also offers a replicable tool to diagnose the quality of pedestrian space in other Latin American cities, especially those with partially pedestrianized historical centers or with pedestrianization projects and informal commercial dynamics that strain the public space. Intermediate cities with monocentric structures, peripheral expansion patterns, and similar social pressures can benefit significantly by adapting this index to their contexts.

Finally, although this study focused on a specific area of Ibague, its findings can be extrapolated to other Latin American urban contexts with monocentric structures, partially pedestrianized historical centers, and problems associated with informal trade. The methodology used allows replicability and adaptation in intermediate cities with similar conditions, which contribute to the development of diagnostics and public policies that favor inclusive and sustainable urban mobility. In addition, it makes aspects usually relegated to infrastructure plans visible, such as the perception of safety, multisensory comfort, and obstacles on the sidewalk, which are key to achieving more walkable and fairer cities.

VIII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization, M.S. J.G. M.R. J.G.; Data Curation, M.S. J.G.; Formal Analysis, M.S. J.G. M.R. J.G.; Acquisition of financing N/A.; Research, M.S. J.G.; Methodology, M.S. J.G. M.R. J.G.; Project Management, M.S. J.G.; Resources, X.X.; Software, X.X.; Supervision, M.S. J.G. M.R.; Validation, M.S. J.G. M.R. J.G.; Visualization, M.S. J.G. M.R. J.G.; Writing - original draft, M.S. J.G.; Writing - proofreading and editing, M.S. J.G. M.R. J.G.

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DISTRIBUCIÓN URBANA DE ADULTOS MAYORES: CONCENTRACIÓN Y TIPOLOGÍAS SOCIOESPACIALES EN SANTIAGO DE CHILEA
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URBAN DISTRIBUTION OF OLDER ADULTS: CONCENTRATION AND SOCIO-SPATIAL TYPOLOGIES IN SANTIAGO, CHILE [1]

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Aunque existen estudios previos sobre la distribución espacial de la población envejecida en diversas regiones del mundo existe una notable brecha en el conocimiento sobre Sudamérica. Esta investigación propone abordar el acelerado cambio demográfico hacia una población más envejecida en ciudades que no han sido planificadas para este cambio y no han desarrollado estrategias urbanísticas adaptativas. Se identificaron tipologías socioeconómicos y espaciales que influyen en las trayectorias de envejecimiento urbano en Santiago de Chile mediante tres métodos: un análisis geoespacial, un panel de datos y un análisis de k-media. Se encontró evidencia de un cambio en las zonas de concentración de adultos mayores, desde el centro hacia la periferia, y que variables como las familias monoparentales, la densidad poblacional y un alto nivel educacional son factores que aumentan la concentración de adultos mayores a nivel comunal. En contraste, ser propietario de una vivienda influye negativamente.

Palabras clave: envejecimiento poblacional, estrategias urbanísticas, distribución espacial, espacio urbano.

Although previous studies have examined the spatial distribution of the aging population in various regions of the world, a significant knowledge gap remains regarding South America. This research aims to address the accelerated demographic change towards an older urban population in cities that have not been planned for this shift and have not developed adaptive urban planning strategies. Socioeconomic and spatial typologies that influence urban aging trajectories in Santiago, Chile, were identified using three methods: geospatial analysis, a data panel, and k-means clustering analysis. It was found that there is a shift in the areas of concentration of older adults, from central to peripheral communes, and that variables such as single-parent families, population density, and high educational levels are factors that increase the concentration of older adults at a communal level. In contrast, homeownership has a negative influence.

Keywords: population aging, urban strategy, spatial distribution, urban space.

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I. INTRODUCTION

The urban dynamics of Latin American cities are facing significant challenges due to the rapid aging of the population in urban areas that were not planned for this population. In this context, it is essential to identify how economic, social, and spatial processes shape the distribution of older adults in the urban territory. The lack of adaptive urban planning strategies has limitations for adequate infrastructure but also intensifies problems such as residential segregation, territorial marginality, and urban informality, which affect the sustainability of cities (Vecchio, 2022; Godoy Ossandón, 2024; Herrmann-Lunecke et al., 2024).

Traditional urban planning has proven to be insufficient to address the complexity of population aging. Faced with this challenge, an adaptive and comprehensive approach is required that considers the multifactorial dynamics of the territory. For this, it is important to overcome disciplinary fragmentation and adopt a transdisciplinary perspective that includes economic, political, cultural, and institutional dimensions. This approach must be based on a local contextualization, which promotes specific solutions that balance formal regulation with flexible mechanisms for emerging urban dynamics (Baigorri, 1995). This view coincides with what was proposed by Olay Varillas and Fernández Bustamante (2024), who highlight the need to overcome the multidisciplinary atony in urban management through planning capable of addressing structural problems from multiple, economic, social, and cultural facets, recognizing their interdependence.

In this context, different studies have explored how demographic dynamics affect urban planning. According to Sabatini and Wormald (2013), residential segregation limits social integration and accentuates inequalities. Barros (2004) points out that uncontrolled urban expansion generates vulnerable settlements and reinforces socio-spatial inequalities. Meanwhile, Seguin et al. (2015) identified *gentrification* in central urban areas, but also *juvenilization* and demographic renewal that displaces and/or replaces the aging population. On the other hand, some authors emphasize that social institutions have not evolved at the pace of demographic changes, which generates a *structural lag* (O'Rand & Bostic, 2016). In the Latin American context, Vecchio (2022) mentions that there is a limited institutional capacity to face the population's needs, which he conceptualizes as *territorial marginality*.

Although these studies have made progress in understanding the dynamics of urban and demographic planning, a gap persists in the literature about how social and territorial characteristics influence the spatial distribution of older adults in Latin American cities. This restricts the development of adaptive urban strategies that promote social and territorial inclusion in a context of accelerated population aging and a territorial concentration of vulnerable populations. The relevance of this study contributes to the development of urban policies with an adaptive approach, which identifies the communal factors that drive the displacement and concentration of older adults, by facilitating the implementation of inclusive strategies in vulnerable areas.

Therefore, two hypotheses are formulated: (1) There is a displacement of the older adults towards the periphery, which generates an unequal demographic concentration pattern that is molded or contained in a planned urban environment, but not thinking about the aging population; and (2) The changing distribution of the older population concentrated in some communes is influenced by social variables associated with the life cycle.

To address these hypotheses, the following section outlines a theoretical framework on communal gentrification and juvenilization, followed by a methodology that integrates geospatial analysis (LQ segregation index) and a data panel to study the concentration of the aging population, which is complemented by *k-cluster* for their grouping. The subsequent sections present results, a discussion, and conclusions.

II. THEORETICAL FRAMEWORK

The older population has a territorial distribution that we try to identify through urban concentration during the life cycle. This distribution process implies different concentration levels, which are manifested in territorial, temporal, and socio-economic dimensions.

To understand the population distribution in an urban territory, the research structures the population according to *population heterogeneity*, characterized by the coexistence of people of different ages in the same space, and *population homogeneity* with a predominance of groups with similar characteristics, such as age, in nearby geographical areas.

When we consider the temporal factor, possible changes in concentration levels emerge, which is known as *urban cyclicity*. These changes are influenced by socio-economic characteristics of the population, which, according to Seguin et al. (2015), are based on mobility and competition hypotheses that explain the underlying factors.

This is how population homogeneity, closely linked to high levels of separation in different social groups within an urban environment (residential segregation), according to Janoschka (2018), tends to develop in contexts where urban planning and its state and private actors implement

market strategies aimed at specific groups. These strategies, often designed to meet the demands of aging middle-class sectors, prioritize elitist interests and exclude other population segments. These urban dynamics, supported by urban planning and reflecting and reinforcing patterns of exclusion by age and social class, contribute to the commodification of urban space (Hochstenbach & Boterman, 2018).

In this context, age is used as a key criterion to justify housing policies that benefit specific groups, such as affluent older adults, while neglecting others, such as young families with lower incomes or older adults with limited resources. Campos Alanis et al. (2024) also argue that the patterns of population homogeneity and heterogeneity by age are explained by a structural change in families, due to increased longevity. This change has expanded family structures to include older generations, such as great-grandparents. According to their analysis, low-income families tend to share the same dwelling, which encourages population heterogeneity.

Meanwhile, in *urban cyclicity*, it is proposed that the aging urban population tends to be concentrated in central territories initially. However, over time, it migrates towards the periphery, generating two possible results: residential segregation (Feitosa et al., 2007) and juvenilization, which is a phenomenon that describes the arrival of young people to areas traditionally occupied by older adults. This dynamic does not always imply forced displacement, but it does produce significant social and spatial transformations (Seguin et al., 2015).

Within this urban framework, the residential mobility hypothesis proposes that the population concentration changes due to residential mobility decisions, and according to Graff and Wiseman (1978), it focuses on some decisions such as: the emigration or immigration of young people, the departure or permanent arrival of older adults, and aging in place until death.

The lack of labor demand can generate emigration of young people to areas with higher employment, which influences the increase of older adults in the territory (labor emigration of young people). At the same time, an inverse phenomenon begins in areas with an increase in labor demand and educational supply, which generates juvenilization and gentrification in areas close to work or education (immigration of young people), which influences social exclusion (Burns et al., 2012).

While retirement and a loss of interest in living in residential areas close to work suggest that older adults may consider moving to areas with a greater provision of services and/or close to relatives or places where they lived during their childhood, this mobility can lead to the depopulation of central urban areas and contribute to a population renewal as proposed by Hagestad and Dykstra's research (2016).

Finally, the decision to live in a place until the end of life can generate urban concentration of older adults, which contributes to residential segregation and juvenilization (due to the death of part of the aging population).

However, changes in population concentration may be due to a competition for territory as proposed by Park (1936), in the hypothesis of competitiveness that argues that territorial competition is driven by land value and population density, and could displace older adults to peripheral areas due to their limited economic capacity (Liu, 2024). This process, as described by Burns et al. (2012), structures residential segregation according to the life cycle and purchasing power of older adults who are less competitive compared to young professionals and families with greater resources.

In this context, older adults tend to be located in more economical areas, away from urban centers where demand and housing value are higher, which leads to gentrification. The search for accessibility to services and smaller spaces also reinforces this displacement. Recent studies agree on an intergenerational competition, where older adults are disadvantaged, which affects the development of residential segregation and a greater homogeneity of the aging population in peripheral areas (Seguin et. al., 2015). At the communal level, this is reflected in the concentration of older adults in areas of lower economic and social competitiveness.

For example, these competitiveness dynamics are accentuated by the specific conditions of the rental market in Santiago, which has dynamics that affect older adults, who face high levels of vulnerability due to the lack of formal contracts, dependence on internal relationships, and disproportionate spending on rent (Link et al., 2019), differing from other countries such as Mexico, where the conversion of housing is a strategy to address the economic insufficiency of older adults (Campos Alanis et al., 2024).

III. METHODOLOGY

To analyze the spatial and temporal distribution of the population, three approaches were used: the localization coefficient index (LQ) (Xu et al., 2018), to identify levels of communal concentration; a multiple regression model to capture temporal evolution and territorial distribution; and the k-means method that groups communes according to their sociodemographic similarity.

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First of all, the LQ index analyzes the spatial concentration of the older adult population (Yao et al., 2019). This method compares the proportion of older adults in a specific commune with the total proportion of older adults in all communes, classifying them into three levels to identify the population's homogeneity or heterogeneity: low (LQ < 0.49), medium (LQ between 0.5 and 0.99), and high (LQ ≥ 1).

To calculate the LQ, the ages of older adults aged 60 and above and young adults aged 25 to 39 were used. The group of young adults was chosen to compare concentration trends because they are in the initial stages of independent life, characterized by the beginning of working life, the formation of a family, and the acquisition of the first home (Hagestad & Dykstra, 2016; Sabater & Finney, 2023).

Secondly, a multiple regression model with a data panel is used according to the typological structure proposed later. This approach evaluates how different explanatory variables affect the concentration of older adults (LQ_{anc}) in each commune, when considering the fixed and temporary effects (Equation 1). For its implementation, the R package of Croissant and Millo (2008) was used, following the methodology of Baltagi (2021).

$$LQ_{anc} = b_1 Perm_5 + b_2 F\_mon + b_3 Ppv + b_4 Den + b_5 LQjov + b_6 Ho\_uni + b_7 Due + b_8 Alta\_e + b_9 Tn + b_{10} Migra + \epsilon$$

(Equation 1)

The model is based on the theoretical framework and is structured in three main categories: (1) *residential mobility typologies*, represented by single-parent families (F_mon), the average number of people per dwelling (PPV), single-person households (Ho_uni), and the young people concentration index (LQjov). These typologies reflect occupation and displacement dynamics in the urban environment; (2*) territorial competitiveness typologies*, which includes a permanence greater than 5 years (Perm_5), the population density (Den), the home ownership (Due) and the university educational level (Alta_e), which indicate stability and economic capacity in the occupation of the space; and (3) *social and demographic factors typologies* such as the birth rate (Tn) and the proportion of foreign immigrants (Migrates), which are elements to measure the generational composition and renewal.

Thirdly, the k-means method is used to group communes according to the typologies of older adults who have similar characteristics and offer greater descriptive specificity, as proposed by Apparicio et al. (2015). The implementation of the method is based on the R package of Kassambara and Mundt (2020). The model identified five groups with a better fit of older adults.

For the analysis presented in this article, census data from 1992, 2002, and 2017 were used as a primary source (National Institute of Statistics of Chile [INE], 1992; INE, 2002; INE, 2017), supplemented with information on the birth rate from the Department of Statistics and Health Information [DEIS] (n.d.). These data were standardized for each of the years of study, which ensures the comparability of trends over time in the 31 selected municipalities of the Metropolitan Region of Chile. The communes of Santiago were chosen because they have a broad socio-economic diversity and are geographically close. Another spatial selection criterion at the communal level was based on the fact that urban planning tends to be done at this administrative level. The comparison between the three years under study is also facilitated at the communal level, because the information from the 1992 Census (INE, 1992) does not permit a lower level of disaggregation, which prevents comparing each year at the neighborhood or district level.

IV. RESULTS

Population distribution

The LQ index at the spatial level for the 31 study communes is shown in Figure 1. In 1992, the urban center had a high concentration of older adults (LQanc > 1), while the peripheral communes showed lower levels of concentration. In 2002, the concentration in the urban central communes decreased, and a centrifugal displacement towards communes neighboring the center was observed, while in 2017, the LQ_{anc} index shows that the concentration of older adults is moving away from the center towards peripheral communes.

These results show a spatial trend away from central communes towards peripheral communes and evidence a decreasing trend of the concentration level over time, because in 1992 the concentration ranges give an LQ_{anc} index between 0.42 to 2.24; and for the 2002 census, the results indicate an LQ_{anc} index between 0.36 to 1.81; while in 2017 the LQ_{anc} index decreases to a range between 0.55 to 1.4, evidencing an increase in the heterogeneity or dispersion of older adults in the 31 municipalities observed.

Communal descriptors, data panel, and k-media.

Table 1 describes the results of the data panel, according to the proposed typology. The model in general explains 86% (R2) of the variability in the communal concentration of older adults.

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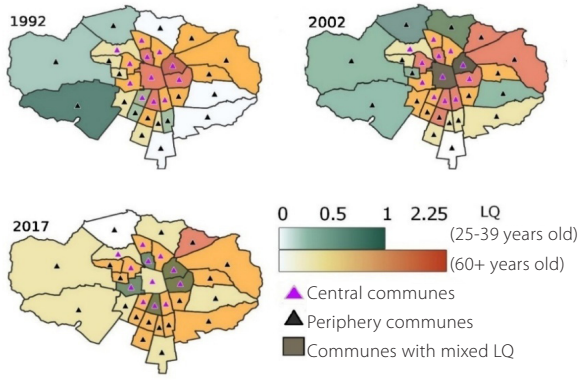

Figure 1: Communal concentration - LQ. Source: Prepared by the Authors.

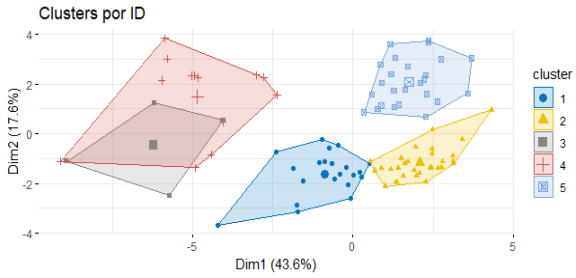

Figure 2: Similar groups of older adults. Source: Prepared by the Authors.

Effect	Value	Std. Dev.	Weight
Idiosyncratic	0.00986	0.09930	0.644
Communes	0.00545	0.07387	0.356
Time	0	0	0
Theta	0.31 (Communes)	0 (Time)	0 (Total)

Estimator	Value	Error	Z-value	P(>/z|)	
(Intercept)	1.387	0.017	62.17	< 2.2e-16	***
(F_mon) Single-parent families	0.197	0.019	10.22	< 2.2e-16	***
(Due) Homeowner	-0.112	0.031	-3.63	0.000284	***
/Perm_5) Permanence over 5 years	-0.070	0.024	-2.92	0.003446	**
(Den) Population density per km2	0.040	0.021	1.89	0.058891	,
(Alta_e) University education	0.055	0.032	1.74	0.081187	,
(Tn) Communal birth rate.	-0.034	0.018	-1.87	0.062164	,
(Migra) Immigrants in the commune	-0.036	0.021	-1.71	0.087194	,
(LQ_joven) Concentration index 25-39 years	-0.033	0.021	-1.6	0.109147	
(PPV) Average number of people per household	-0.048	0.032	-1.49	0.135847	
(Ho_un) Single-person Households	-0.003	0.012	-0.23	0.817893	

Note: Significance, 0 *** 0.001 ** 0.01 '*' 0.05 '.' 0.1. R2 (0.86), R2 aj. (0.84), χ2 (504.7) with 10gl, p-value (< 2.22e-16). P. balanced: n=31, T=3, N=93.

Table 1: Descriptor data panel4. Source: Preparation by the Authors

The most significant result is explained as an increasing result, when the number of single-parent families is increased by 1%, the concentration of older adults increases by 0.19%; it is followed in significance by the level of university education with 0.055%; which implies that, the higher the education, the higher the level of territorial concentration. Following the theory of competitiveness, the territorial population density per km^2 is 0.04%, which explains that the more people per km^2, the higher the aging population density, being a factor of population homogeneity related to the hypothesis of competitiveness.

Among the negative and significant coefficients, the following stand out: homeownership, with an impact of -0.11% and high significance, influenced by competitiveness by land use, perhaps enhanced by younger age groups, but with higher income, which drives a gentrification process. Another negative typology is remaining in a property for five years or longer, which has -0.070% and high significance. This occurs when groups under 60 decide to stay in an area, which decreases the concentration of people over 60.

As expected, an increase in the birth rate decreases the weight of the LQ_{anc} index. The immigration process of foreigners is similar, with -0.036%. Therefore, when the number of people in the communes increases, a greater distribution of the population of different ages is generated (population heterogeneity).

Figure 2 shows the previous model, but groups of communal clusters of older adults are added. The best-fit model is the 5-commune model. Two main trends are observed: communes 3

4 Descriptors with heteroscedasticity and autocorrelation were eliminated. In addition, the VIF excludes 5 descriptors due to multicollinearity. The Lagrange test ruled out temporal effects (χ2 = 0.524, p = 0.4691) but confirmed individual effects (communes). The Breusch-Pagan test validated the heteroskedasticity (χ2 = 22.608, p = 0.01229) that justifies the use of the model and the Breusch-Godfrey test did not detect autocorrelation (χ2 = 2.8, p = 0.41).

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Estimator	Value	Error	T-value	Pr(>/t|)	
(F_mon) Single-parent families	0.157	0.022	7.11	4.84e-09	***
(PPV) Average number of people per household	-0.100	0.042	-2.35	0.022	*
(Den) Population density per km² (communal)	-0.145	0.083	-1.73	0.008	.
(LQ_joven) Concentration index 25-39 years	-0.043	0.025	-1.71	0.093	.
(Due) Homeowner	-0.02	0.110	1.82	0.073	.
(Ho_uni) Single-parent households	-0.014	0.011	-1.25	0.216	
(Perm_5) Permanence over 5 years	-0.019	0.028	-0.67	0.504	
(Alta_e) University education	-0.142	0.090	-1.48	0.144	
(Tn) Communal birth rate.	-0.029	0.020	-1.43	0.159	
(Migra) Immigrants in the commune	-0.009	0.022	-0.41	0.682	
(Cluster)2	-0.273	0.210	-1.28	0.204	
(Cluster)3	-0.058	0.080	-0.67	0.050	
(Cluster)4	-0.078	0.110	-0.68	0.497	
(Cluster)5	0.173	0.140	1.18	0.241	

Note: Significance, 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1. R2 (0.85), R2 adjust. (0.73), F-statistical (23.1) with 13 gl, p-value (< 2e-16). Balanced panel: n=31, T=3, N=93.

Table 2: Data panel with k-means. Source: Preparation by the Authors.

and 4 have similar characteristics, while communal clusters 1, 2, and 5 show differences in communal typology.

In Table 2, the results are presented on incorporating the clusters that were not significant and did not improve the analysis, indicating that the demographic and spatial characteristics of older adults are adequately explained by the previous model and do not need to be differentiated by communal groups.

V. DISCUSSION

The LQ index confirms a change in the older population from urban centers to the periphery of Santiago de Chile, driven by processes related to the life cycle (gentrification and juvenilization), in line with previous studies in cities such as Montreal (Seguin et al., 2015).

The data panel model globally explains 85% and complements the theoretical framework of the study. Within the typologies, single-parent families are the most significant typology. They are positively correlated with the concentration of older adults (0.19%), which suggests specific family dynamics in the context of Santiago. This is similar to what was found in Montreal by Seguin et al. (2015), and it can be transformed into more vulnerable families, who need full-time jobs to support themselves, which aggravates their vulnerability to possible residential segregation processes.

Although the literature from Canada indicates that single parents tend to resort more frequently to the use of

private vehicles and full-time employment, especially in single-parent families (Roorda et al., 2010), a situation of vulnerability is likely to arise when these parents reach old age. As evidenced in Santiago de Chile, this dynamic can exacerbate residential segregation due to the lack of access to adequate or planned public transport, which results in territorial marginality.

Another positive relationship is generated between the level of university education (0.055%) and the concentration of older adults, consistent with the hypothesis of competitiveness. The communes with a higher proportion of older adults with higher education could be more consolidated areas, with better access to services and amenities, where this group has been able to stay over time due to their socio-economic position. This contrasts with the displacement processes associated with gentrification, which tend to affect populations with lower purchasing power and possibly greater dispersion in space.

Similarly, the positive correlation between population density (0.040%) and the concentration of older adults can be interpreted as a reflection of population homogeneity in areas that have experienced aging in place. These dense communes could have attracted and retained population cohorts that have co-aged. However, it could also indicate pressure on resources and infrastructure in these areas, which impacts the quality of life of older adults, as mentioned by the theoretical framework when referring to territorial marginality.

The negative and significant coefficients for homeownership (-0.11%) and residence over five years (-0.070%) are consistent with the theories of territorial competitiveness and gentrification/juvenilization. The lower concentration of older adults in communes with a high proportion of owners suggests that the increase in land value and the arrival of younger populations with greater purchasing power generate an indirect displacement of older adults, who could be forced to look for cheaper housing alternatives in the periphery, as proposed by the hypothesis of residential mobility and the theory of competitiveness. This dynamic makes a difference in the context of developed cities, where property can offer greater stability in old age.

The decrease in the LQ index due to an increase in the birth rate and the immigration of foreign people reinforces the idea of a growing population heterogeneity in the communes. These demographic processes contribute to juvenilization, which alters the proportion of older adults and, potentially, modifies the changing needs, according to the demand for specific services for the population according to the age group.

Despite the relevance of communal factors in the concentration of older adults, the study presents spatial limitations, focusing on the communal and non-district level due to the lack of disaggregated information in 1992. Likewise, the cross-sectional information does not allow determining, in the long term, whether people have died or migrated to other communes, which restricts the interpretation.

VI. CONCLUSIONS

The findings confirm the hypotheses about the distribution of older adults, who moved from the center to the periphery between 1992, 2002, and 2017. At the same time, dynamics such as educational level and family structure determine specific patterns of population redistribution, which generates a pattern of unequal demographic concentration that is molded or contained in a planned urban environment, but not thought of for an aging population, which leads to gentrification or juvenilization, in addition to the move away from central areas, which contribute to greater residential segregation.

On the hypothesis of the changing distribution of the older population, which is concentrated in some communes, the hypothesis on the influence of intrinsic variables on the competitive hypothesis, residential mobility, and social variables is accepted. However, it should be noted that the population characteristics in central and peripheral communes persist over time. This means that where there is a concentration of older adults, there are patterns of high educational level and single-parent family structure. An uneven demographic concentration pattern is generated that is molded or concentrated in a changing spatial location towards the peripheral communes of the city of Santiago.

These results highlight the need for adaptive strategies that reduce the structural gap between demographic dynamics and urban planning, avoiding reactive solutions to structural problems. Public policies are proposed, such as: (1) inclusive housing policies in central communes to curb exclusion due to gentrification; (2) mapping of critical areas (LQ) for social integration projects and services in peripheries; and (3) inclusive transport and land regulation. The evidence suggests taking inspiration from cases such as Asturias (Spain), where territorial rebalancing strategies mitigated marginality in contexts of population aging (Olay Varillas & Fernández Bustamante, 2024), which adapts its three priority lines: peripheral infrastructure, land regulation, and connectivity.

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Future research could analyze the impact of the increase in land prices and services at the neighborhood level as a determining factor in the voluntary relocation of older adults to economic areas, and also explore the conversion of homes into businesses (to cover medical and orthopedic expenses) and its relationship with residential displacements in this age group, in addition to evaluating how the death of older adults influences urban renewal, particularly through inheritance processes and the establishment of younger relatives in such properties.

VII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization, P.C.R.; Data Curation, P.C.R.; Formal analysis, P.C.R.; Research, P.C.R.; Methodology, P.C.R.; Resources, P.C.R. and M.L.V.; Supervision, M.L.V.; Validation, P.C.R. and M.L.V.; Visualization, P.C.R.; Writing - original draft, P.C.R.; Writing - revision and editing, P.C.R.

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CARLOS NIETO-CAÑARTE, PEDRO HARRYS LOZANO-MENDOZA, VÍCTOR MANUEL GUAMÁN-SARANGO, MAYRA CAROLINA VÉLEZ-RUIZ, WILMER MARIO DOMÍNGUEZ-ZÚÑIGA
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URBAN GROWTH AND VULNERABILITY TO CLIMATE CHANGE OF THE QUEVEDO CONURBATION, ECUADOR [1]

CRECIMIENTO URBANO Y VULNERABILIDAD AL CAMBIO CLIMÁTICO DE LA CONURBACIÓN DE QUEVEDO, ECUADOR

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El cambio climático es un desafío global con impacto desigual. En Ecuador, el Cantón Quevedo, por su ubicación geográfica y características topográficas, es vulnerable a riesgos climáticos. Este estudio identificó la vulnerabilidad al cambio climático vinculada al crecimiento urbano del Cantón Quevedo, se utilizaron herramientas de sistemas de información geográfica (sig) para generar mapas de amenaza, exposición, sensibilidad, adaptación y riesgo climático, a través de un diseño cuasiexperimental y de enfoque cuantitativo. Los resultados indican un alto riesgo climático en general; 32,62 % del territorio presenta una exposición muy alta, especialmente en zonas con pendientes pronunciadas. Las zonas con alta sensibilidad y baja capacidad adaptativa son principalmente rurales y periféricas. En conclusión, el crecimiento poblacional causa la expansión urbana no planificada, que genera impactos ambientales negativos, como la degradación de la cubierta vegetal, que disminuye la resiliencia ecológica y la provisión de servicios ecosistémicos. esto incrementa la exposición y la sensibilidad (asociada a infraestructuras inadecuadas), y reduce la capacidad de adaptación. Se propone mejorar la infraestructura de drenaje, construir viviendas más resilientes y programas de educación y capacitación en cambio climático, así como promover soluciones basadas en la naturaleza.

Palabras clave: resiliencia, adaptación, riesgo, vulnerabilidad, cambio climático.

Climate change is a global challenge with uneven impact. In Ecuador, the Quevedo Canton, due to its geographical location and topographical characteristics, is vulnerable to climate risks. This study identified the vulnerability to climate change linked to urban growth in the Quevedo Canton. Geographic information system (GIS) tools were used to generate maps of threat, exposure, sensitivity, adaptation, and climate risk through a quasi-experimental design and a quantitative approach. The results indicate a high overall climate risk, with 32.62% of the territory being highly exposed, particularly in areas with steep slopes. Areas with high sensitivity and low adaptive capacity are mainly rural and peripheral. In conclusion, population growth leads to unplanned urban expansion, resulting in adverse environmental impacts, including degradation of vegetation cover, which reduces ecological resilience and the provision of ecosystem services. This increases exposure and sensitivity (associated with inadequate infrastructure) and reduces adaptive capacity. It is proposed to improve drainage infrastructure, build more resilient housing, implement climate change education and training programs, and promote nature-based solutions.

Keywords: resilience, adaptation, risk, vulnerability, climate change.

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I. INTRODUCTION

Rapid and unplanned urban growth has been a global phenomenon that has transformed the spatial and social organization of cities, becoming a key ecological and human challenge of the 21st century (Jordán et al., 2017). By 2045, the global urban population is expected to increase 1.5 times (United Nations Organization [UN], 2024), driven by factors such as rural-urban migration, industrialization, and globalization (Jordan et al., 2017). However, in Latin America, this accelerated urbanization has not guaranteed sustainable economic development or a significant reduction of poverty and inequality (UN, 2024). On the contrary, environmental degradation has consumed agricultural lands and habitats by fragmenting ecosystems (World Health Organization [WHO], 2022). It has also left an estimated million species at threat of extinction if important ecological changes are not made in the coming years (Díaz et al., 2019).

As a result, deforestation and the loss of green spaces are reducing carbon sequestration and leading to poor air and water quality. The alteration in the natural water cycle is behind more prolonged droughts and intense rainfall, leading to increased runoff and reduced infiltration. This, in turn, has led to water shortages and floods (Gómez-Guerrero et al., 2021). Unsustainable anthropogenic development, especially urban growth, is the primary driver of this climate change. Cities are primarily responsible, as they consume more than two-thirds of the global energy and emit 70% of the greenhouse gases (Masson-Delmotte et al., 2019). Furthermore, within these cities, urban populations are the most vulnerable, as they experience temperatures 3°C to 5ºC higher than the surrounding rural areas, due to the so-called urban heat island effect generated by their large concrete surfaces and the lack of vegetation cover (Lane et al., 2024).

According to this argument, informal settlements are the most vulnerable to risks arising from weather patterns. As such, analyzing vulnerability in areas with high demand for land and significant ecological impact (Duque & Montoya, 2021) is particularly relevant, given its importance in reducing thermal contrasts and humidity (Mendes et al., 2020). Along these lines, the destruction of 85% of the world's wetlands has been reported, and 23% of the planet's land is considered ecologically degraded. The destruction of coastal mangroves is threatening 300 million people (Díaz et al., 2019) due to the ecosystem's vulnerability associated with low resilience capacity. Therefore, unplanned urbanization represents unsustainable development, which amplifies climatic or geological hazards (UN, 2024).

New intermediate cities, such as the conurbation of Quevedo, have emerged in Ecuador, along previously non-existent lines (Narváez Quiñonez et al., 2020). With its metropolitan area, as well as intermediate parishes and cities, the functionality and operation of this conurbation is confirmed, although it is neither administratively nor politically defined (EcuRed, 2025). However, Quevedo is exposed to natural, geological, and hydrometeorological threats, with risks of soil degradation and water scarcity (Narváez Quiñonez et al., 2020). Annual rainfall patterns have led to increased saltwater intrusion, sea level rise, and a higher frequency and intensity of extreme weather events, such as floods and hurricanes (Song et al., 2023).

A phenomenon that has been documented in coastal provinces such as Manabi and Guayas, damaging more than 6,900 homes and destroying 72 of them (Fan & Zhao, 2025).

Therefore, it is crucial to examine how unplanned urban expansion exacerbates climate vulnerability in Quevedo by generating threat, exposure, sensitivity, adaptation, and climate risk maps, utilizing advanced data processing tools in geographic information systems (GIS). A research goal is established from this perspective, namely, to identify the vulnerability to climate change linked to urban growth in the canton of Quevedo, to generate data to understand specific challenges, and to facilitate effective adaptation strategies. Similarly, the environmental information obtained can help improve the interpretation of these spaces and their consideration in local resilience calculations (Hernández Aja et al., 2020), thereby contributing to sustainable urban planning. This local approach could then be extrapolated to a national or even regional level.

II. THEORETICAL FRAMEWORK

Urban growth refers to the change in land use that necessitates planning, design, and construction of spaces and structures to improve the quality of life for its inhabitants and ensure sustainable urban development. However, rural-urban migration fosters the development of unplanned, informal cities (Jordan et al., 2017), which contribute to climate change. The latter is the prolonged variation of weather patterns due to natural causes or, primarily, due to the burning of fossil fuels and deforestation (UN, 2024). In informal urbanization, land use and land-use change are the most significant sources of net CO_2 emissions (Ghosh et al., 2022; Kim & Park, 2023; Bufalo et al., 2024).

In this context, planning is crucial for mitigating the effects of climate change by creating resilient structures that are informed by environmentally friendly and

sustainable policies (Murillo Delgado et al., 2023). This, in practice, presents a challenge in itself, particularly in areas that should be protected due to their ecosystem contributions or greater vulnerability to changes. Therefore, urban and environmental development planning must be based on the benefits that ecosystems offer to guarantee human well-being, known as ecosystem services, which include the provision of indispensable resources (water, food, and medicine), as well as their contributions to climate stabilization, the regularization of the water cycle, their protective function against floods, soil erosion, and landslides, among others (Córdoba-Hernández, 2021).

For efficient planning, areas of high ecosystem value that require protection and conservation should be identified and prioritized. Ensuring the integration of environments into mitigation and adaptation strategies is also necessary. This includes the implementation of nature-based solutions (NbS), which are actions to protect, sustainably manage, and restore natural or modified ecosystems, effectively and adaptively addressing socio-environmental challenges, and simultaneously providing benefits for human well-being and biodiversity (Rojas Morales, 2024). Therefore, it is essential to note that climate vulnerability refers to the susceptibility to damage from climate change, encompassing both sensitivity and responsiveness. Ecosystem vulnerability is associated with the loss of habitats and the replacement of ecosystems with less future resilience. On the other hand, vulnerability arises when ecosystems lose their ability to provide essential goods, functions, and services, ultimately affecting territorial recovery in the face of an environmental crisis (Córdoba-Hernández, 2021).

Considering all the above, it is important to define ecosystem resilience. This refers to a system's ability to maintain or return to its desired functions in the face of a disturbance, adapting and transforming systems despite limitations (Meerow et al., 2016). This should be considered in conjunction with the transformation of the habitat, climate change, the overexploitation of resources, the introduction of invasive species, pollution, and nutrient enrichment (Córdoba-Hernández, 2021), both in urban planning and in territorial urban development and housing strategies for the years to come. Hence, climate vulnerability considers the exposure of goods, infrastructure, assets, people, species, or ecosystems in affected environments, and the degree to which a system is affected by climate change, directly or indirectly, is referred to as sensitivity. Finally, adaptive capacity refers to the faculty that ecological, social, or economic systems, human institutions, and other organisms have to take advantage of opportunities or respond to climatic consequences.

III. CASE STUDY

The Canton of Quevedo is located in the province of Los Ríos and encompasses both urban and rural areas (Figure 1). It is located at 74 meters above sea level. Quevedo has a surface area of 303 km2 and borders the cantons of Buena Fe and Valencia to the north, El Empalme to the east, Mocache to the south, and Quinsaloma to the west. Its projected UTM coordinates are East (X) 670965 and North (Y) 9886264. The central city is Quevedo, which has seen substantial population and economic development. Among the ecosystem factors, the Quevedo River, which crosses the city's urban area and practically the entire canton, and other water sources that influence climate and biodiversity, which favor ecosystem services, stand out. Landscape fragmentation has been identified as a result of the conversion of forests into agricultural or urban lands, which alters ecological connectivity and hinders the movement of species (Villavicencio-Ordóñez et al., 2024). Due to intense agricultural activity, these water bodies can be affected by the use of fertilizers and pesticides (EcuRed, 2025).

The breakdown of the rainfall timeline (Figure 2) for Quevedo Canton (Figure 2.A.) exhibits a well-defined rainy seasonal precipitation pattern. The rainfall has reached significant peaks, especially around the turn of the century (2000), due to extreme weather events such as El Niño. Similarly, the temperature timeline depicted in Figure 2B describes a seasonal pattern with accentuated annual variations. Since the 1940s, temperatures have gradually increased, followed by fluctuations around a constant level. Occasionally, extreme temperature events, such as heat waves, are observed.

Quevedo is the tenth most populous city in Ecuador; according to the National Institute of Statistics and Census [INEC] of 2022, its population has risen considerably. In 2010, 150,827 inhabitants were registered, and by 2022, it was 177,792 inhabitants (INEC, 2022). The population estimate for 2024 was 208,000 people. In 2000, the urban sprawl of Quevedo covered a population of 932.55 inhabitants. When representing the 2010 population and housing census in the urban area, Narváez Quiñonez et al. (2020) indicated a growth rate of 41.72%. Similarly, through their simulation research between 1998 and 2019, they revealed that organic growth is more than fourfold, with a surface area of 304.67 km^2 by 2020. Moreover, they warned about a likely increase, based on the population growth in the area, which is estimated to be 251,922 inhabitants by 2030 (Villavicencio-Ordóñez et al., 2024).

The area is characterized by being almost flat, which facilitates the development of urban infrastructure, roads,

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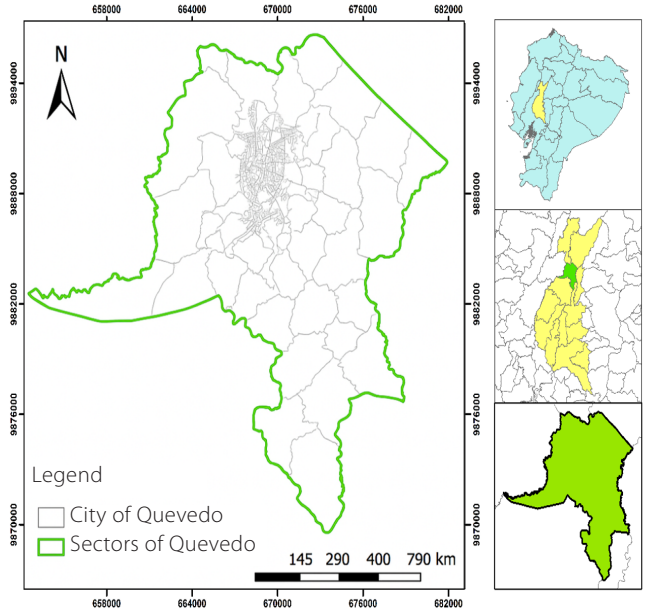

Figure 1: Map of the canton of Quevedo. Source: Prepared by the Authors based on data in shape format from 2023 of the Ecuador Military Geoportal (2024).

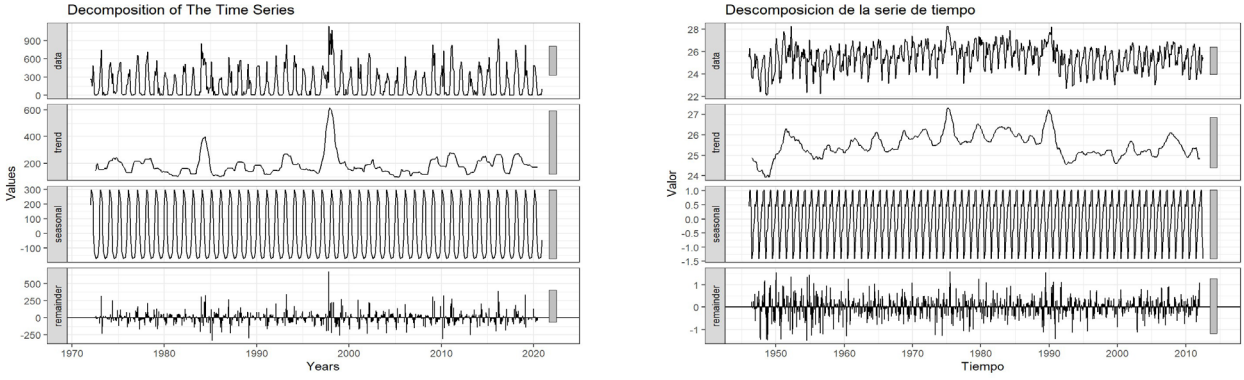

Figure 2: A. Rainfall records. B. Temperature records timeline. Source: Preparation by the Authors based on data from 2023 of the Ecuador Military Geoportal (2024).

and agricultural areas without facing significant geographical challenges, such as mountains or steep slopes. Despite having a large number of gorges and bodies of water, the slopes do not exceed 10 degrees, conditions that make the area prone to flooding (EcuRed, 2025). Low-lying swaths of the canton's western area are also prone to flooding in the rainy season (Flores & Vlassova, 2022). The urban sprawl of the canton has expanded towards these threatened areas, disregarding the physical-natural realities such as proximity to water bodies, slopes, lack of services, or the frequency of adverse events in the area, which impacts the environment and increases the risk of disasters (Narváez Quiñonez et al., 2020; Flores & Vlassova, 2022).

Two seasons of a sub-humid-tropical climate are marked out: rainy and dry. The annual temperature ranges from 22 °C to 31 °C, and abundant rainfall exceeding 2,600 mm per year is recorded, with a regular pattern (EcuRed, 2025). These

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meteorological data are considered for the exposure variable. In terms of sensitivity, population density, access to basic services, the expansion area, and vegetation cover were evaluated. Finally, for the adaptation capacity, the National Climate Change Adaptation Plan (PLANACC) of Ecuador, 2023-2027 (MAATE, 2023) was considered.

IV. METHODOLOGY

This study employed a quasi-experimental design and a quantitative approach to identify the vulnerability to climate change associated with urban growth in the Quevedo canton. For this reason, an applied and exploratory research was conducted.

GIS software with shapefiles from the National Institute of Statistics and Censuses (INEC, 2022) was used to determine the level of exposure to climate risk. Layers were added and adjusted to the canton's boundaries by using the "Clip" tool. The slope layer (derived from a Digital Elevation Model, MDE) and the layer of cantons and provinces, limited to the Quevedo canton, were considered to calculate threat and exposure. In addition, a Geodatabase of Quevedo's sectors (a shapefile of analysis units) was used to assign values by sector, and a table of Redatam attributes (2022 census variables) was linked using a "Join" operation for sensitivity and adaptability (Nieto Cañarte et al., 2023). First, the exposure of each type of soil was calculated based on its slope, classifying them by degree of exposure, as described in Table 2. The final layer was converted to raster and reclassified to obtain the exposure scale.

The climatic threat was also determined using GIS software and the study area layer, where a new column called "Threat" was added to its attribute table (Table 1). Using the "Field Calculator" tool, a value of four (4) was assigned to the entire canton based on weather conditions. This value was used to classify the threat level according to the degree of exposure. As for the analysis of the climatic exposure range, this was based on the aspects established by MAATE (2019) (Table 2).

To assess vulnerability to environmental risks, a sensitivity analysis was performed with socio-economic data processed in "Red7 Process". Two Excel files were created: one for sensitivity analysis (considering the type of housing and construction materials) and another for adaptability (which included factors such as illiteracy and access to services). Percentages and averages were calculated, and this information was added to the shapefile of the canton's sectors to classify the variables later and transform them to a raster format for

Degree of exposure			Ranges
	1	Very low	≤5%
	2	Low	>5 - 12%
	3	Moderate	>12 - 25%
	4	High	>25 - 50%
	5	Very high	>50

Table 1: Attributes according to the Degree of exposure. Source: MAATE, 2019

Exposure	Interpretation of the degree of exposure
The estimation of the degree of exposure considers the proportion of the element susceptible to climatic threats, changes in exposure over time, and the frequency of extreme weather events and their direct physical effects, such as landslides and floods.	Very low. Proportion of the area: 0% to 20%.
	Low. Proportion of the area: 21% to 40%.
	Moderate. Proportion of the area: 41% to 60%.
	High. Proportion of the area: 61% to 80%.
	Very high. Proportion of the area: 81% to 100%.

Table 2: Levels of climate exposure. Source: MAATE, 2019.

Sensitivity	Interpretation of the degree of exposure
The susceptibility of an element to climatic threats depends on its characteristics and increases if the threats impact key resources for the project. It is also influenced by "non-climatic pressures" (environmental, social, political, or economic), identifiable during the diagnostic phase of the PDOT.	Very little susceptibility, allowing the program or project to operate normally.
	Little susceptibility, allowing the program to operate relatively normally.
	Moderately susceptible, limiting the normal operation of the program/project.
	Highly susceptible, causing temporary but frequent closures of the project.
	Very high susceptibility, causing permanent closures of the programs.

Table 3: Considerations for sensitivity analysis. Source: MAATE, 2019.

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their analysis, following the guidelines of MAATE (2019). Following this, the vulnerability analysis considered susceptibility to climate change, encompassing sensitivity to damage and response capacity.

To estimate vulnerability, it is crucial to analyze the relationship between "sensitivity" and "adaptive capacity". In the case of Quevedo canton, sensitivity is evaluated according to the criteria outlined in Table 3, which considers the degree of exposure for the sensitivity analysis.

The adaptive capacity was analyzed when evaluating the response potential of the Quevedo Canton, which considers the capacity of systems, institutions, human beings and other organisms to adapt, prepare, and respond to possible damages, take advantage of opportunities, or face the consequences of climate threats or their effects and the projects with the best responses to climate threats (Table 4).

Finally, to determine the climate risk, the calculation of the raster is carried out with the "raster calculator" tool, applying the formula (1):

$$\text{Climate risk} = \left\{ (\text{Danger})(\text{Exposure}) \left[\frac{(\text{Sensitivity})}{(\text{Adaptive Capacity})} \right] \right\}$$

The results are transformed into a raster and reclassified to analyze the climate risk levels of the canton, classifying them according to the degree of exposure.

V. RESULTS

The threat level, calculated based on the slope layer and meteorological records, indicates that Quevedo Canton is an area prone to heavy rainfall, suggesting a high probability of flooding. Figure 3 shows that most of the canton has a moderate threat level (yellow). There are some scattered areas with a high threat (orange), which are characterized by steeper slopes, making them more susceptible to landslides, erosion, and runoff. As for the level of exposure, also valued by the slope layer and the presence of elements (population, infrastructure, goods), 32.62% of the territory is at a very high level of exposure (red). This area, primarily the canton's central and southeastern sectors, has significant slopes (indicating potential danger) with a high concentration of population and/or infrastructure, which exacerbates the vulnerability. The rest of the territory, a rural area, is at a moderate level of exposure (orange) with 39.24%, which highlights a considerable threat due to the terrain's morphology and the

Ability to adapt	Interpretation of the degree of exposure
The capacity of systems, institutions, human beings, and other organisms to adapt, prepare, and respond to possible damages, seize opportunities, or face the consequences of climate threats or their effects.	Very little. It would not reduce the damage.
	Little capacity. It would not reduce the full extent of the damage.
	Moderate. It would partially reduce the damage.
	High capacity. It would significantly reduce the damage.
	Very high. It would completely reduce the damage.

Table 4: Considerations for the analysis of adaptive capacity. Source: MAATE, 2019.

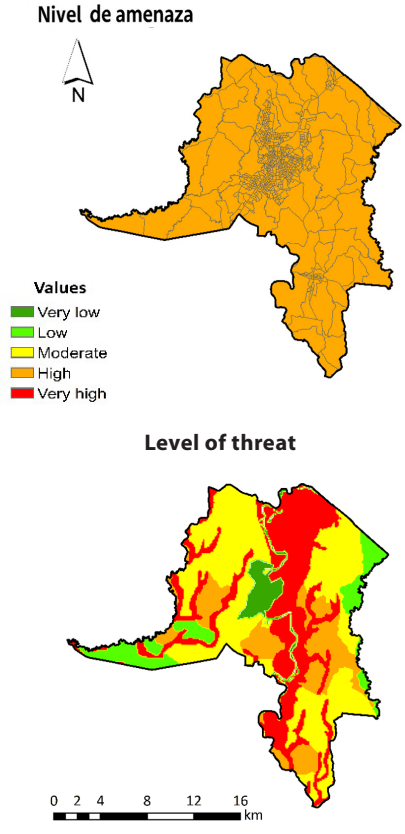

Figure 3: Threat and exposure map of the Quevedo canton. Source: Prepared by the Authors based on data in shape format from the INEC (2022).

CRECIMIENTO URBANO Y VULNERABILIDAD AL CAMBIO CLIMÁTICO DE LA CONURBACIÓN DE QUEVEDO, ECUADOR
CARLOS NIETO-CAÑARTE, PEDRO HARRYS LOZANO-MENDOZA, VÍCTOR MANUEL GUAMÁN-SARANGO, MAYRA CAROLINA VÉLEZ-RUIZ, WILMER MARIO DOMÍNGUEZ-ZÚÑIGA-
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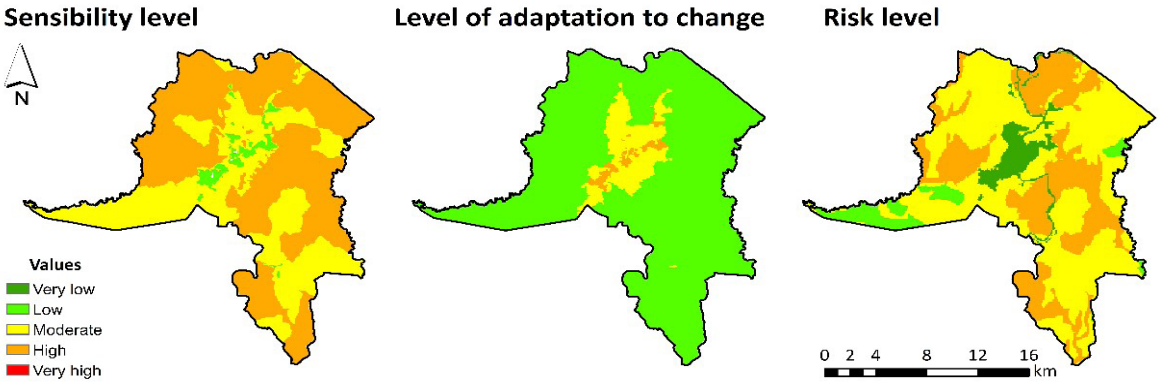

Figure 4: Maps of the sensitivity, level of adaptation to climate change, and climate risk in the Quevedo canton. Source: Prepared by the Authors based on data in shape format from the INEC (2022).

lack of urban planning. The low and very low levels represent only 13.41%, which reflects relatively safer, but smaller areas (Figure 3).

On the other hand, Figure 4 shows sample areas with different levels of sensitivity. An extensive area of the canton, encompassing rural regions, exhibits moderate sensitivity (yellow), indicating an intermediate susceptibility to the impacts of climate change, in conjunction with socio-economic and biophysical factors. However, the areas with high sensitivity (orange), concentrated in the center and southeast regions, are characterized by high population density and intensive agriculture, making them more vulnerable to climate change. Regarding the level of adaptation, the green areas on the map indicate a low capacity for adaptation, resulting in increased vulnerability due to a lack of resources, education, and infrastructure. On the other hand, in some urban and developed areas (yellow), there is a greater capacity for adaptation, suggesting better living conditions; rural and some less-favored urban areas are at a disadvantage in facing climate challenges.

Finally, the climate risk map (Figure 4), which combines threat, exposure, sensitivity, and adaptation, highlights that the high-risk areas (orange) are concentrated in the central and southeastern areas of the canton. This is probably due to an unfavorable combination of high threat, high exposure, high sensitivity, and low adaptability. Research indicates that the most pressured ecosystems are urban areas, crops, and hydrological sources. The projections suggest that the impacts will be most evident in the central and southeastern areas of the canton. Climate change will have a moderate effect, but urbanized land, agricultural lands, and the Quevedo River will be the most vulnerable to temperature and precipitation variations, with a greater probability of extreme events. Urban areas pose the highest level of danger, and pollution and nutrient enrichment will significantly impact both urban and agricultural ecosystems, as well as Quevedo's primary water source.

VI. DISCUSSION

To mitigate climate change, particularly in developing countries, it is essential to comprehend the accelerated urban growth. The creation of intermediate cities without proper planning dismantles the natural vegetation cover, increasing the need for services and resources, which in turn contributes to environmental pollution (Duque & Montoya, 2021). This study corroborates that unplanned urban expansion in Quevedo leads to the progressive degradation of natural ecosystems, as manifested in the loss of riparian forests, alterations in land use, and the degradation of wetlands. This transformation of the urban landscape inherently reduces the ecological resilience of the area by compromising the ability of natural systems to regulate the water cycle and mitigate the intensity of extreme weather events. Thus, the results of this research revealed a relationship between unplanned urban growth, climate change, and climatic vulnerability, indicating a trend towards growth in threatened flood-prone areas, thereby increasing exposure and climatic vulnerability (Song et al., 2023; Lane et al., 2024). It is essential to recognize that informal urbanization not only increases physical exposure but also aggravates pre-existing social inequalities by leaving the most vulnerable populations with less access to basic resources and services to cope with climate impacts (UN, 2024).

On the other hand, it was necessary to outline the spatial distribution of threat and exposure levels, sensitivity, adaptation, and climate risk, which facilitates the

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identification of vulnerable areas in the canton. The results are similar to those reported by other researchers (Ghosh et al., 2022; Kim & Park, 2023; Fan & Zhao, 2025; Kythreotis et al., 2024) who state that the main vulnerability risks are water and soil pollution, the emergence and increase of poverty, the confirmation of diseases caused by climate change, and climate variability. Similarly, it is confirmed that the study area has a moderate risk, consistent with that stated by Burgos Choez et al. (2019) in their study, carried out in the province of Manabi, Quevedo, Ecuador. Through the analysis of the physical, social, economic, and ecological components, they estimated an average global vulnerability of 55%, influenced mainly by the social aspect due to the lack of preparedness to the risk on the part of local government institutions and inhabitants. This is followed by the physical aspect, due to the proximity of a large part of the housing to the river; then the ecological aspect, due to the decrease in vegetation cover and soil sealing, which negatively impacts the provision of vital ecosystem services such as water regulation and erosion protection (Córdoba-Hernández, 2021) and finally, to a lesser extent, the economic aspect, due to the location of the commercial zone on an area with slopes of less than 2.5 degrees. This interconnection between biophysical, social, and economic factors necessitates a holistic approach to vulnerability assessment, which not only maps risks but also understands the underlying socio-economic dynamics that amplify or mitigate climate impacts.

The connection between these findings highlights the importance of planning urban growth sustainably, incorporating strategies that address climatic vulnerability (Ávila, 2024). Based on the literature (Burgos Choez et al., 2019; Mendes et al., 2020), the need to carry out studies of climatic variability, historical in the region, was confirmed, especially in the face of extreme events (droughts, floods, heat waves), to determine vulnerabilities and the capacity of communities to face these risks (Gómez-Guerrero et al., 2021; Murillo Delgado et al., 2023). Climate risk studies, in conjunction with spatial planning plans, response/emergency and adaptation strategies, are crucial for generating knowledge and skills in the most vulnerable communities (Dey & Lewis, 2021; Duque & Montoya, 2021). To address this vulnerability and strengthen ecological resilience, it is essential to implement SBNs that contribute directly to climate change mitigation and the improvement of ecosystem services (Rojas Morales, 2024) in the Quevedo canton.

VII. CONCLUSIONS

In short, the unplanned urban expansion in Quevedo is a key factor that degrades local ecosystems and, consequently, weakens the ecological resilience of the canton by increasing its vulnerability to climatic threats. The cartographic analysis reveals that the Quevedo canton faces a high level of climatic threat, particularly in areas with steep slopes that increase its susceptibility to flooding. Rural areas, with moderate exposure, are equally susceptible to natural disasters, which increases climate vulnerability. When considering sensitivity and adaptive capacity, it is noted that peripheral areas and some rural areas exhibit moderate to very high levels of sensitivity, associated with inadequate housing conditions and construction materials, and have a low adaptive capacity due to limitations in economic resources, educational levels, and access to services. The loss of vegetation cover in these areas also affects the provision of crucial ecosystem services such as water cycle regulation and soil protection, further decreasing their capacity to face the risks. The absence and non-compliance of land use regulatory frameworks exacerbate this vulnerability yet further.

Therefore, to mitigate climate risks in the Quevedo Canton, it is essential to continuously monitor the areas of high exposure and improve the drainage infrastructure by integrating principles of sustainable urban drainage. The construction of more resilient housing and the improvement of existing ones in areas of high sensitivity should be encouraged by using local materials and employing resilient/efficient techniques. It is also crucial to implement participatory education and training programs on climate change and risk management to increase the community's adaptive capacity, preparing them to face future climate challenges. Ultimately, the reforestation and conservation of the natural environment are crucial for improving ecological resilience and strengthening ecosystem services. The implementation of territorial planning policies that restrict development in high-risk areas and protect key ecosystems will also be crucial to ensure the long-term success of these measures.

VIII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization, C.A.N.C.; Data Curation, V.M.G.S.; Formal analysis, M.C.V.R.; Acquisition of financing, C.A.N.C.; Research, P.H.L.M.; Methodology, M.C.V.R.; Project management, W.M.D.Z.; Resources, C.A.N.C.; Software, P.H.L.M.; Supervision, M.C.V.R.; Validation, P.H. L.M.; Visualization, W.M.D.Z.; Writing – original draft, V.M.G.S.; Writing – revision and editing, W.M.D.Z.

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APROPIACIÓN COLECTIVA DEL ESPACIO PÚBLICO BARRIAL. REFLEXIONES SOBRE EL PROYECTO "CAMINO AL BARRIO", CALI, COLOMBIA
CAROLINA POLO-GARZÓN, CRHISTIAN CAMILO VILLA-VELASCO
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COLLECTIVE APPROPRIATION OF NEIGHBORHOOD PUBLIC SPACE. REFLECTIONS ABOUT THE "CAMINO AL BARRIO" PROJECT, CALI, COLOMBIA [1]

APROPIACIÓN COLECTIVA DEL ESPACIO PÚBLICO BARRIAL. REFLEXIONES SOBRE EL PROYECTO "CAMINO AL BARRIO", CALI, COLOMBIA

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Este artículo muestra las reflexiones del proceso de investigación desarrollado en articulación interinstitucional entre entidades públicas y privadas, adelantado en el sector de San Francisco del barrio Siloé de Cali, Colombia, entre los años 2018 y 2023. Objetivo: trabajar con una comunidad vulnerable frente a condiciones socioambientales, al motivar su participación y empoderamiento como actores de cambio, al tiempo que se fortalecían los vínculos vecinales que dan soporte a procesos de mejoramiento del espacio público urbano del sector. Metodología: bajo un estudio cualitativo, se tomaron elementos de la Investigación Acción Participación (IAP), para adelantar acciones de mejoramiento del espacio público a escala barrial, al tener como norte la formación e integración vecinal desde un nuevo sentir social y comunitario, a través de recorridos urbanos, talleres participativos y grupos focales. Resultados: aplicación de una estrategia de ejecución de proyectos de base comunitaria que canaliza las potencialidades del liderazgo comunitario y permite avanzar hacia ciudades con espacios públicos más articulados, funcionales y con una operatividad en servicio de la comunidad. Conclusiones: el proyecto arrojó la conformación del colectivo barrial "Camino al Barrio"; estrategia con enfoque pedagógico, para fomentar la participación ciudadana y la apropiación colectiva del espacio público barrial.

Palabras clave: cultura de paz, participación comunitaria, autonomización, desarrollo comunitario, planificación urbana.

This article presents reflections on the research process conducted through inter-institutional coordination between public and private entities in the San Francisco sector of the Siloé neighborhood in Cali, Colombia, between 2018 and 2023. Objective: Work with a vulnerable community in the face of socio-environmental challenges, motivating their participation and empowerment as agents of change, while strengthening neighborhood ties that support urban space improvement processes in the sector. Methodology: This qualitative study employed elements of Participatory Action Research (PAR) to implement actions aimed at improving public space on a neighborhood scale. The goal was to foster training and neighborhood integration through a new social and community feeling, achieved via urban routes, participatory workshops, and focus groups. Results: Application of a community-based project strategy that channels the potential of community leadership and allows progress towards cities with more articulated, functional public spaces that operate in the service of the community. Conclusions: The project led to the formation of the neighborhood collective "Camino al Barrio," a strategy with a pedagogical approach to encourage citizen participation and collective appropriation of neighborhood public space.

Keywords: culture of peace, community participation, autonomization, community development, urban planning.

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I. INTRODUCTION

The accelerated urban expansion in Latin American cities has generated a series of problems associated with informal settlements, especially on hills and mountainsides. These neighborhoods are characterized by conditions of social and environmental vulnerability, as well as a high risk of disasters. This study focuses on the case of the San Francisco neighborhood, located on the hillside of the city of Cali, Colombia, where factors such as poverty, violence, and environmental deterioration have generated a context of social exclusion and limited quality of life for its inhabitants.

In this sector, flooding and flash floods have occurred as a result of the Isabel Pérez gorge, located in the sector's lower part, overflowing. This has produced enormous material losses, the collapse of homes, and the loss of human lives since 2016. Municipal authorities have tried to address this complex problem; however, no substantive solutions have been implemented that effectively involve the community.

There is a growing concern about citizen participation and the mechanisms to enhance its effectiveness in urban decision-making. However, there are still gaps in understanding how long-term community interventions influence the development of active citizenship and the transformation of urban spaces.

This study aims to analyze the case of Camino al Barrio, identifying the factors that facilitated citizen participation, the changes observed in the social fabric and public space, and the lessons learned for future interventions. It is expected that this study will contribute to enriching knowledge about social intervention practices and inform the design of more participatory public policies.

Firstly, the text illustrates the contextualization of the place and the importance of public space as a facilitator of social structures. Subsequently, the methodology, based on the sociological intervention and Participatory Action Research (PAR) approach, is presented. The results obtained show three elements: 1) intervention and accompaniment strategy, 2) community-based exercises, and 3) consolidation of the proposal and the Camino al Barrio collective. Finally, the discussion and conclusions focus on the dilemma of building and reconstructing in the neighborhood of Cali, which provides valuable lessons for implementing similar projects in similar contexts.

II. THEORETICAL FRAMEWORK

Extreme weather events, such as flooding or flash floods, disproportionately affect vulnerable communities due to their limited capacity to respond. The distribution of these impacts is not equitable; the poorest regions and developing countries are disproportionately affected, as their coping mechanisms are often overwhelmed (United Nations Development Programme [UNDP], 2008; Pörtner et al., 2022). In the case study, there is evidence of an increase in impervious areas and human settlements at the expense of forest and environmental protection areas. This significantly raises the risk of flooding due to increased surface runoff, since the "gray infrastructure" (Chen et al., 2021) disrupts the natural hydrological cycle of assimilation, infiltration, and evapotranspiration.

From the human sciences, the problem of risks is understood as a social construction and a rational perception influenced by the lack of information and the omission of social dynamics (Duclos et al., 1990; UN-Habitat, 2012; Vallejos-Romero et al., 2022). For this reason, it is essential to strengthen territorial governance from the communities, articulated with government development policies, to establish an alternative public management model of co-responsibility between the State and society.

According to Bonilla Sandoval (2012), achieving greater protection and social equality can foster transformative economic dynamism. The challenge lies in finding the synergies that allow equality, growth, and sustainability to generate virtuous dynamics that promote social inclusion and reduce territorial inequalities. These productive, social, and territorial synergies can positively impact the collective imagination (ECLAC, 2012) and open up opportunities for community work that improves the living conditions of vulnerable populations. For this reason, the proposal was structured based on the identification of the vulnerability issue and the potential for social resilience in the study area.

In this context, the proposal seeks a new way of understanding the city and the role of citizenship in shaping public space, which involves its shared use by citizens and community-based citizen representative bodies (Cuéllar Obando, 2015). Participation promotes pride and awareness about taking care of one's physical environment (Hernández García, 2008; Ong et al., 2018; Matherne et al., 2018; Ibarra-López, 2023). In this project, the community focused on improving the neighborhood's public space, as its collective nature makes it a key point for self-organization in the common interest.

The public space, as Jane Jacobs (1961) notes, is fundamentally a construction on a human scale. Its design and management are crucial for strengthening social life, fostering interactions, promoting community cohesion, and empowering the inhabitants. Regarding the community process, this project is based on two theoretical pillars of Jacobs' work (1961): first, public space as an adaptive organic system, which is planned with a "bottom-up" approach that gives priority to the role of the local community to address

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Figure 1: Location of the city of Cali in Colombia. Source: Google Maps, 2025.

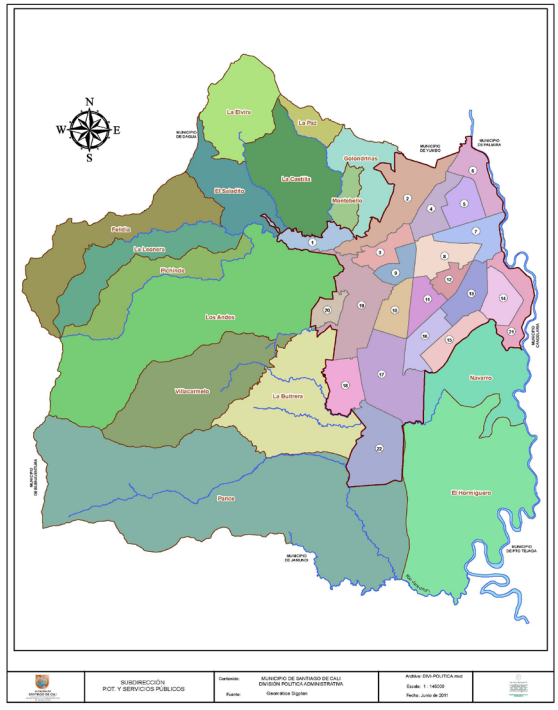

Figure 2: Location of the case study. Source: Mayor's Office of Santiago de Cali, 2014.

territorial challenges; and second, its role as a facilitator of a network of more resilient neighborhood relations with the capacity for self-organization.

From the perspective of community resilience, the work of Jacobs (1961) is complemented by that of Granovetter (1973). While Jacobs highlights the importance of human interactions for neighborhood cohesion in what can be called "strong or intermediate ties", Granovetter (1973) emphasizes that community resilience, measured from its capacity for adaptation, innovation, and access to external resources, also depends on the existence of "weak ties".

In his theory, 'the strength of weak ties,' Granovetter (1973) states that weak ties allow opportunities, resources, or ideas for improvement to flow from outside the circle of strong ties of a community, which encourages access to different perspectives and solutions that can contribute to the improvement of public space and the empowerment of the community. That is, strong ties give internal confidence, while weak ties connect the community with a broader world of resources and information.

Taking this into account, the methodology designed allowed for the identification of strong, intermediate, and weak ties in the community. Strong and intermediate ties (organized community) were key to integrating weak ties (detached individuals). The latter, as they became involved, not only showed increasing interest but also brought unexpected and valuable external contacts to the process.

III. CASE STUDY

The Camino al Barrio project was conducted in the city of Cali, in Colombia (Figure 1), in a sector known as Siloé, located in commune 20 (Figure 2). This area is located on the western margin of the city, marking the urban-rural border. It is one of the points where the urban layout ends, adjoins rural land, and borders the city's environmental reserve, known as the Los Farallones National Natural Park.

IV. METHODOLOGY

The project employed elements of the Participatory Action Research (PAR) methodology (Fals Borda & Rodríguez Brandão, 1987), particularly in the qualitative data obtained from direct observation, which involved the application of interpretative and analytical procedures to address the object of study

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Figure 3: Project participants. Source: Prepared by the Authors, 2020.

(Colmenares, 2012; Delgado-Algarra, 2015). The strategies were applied transversally throughout the project. During the local participatory diagnosis, tours of the area, interviews and meetings with community leaders, and participatory workshops were conducted for the diagnostic stage, as well as the collective construction of a map of the project's actors and their lines of action at the local level.

The methodology applied aimed to transform community attitudes, particularly in San Francisco and its agents, in favor of physical intervention in the area. To this end, activities were held to ensure the permanence of people in the intervention activities, most of which involved sharing food, cultural activities, and sports activities.

Participants

The project aimed to connect all citizens living in the sector. To achieve this, a focus group of community leaders was formed, who work in different instances according to the role assigned within the process (Figure 3). Female participation stands out, since out of the thirty (30) community members who permanently participated in the project, fourteen (14) are female leaders who already had a particular background in the local context.

Tools

To conduct the project, guided visits were conducted with community leaders, and technical and logistical support was provided by entities such as the Administrative Department of Environmental Management (DAGMA), the Special Administrative Unit of Public Services (UAESP), and the Secretary of Citizen Security of the Municipality of Cali. Local meetings and festivities were also attended to strengthen the ties between the project's group of professionals and the community.

Procedure

The proposed methodology was conducted following the thematic phases and lines associated with Urban Pedagogy (Pérez Preciado, 2000; Rubio Noha & Majadas Andray, 2007; Salinas, 2009; Páramo, 2009; Mora Ardila, 2012; Moncada Cardona, 2015; Lopes, 2016; Mora Gómez, 2018), in three moments: a) Recognizing the city and the neighborhood context, b) Identifying the problems and potentialities of urban space and, c) Participation and responsibility as a citizen (Villa Velasco, 2020).

V. RESULTS

The intervention began in the profound ignorance of the community where it would take place, and with the reading of some references, especially those related to Participatory Action Research (PAR) (Fals Borda & Rodríguez Brandão, 1987; Martí, 2002; Colmenares, 2012; Arkedis et al., 2021). In this context, PAR focuses on transcending academic language and aims to connect scientific knowledge with the wisdom and experiences of communities, utilizing various citizen participation mechanisms with multiple dimensions, including inclusion, deliberation, and impact on public policies.

However, it would be discovered that, while the exercise was taking shape, a mobilizing agent in the dynamics between external agents (researchers, government entities, private parties) and neighborhood and community forms of organization is the work around food. The latter would indicate a harsh reality that these exercises face: it is difficult to mobilize people to causes such as "the environment" or "risk management" when people attend meetings on a diet of two meals a day. In this context, the dimensions, scope, limitations, and achievements of voluntary and solidarity action (García-

Colín & Verduzco Igartúa, 2016) are associated with a notion of reciprocity (Zamudio-Nieto et al., 2018).

Documents were reviewed, and initially, five (5) community leaders of the sector were spoken to, seeking guidance on how to consolidate the exercise. All the neighbors with whom we spoke had an interest in working together; however, each one had their particular interest, and in most cases, they were looking for a personal benefit. In this context, the decision to work on improving the neighborhood public space as a strategy to mobilize people towards collective thinking turned out to be a good decision, as the communities actively participate in the transformation of the problems identified for the transformation of reality, and this participation is more cohesive if it is around a common goal (Valderrama Hernández, 2013).

In the process, as already indicated in the methodology, some projection activities were carried out, in which more people from outside the neighborhood participated than the sector's inhabitants themselves. The exercise focused on community work with the following premises (Enesterio Reyes & Góngora Trujillo, 2010): 1) community work with a global approach, which will go beyond the assistance of conventional interventions, 2) community work for the development of a project in the area that involves an interdisciplinary approach and, 3) community work that relies on existing social organizations to achieve a common goal.

The beginning of the process did not extend beyond assistentialism and the exchange of goods for participation, and some similar interventions do not exceed this level (Velásquez Carrillo, 2001). At this point, it was evident that work with communal action groups is currently devalued and highly permeated by various forms of political patronage. These legitimize the continuity or the promotion of political projects, some of which are self-described as "alternative" ones that continue to use classic repertoires of outreach with political groups, where promises and institutional supports stand out, which, without the approval of some state organs, are practically impossible (Fals Borda, 1999).

One of the great lessons that emerged from conducting community-based exercises is this. If the project or strategy does not have immediate access to financial resources for its consolidation, people's expectations may turn against the project, given that community actors have immediate needs to address in their environment, and sometimes the patience and slow response with which external agents are mobilized is not tolerable.

So, what allowed the intervention to be different in this context? Several elements. To begin with, the project team was not the only actor in the territory; there were other participating entities. Interestingly, a turning point occurred when several community members asked to work together, all in the same meeting space. Here, from an academic and university exercise, one moves on to a community one, one that from now on would be called Camino al Barrio.

This scenario allowed combining efforts and financial, logistical and technical resources of the participating institutions, which allowed participatory planning with the following principles (Elvis Sierra & Peña Fajardo, 2013): 1) The planning and the expected results were always thought to benefit the community, 2) Identification of problems and viable solution alternatives according to the local context, 3) The commitment and willingness to action and organized mobilization by the community to implement the plans was the pillar of the project.

Another distinctive element of this project was the close and ongoing collaboration with the community, which was grounded in Urban Pedagogy (Páramo, 2009). Through this, it is sought that communities learn to participate in the construction of the city, the latter, understood as a learning environment (Sarmiento-Díaz, 2023), where, based on the route of the territory, it is possible to make a comparison between urban reality, the norm, theory, and imaginaries, to understand and transform public space. In this context, the city is viewed as a valuable educational resource in socio-urban participation and integration processes (Guzmán Ramírez, 2020). These guided tours enabled the community to become familiar with and reacquaint itself with its context and the habitability conditions associated with occupying the hillside land (Figure 4).

The multidisciplinary team comprised different external agents: Undersecretary of Territories, Inclusion and Opportunity TIO of the Mayor's Office of Cali, YMCA-Cali Christian Youth Association, and the team of teachers and students of the Universidad del Valle (architects, visual designers, communicators, sanitary engineers), who came together to plan actions in the area, discuss problems, provide training on a topic, or share.

In the meetings, regardless of the role or rank, decisions were made collectively. There were no notable leaders, and actions were not decided until everyone in the group had approved them. As a result of the exchange of ideas, it was decided to prioritize the intervention of a public space. This included the construction of a retaining wall using tires, the planting of vegetation to stabilize the land on the slope, the installation of a sustainable urban drainage system that filters runoff water from the upper part of the slope, and the construction of an urban garden.

One of the highlights of the process was the high level of female participation. The collective comprises more than fourteen (14) women who continuously and permanently worked in the Female Panel, which would become the driving force for the project. They worked long days, during which, thanks to their efforts, one of the project's most significant challenges would be consolidated: motivating participation in an urban intervention

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Figure 4: Occupation of the hillside, San Francisco sector. Source: Prepared by the Authors, 2020.

Figure 5: Women were the driving force behind the community work exercise. Source: Prepared by the Authors, 2021.

exercise. The role of women and their positive impact on territorial and community exercises is highlighted (Figure 5). Their participation in this project represents a concrete and quantifiable action to close the inequality gaps between men and women (UN Women, 2016).

VI. DISCUSSION

The "Camino al Barrio" project, conceived in Siloé, successfully brought together neighbors, the government, and academia over a period of more than two years to improve the urban environment. Its key achievements include community empowerment and leadership, collaborative learning, the construction of lasting networks, and the appropriation of public space.

The project provides methodological guidelines to facilitate progress in the effective engagement of the community, as the leading actors in defining the problems and solutions were the neighbors themselves. From a horizontal approach, teamwork was also prioritized, and the concentration of power in a few leaders was avoided, which promoted reflection on practices and power dynamics in the community and allowed recognizing the importance of the collaborative process, where the transformation process was valued more than the immediate results.

Among the primary challenges faced by the project are the rotation of participants, resistance to change, and limited resources. Camino al Barrio demonstrated the importance of community participation in achieving social and urban change. In addition, it highlighted the need for different actors and disciplines to collaborate on addressing complex city problems through joint initiatives that have the potential to be lasting, as is the case with this project.

VII. CONCLUSIONS

This experience highlighted a severe criticism of urban development models that fail to integrate the daily subsistence needs of vulnerable communities into their strategies. The expectation of effective participation in collective causes crumbles in the face of immediate needs, which reveals a deep gap between external agendas and the reality of the communities. For this reason, achieving community participation was the greatest challenge of the project.

The transformation of a neighborhood public space has become a successful strategy to catalyze participation, revealing that working towards tangible and common goals brings the community together in a way that welfare or clientelist approaches do not achieve. The collaboration between multiple external actors and the community, united under the "Camino al Barrio" project, was fundamental to pooling resources and planning participatory actions that benefited the population.

Under the "Urban Pedagogy" approach, the inhabitants understood and transformed their environment. The remarkable and sustained participation of women as the driving force behind this process was highlighted, demonstrating the transformative power of women in community motivation and reducing inequality gaps. This underlines the need to integrate gender perspectives into any community development initiative.

This participatory process in Siloé is unprecedented and culminated in the construction of a public space dreamed of and designed by the community itself, the result of collective effort. This achievement is a powerful demonstration of the transformative power of strategic alliances and community leadership in driving change to the physical and social environment.

VIII. AUTHOR CONTRIBUTIONS CRediT:

Conceptualization, C.P.G.; Data curation, C.P.G.; Formal analysis, C.P.G.; Funding acquisition; Investigation, C.P.G., C.C.V.V.; Methodology, C.C.V.V.; Project management; Resources; Software; Supervision; Validation; Visualization; Writing – original draft, C.P.G.; Writing – review and editing, C.P.G., C.C.V.V.

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ABANDONED BARRACKS AS URBAN VOIDS. REUSE AND REGENERATION IN THE ITALIAN CASES OF LUPI DI TOSCANA AND SANTA CATERINA[1]

LOS CUARTELES ABANDONADOS COMO VACÍOS URBANOS. REUTILIZACIÓN Y REGENERACIÓN EN LOS CASOS ITALIANOS DE LUPI DI TOSCANA Y SANTA CATERINA

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Esta investigación aborda los factores determinantes para desencadenar la reutilización de los cuarteles militares abandonados en Italia, un tema relativamente poco estudiado comparado con otros vacíos urbanos, así como el impacto de la reutilización en términos de regeneración urbana. Centrándose en dos casos ubicados en las ciudades de Florencia y Verona, los resultados de este análisis, basado en una metodología cualitativa y trabajo en terreno, ponen de manifiesto la complejidad y desafíos de los procesos de reconversión, que refleja las dificultades y avances logrados en cada caso. La caracterización de ambos procesos permite indicar las causas principales que han influenciado las acciones de regeneración urbana (prolongado abandono, cambio de titularidad en la propiedad, financiación estatal y enfoque integral), además de otros elementos, como el gran coste económico de las operaciones, que pueden impedir que estos desarrollos se conviertan en edificaciones sostenibles e integradas en la ciudad.

Palabras clave: áreas suburbanas, cuarteles militares, uso del suelo, reurbanización, desarrollo sustentable

This research examines the determining factors that trigger the reuse of abandoned military barracks in Italy. This topic, as well as the impact of reuse on urban regeneration, has been relatively understudied compared to other urban voids. Focusing on two cases located in the cities of Florence and Verona, the results of this analysis, based on a qualitative methodology and fieldwork, highlight the complexity and challenges of the conversion processes, reflecting both the difficulties and progress achieved in each case. The characterization of these processes allows identifying the leading causes behind urban regeneration initiatives, including prolonged abandonment, changes in ownership, state funding, and a comprehensive approach, among others. It also highlights other elements, such as the significant economic cost of operations, which may hinder these developments from becoming sustainable buildings that are integrated into the city.

Keywords: suburban areas, military barracks, land use, reurbanization, sustainable development

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I. INTRODUCTION

The conversion of military installations to civilian uses can trigger urban regeneration processes in areas that go beyond physically, symbolically, and socially separating these spaces from their surroundings (Balarezo-Alberca, 2024). In the case of barracks, intended for the accommodation and training of soldiers, these are areas that occupy a large swath of land, constituting a specific typology of urban emptiness.

Although the international literature has mainly addressed the conversion process for national and local urban policies (Peric & Miljus, 2021) and specific topics such as urban development and heritage (Jevremović et al., 2021), few studies have analyzed the factors that contribute to generating the new uses (Szabó et al., 2025). Italy, among other countries, is a notable case in the literature, primarily due to the significant influence that military barracks have had on the expansion and urban planning of many cities (Floris, 2024). Many of the conversion initiatives, especially in Italy, have been superficially analyzed (Spanu, 2023), as, when evaluating them, both in the implementation phase and regarding the results obtained, the triggers for the successful implementation of the conversion processes have not been identified, which has hindered the understanding of urban regeneration issues (Camerin, 2021).

That is why this article focuses on the physical-spatial analysis of the old "Lupi di Toscana" and "Santa Caterina" barracks, located in peripheral areas of the Italian cities of Florence and Verona, respectively, and their conversion processes to civilian uses. The primary objective is to identify, through the analysis of these two experiences and the application of a qualitative methodology, the triggers of their transformation and the tools used to implement urban regeneration in these peripheral areas.

By addressing the conversion of two barracks, the article participates in the field of urban regeneration research in three ways. Firstly, it presents an internationally applicable methodology for comparative analysis of urban voids. In the field of urban studies, most of the research has focused on individual case studies, with few comparative analyses of barracks conversion (Camerin, 2024). Secondly, an approach based on the systematic analysis of primary and secondary sources, combined with fieldwork and archival research, is proposed. Finally, two conversion projects pending implementation are evaluated to broaden knowledge about the issue at hand, which has been barely analyzed by the authorities (Commissione 4 Difesa, 1999).

II. THEORETICAL FRAMEWORK

With the end of the Cold War, a shift in the role that the Armed Forces should fulfill in the 21st century began to emerge. Thus, the countries that were part of NATO and the Warsaw Pact underwent a gradual rationalization process of their armed forces, which involved a reduction in personnel and a decrease in occupied territory. This rationalization was also due to national budgetary revision policies aimed at reducing public debt (Adisson & Artioli, 2020). As a result, the progressive abandonment, underutilization, and dismantling of military real estate assets, including airports, warehouses, shooting ranges, barracks, and powder magazines, were observed. It was estimated that, globally, more than 8,000 military facilities were dismantled, covering approximately one million hectares (Bonn International Center for Conversion [BICC], 1997: 2). This phenomenon was accompanied by domestic conversion programs such as those launched in the United States and France by ***Base Realignment and Closure*** (Clanahan, 2021) and ***Mission pour la Réalisation des Actifs Immobiliers***" (Piganiol, 2022) respectively. On the other hand, in countries such as Spain, only specific closures were decreed (Camerin & Córdoba Hernández, 2023), while one of the few studies that analyzes several conversion cases is that of Bagaeen and Clark (2016).

Although the first transfer program was launched in Italy in 1997, a severe lack of global vision was detected in both the state and local public debates regarding its relationship with territorial planning policies (Camerin, 2022). In light of the absence of a public census of the change of the military presence at a national level (Romano, 2017), it is especially complex to classify cases of reuse as a driving force of urban regeneration. Even so, there is evidence of old facilities that have undergone spontaneous re-naturalization processes, gradually turning them into potential ecological corridors (Ellwanger & Reiter, 2019).

The old barracks and their conversion management are considered a specific typology of "urban emptiness" (Berruete-Martínez, 2017), that is to say, not only as a deteriorated space, but as a complex figure, loaded with potential meanings — historical, identity, or social - that can play a transformative role in urban regeneration processes. Camerin and Córdoba Hernández (2024) underlined their complexity, given the reintroduction of barracks into the city's socio-economic system. This implies interdisciplinary approaches for the recovery of both open and built military spaces, based on the conjunction of architectural, economic, social, and urban aspects that coexist to alter the pre-existing relationship between the previously impassable military areas and their role in the current city. Therefore, their functional and spatial reintegration would require specific actions to balance the relationship between their historical and patrimonial permanence and the existing fabric (Dekel, 2021),

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which makes new uses compatible with contemporary social needs, especially in terms of endowments that guarantee local social reproduction (Balarezo Alberca, 2020).

These spaces, built in Europe between the 19th century and the Second World War, share constructive quality, a discreet state of conservation, and an amplitude and modularity of the built spaces that allow implementing a wide range of new roles that preserve the existing architecture, as pointed out by Turri and Zamperini (2017), despite the difficulties inherent to their reuse. Similarly, their rationally defined and standardized layouts, equipped with wide open and green spaces, initially intended for circulation and training, have the potential to become true "cities within the city," featuring tree-lined avenues and squares (Turri et al., 2008). However, Cacciaguerra and Gatti (2009) point out the existence of a trend in the dual management of abandoned military heritage: military architectures built before 1900 are considered as "cultural heritage" and are treated as a material heritage of military architecture to enhance improvement through rehabilitation, while barracks built between 1900 and 1950 are usually treated differently, since they are perceived as buildings of little architectural value, so their demolition is commonly accepted. Military historical heritage should be handled differently, rather than being demolished to make room for new morphological conformations that are suitable for the needs of 21st-century society.

III. CASE STUDY

The choice of cities and barracks is based on several similar characteristics that help make a comparative analysis based on four common elements:

- Free transfer of the ownership of the "Lupi di Toscana" (2015) and "Santa Caterina" (2016) barracks to the Municipalities by the Ministry of Defense, through the ***demaniale federalism*** mechanism.
- Peripheral location and size greater than 100,000 m^2 are considered an indicator of the potential for transformation.
- Preparation of Master Plans for the conversion. Both documents decreed transformative urban projects that involved modifying local urban planning instruments. In the case of Florence, the Modification to the General Urban Planning Plan placed the barracks in a broader scope of transformation that involved other non-built-up areas around it, covering a total area of 200,000 m^2. For its part, the master plan for the Santa Caterina barracks has not yet been integrated into local urban planning instruments. However, it was considered within the territorial project for the city's candidacy for Italian capital of culture in 2022.
- Beneficiaries of state funding of the "Innovative National Program for Quality of Life" **4** national call, whose objective is to reduce the lack of affordable housing, regenerate the socio-economic fabric of the field of action, in addition to improving accessibility, functionality, and safety of abandoned and degraded spaces. Faced with a planned total cost of €200,000,000 for the Lupi di Toscana barracks and approximately €27,000,000 for the Santa Caterina barracks, the 2021 resolution allocated subsidies of 16% (€32,410,759) and 55% (€15,000,000), respectively, for works that should be completed by 2026.

The Lupi di Toscana barracks occupy approximately 102,015 m^2 in the southwestern periphery of Florence (Figure 1). It spans approximately 33,000 m^2, situated around a large central green square, comprising 26 buildings. Inside the enclosure, a hydraulic power plant and a 25m-high, 80 m^3 concrete water tower stand out. Conceived as isolated and monofunctional U-shaped pavilions, organized in groups of three on both sides of the large central square, the barracks are one of the best examples of functional military architecture in Italy, characterized by a search for maximum ventilation and sunshine. Despite their valuable morphology, these elements have suffered prolonged neglect, resulting in drastic deterioration. In their immediate surroundings, there is vacant land and fragmented residential areas, as is often the case in many other Italian urban peripheries, along with three key attractors of activity: the "Ponte a Greve" shopping center, the "San Giovanni di Dio" Hospital, and a Rehabilitation and Healthcare Center. Accessibility to the city center is guaranteed by public transport thanks to the tram, although the area is subject to traffic congestion at peak hours.

For its part, the Santa Caterina barracks occupies 226,000 m^2 on the Veronese periphery, southeast of the urban center, between the banks of the Adige River and the Milani canal (Figure 2). This settlement is divided into two contiguous constructions: a heritage-protected Vauban-type fortification of 126,000 m^2, built between 1850 and 1852 as part of the city's broader fortification system that, between 2013 and 2020 was the

4 "*Programma Innovativo Nazionale per la Qualità dell'Abitare*" (https://www.mit.gov.it/comunicazione/news/pnrr-assegnati-28-mld-per-il-programma-pinqua-sulla-qualita-dellabitare-il-40-va).

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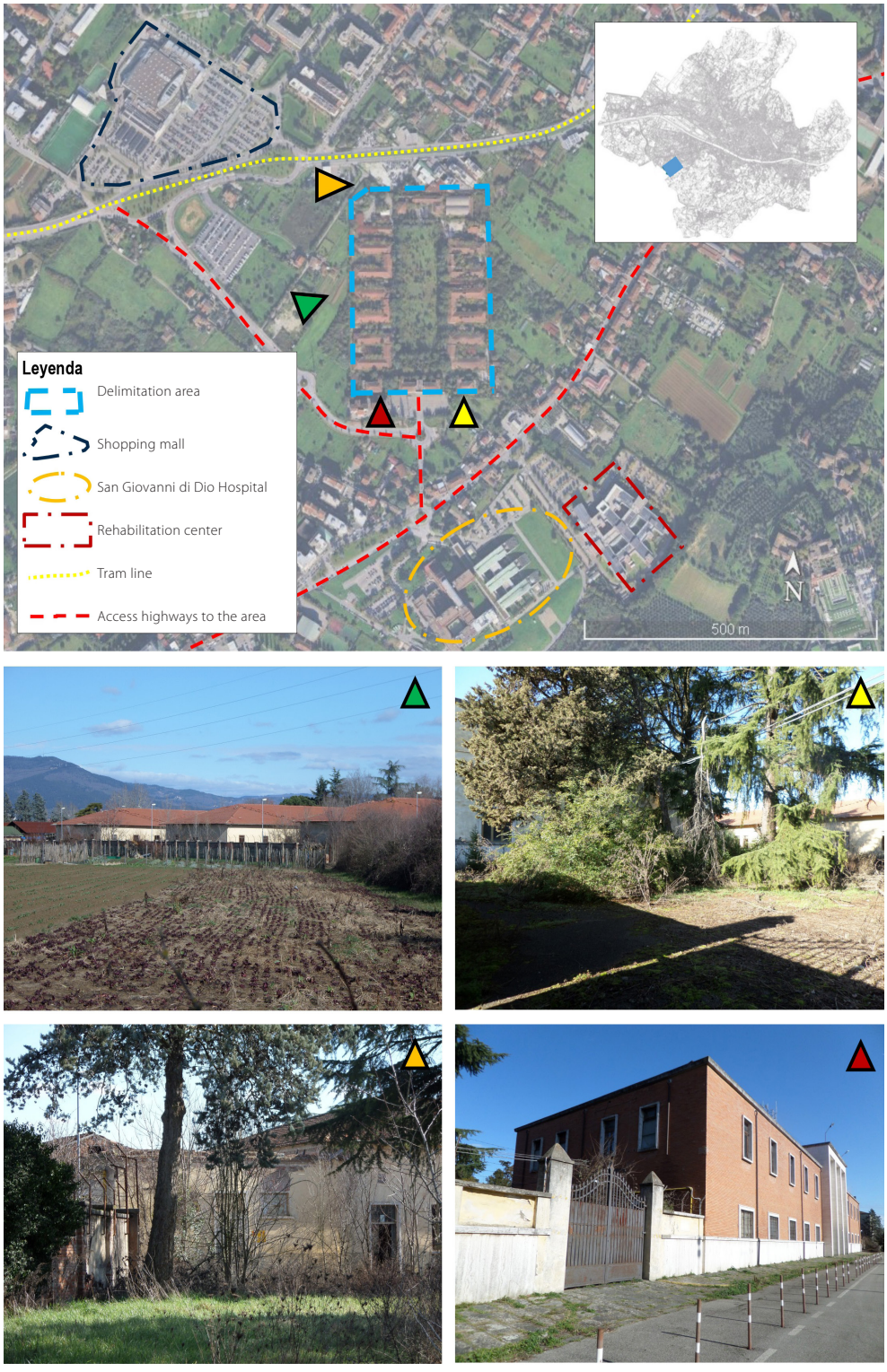

Figure 1. *Walkable catchment*of the Lupi di Toscana barracks and photos of the area. Source: Prepared by the authors (2025).

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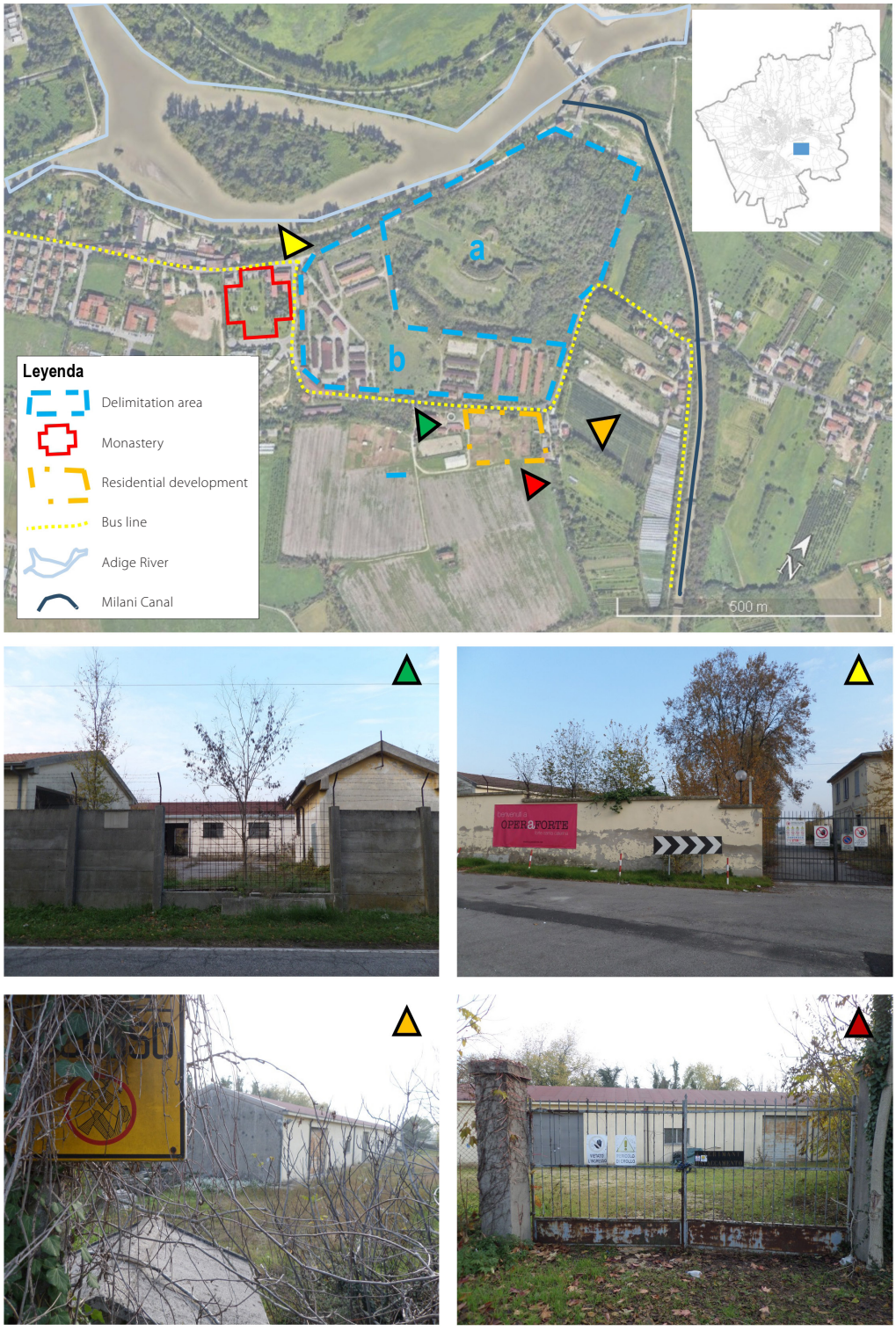

Figura 2. *Walkable catchment* of the Santa Caterina barracks and photos of the area (a: fortification, b: barracks). Source: Prepared by the Authors (2025).

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Variables	Lupi di Toscana Barracks	Santa Caterina Area	
		Fortification	Barracks
Plot size	102,015 m2	126,000 m2	100,000 m2
Built surface	33,000 m2	2,700 m2	77,920 m2
Buildings	26	2	30
Year of construction	1941-1947	1850-1852	1950
Year of underutilization	1995	1970-1997	1997
Year of abandonment	2008	1997	2008
Year of transfer	2016	2013	2016
Number of buildings	26	2	30
Listed buildings	Military Command Building	All	None
Type of morphology	Functional	Vauban-type fortification	None
Temporary reuse	No	1998-2005 and 2013-2020	No
Public participation process	Yes	No	
Average rental and sale prices of homes at a city and area level	City rent: €14.18/m2 City sale: €4,316/m2 Local rent: €14.98/m2 Local sale: €3,763/m2	City rent: €11.54/m2 City sale: €2,583/m2 Local rent: €9.73/m2 Local sale: €1,957/m2	
Cost of the works	€200,000,000	€27,000,000	
Public financing	€32,410,759	€15,000,000	

Table 1. Case studies information. Source: Prepared by the authors (2025).

headquarters of the "Operafortefestival" **5** cultural initiative; and the 100,000 m^2 and 77,920 m^2 barracks, built during the 1950s, and distributed in 30 non-listed buildings without any formal distribution. Around it, there are open spaces accompanied by a company, the ***Monastero di Clausura Serve di Maria Oblate Sacerdotali***, and a residential area of 30,000 m^2 under construction**6** in 2024. Although the area has a bus transport system that ensures connection with the urban center, the transport infrastructure favors the private motorized vehicle as the primary mode of mobility.

IV. METHODOLOGY

At the methodological level, the qualitative perspective enables the analysis of the interrelation between both cases and their immediate surroundings, allowing for an independent exploration of their adaptation to civil use projects. For this, in October and November 2024, semi-structured interviews were conducted to 5 people for each case study (the local town planning councilor, two town planning professors from the local universities and two citizens representing the local associations), accompanied by direct observation, through a field study in each case study**7** and an in-depth documentary analysis of primary and secondary sources (historical cartography, territorial planning, legislation, and press) in the historical archives of the two municipalities.

The primary data for the barracks are presented in Table 1, along with a brief description of the context, using the concept of ***walkable catchment*****8**, as well as a valuation proposal based on the 10 aspects proposed by Ricci et al. (2022). These indicators have been chosen as they propose evaluating qualitatively how the conversion of urban voids can trigger a process of urban regeneration and sustainable development.

5 Evento de teatro, cine al aire libre y música en vivo celebrado cada verano, organizado por una organización sin ánimo de lucro (*Ippogrifo Produzioni*), en colaboración con el Ayuntamiento (http://www.operaforte.it/).
6 http://www.viveresantacaterina.it/
7 The work consisted of a visit to each barracks in December 2024 (without being able to enter their premises for security reasons) and its surroundings independently, taking photographs and notes on the characteristics of urban environments.
8 It consists of identifying the functions located around a certain point within a 5-minute walking radius.

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Variables	Lupi di Toscana Barracks	Santa Caterina Area
Local and supralocal governance	1	1
Public participation	2	0
Sustainable mobility	2	1
Preservation of the existing environment	1	1
Compatible/integrated conversion	2	2
Historical and heritage issues	1	1
Social aspects	2	0
Public facilities	2	1
Common goods	1	1
Renewable energy use	1	1
Total	15/20	9/20

Table 2. Aspects of conversion processes. Source: Prepared by the Authors

Using these indicators provides a comprehensive and multidimensional view of sustainable urban development across various key aspects. This helps consider whether reuse projects of abandoned spaces only physically transform the areas, or if they generate positive impacts on social, economic, and environmental levels. To achieve this, the 10 aspects mentioned above were analyzed and summarized in Table 2, where each one receives a score ranging from 0 to 2: a score of 0 indicates the absence of significant improvements or changes, while a score of 2 represents substantial advances in the integration of these elements.

V. RESULTS

The study highlights the complexity and challenges of the conversion processes, which reflect the difficulties and progress achieved in each case. Both barracks have experienced a prolonged period of underutilization and abandonment, from the mid-1990s to the present, a symptom of the difficulties in coordinating state interests (economic and national defense) with local needs.

One of the distinctive aspects of the development of these projects was the bottom-up approach in the decision-making process, which played a crucial role before the creation of the Master Plan. This participatory process was called "Not housing but City 2.0". The participation took place between April and June 2016, through three dissemination days, 18 interviews with groups of residents, two focus groups, laboratories in eight classes between primary and secondary schools, and three public events (one of presentation, one of a walk, and another of co-design), which involved more than 600 people.**9** On this basis, an International Competition of Urban Design**10** Ideas was convened to create a new residential settlement (October 2016 to July 2018). Despite the failed hypothesis of converting the old military compound into a mosque in 2017, the winning project of 2018 aimed to demolish all the constructions, except the Command Building, and build 53,000 m^2 distributed in social housing of 3 to 5 floors (36,501 m^2, 68% of the total), tertiary use (6,000 m^2), tourist accommodation (4,499 m^2), commercial use (4,000 m^2) and industrial-artisanal use (2,000 m^2) (Figure 3). On the other hand, in Santa Caterina, a top-down approach was employed, where the citizenry was not directly involved, which negatively impacted the social acceptance of the proposed transformation. In this case, the 2021 Master Plan for its conversion considered demolishing the barracks and rehabilitating the fortification, with the creation of a public park exceeding 8 hectares (Figure 4). Its objective was to provide a unified space to store documentation by creating a new urban center dedicated to culture and leisure time, which would save the City Council €340,000 per year in storage costs. The barracks spaces would feature a new 16,000 m^2 L-shaped building for the municipal archives, local foundations, and civic museums, in addition to the construction of three residential buildings totaling 2,600 m^2. The elaboration of the Master Plan at the end of 2020 has favored the debate around its content, but without considering the community's participation in the decision-making process.

Both projects foresee infrastructures for sustainable mobility. In Florence, a new system of bicycle lanes is planned that will

9 https://open.toscana.it/web/noncasemacitta2.0/home
10 https://concorsolupiditoscana.comune.fi.it/

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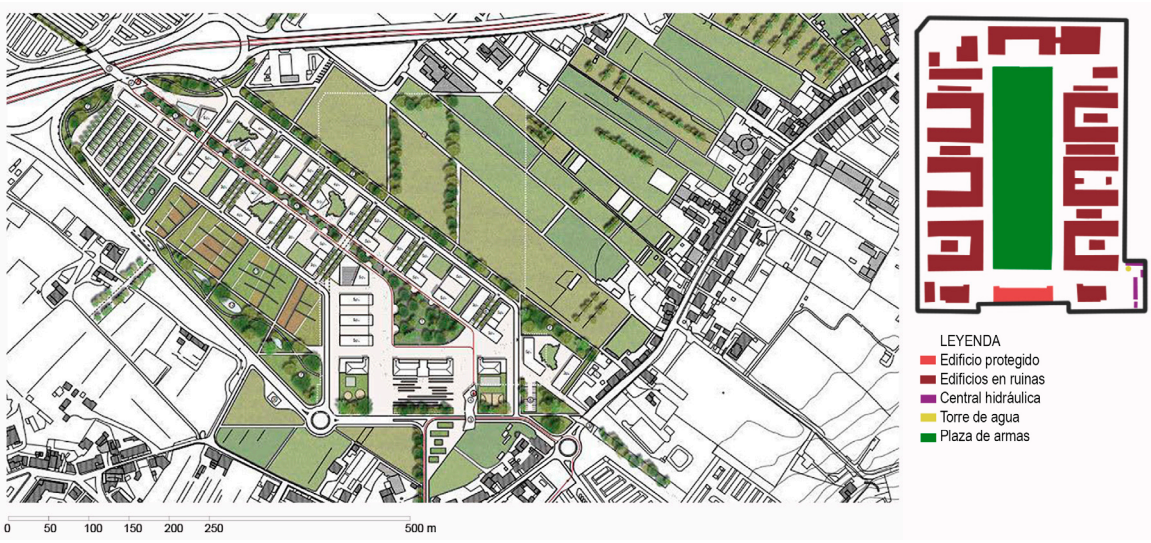

Figure 3. Planimetry of the Lupi di Toscana barracks (above) and the proposal of the Master Plan (below). Source: Prepared by the Authors based on the material provided by the City of Florence.

connect with the existing cycling and pedestrian network, which will run around the perimeter of the intervention area, and a modular "on-demand" self-driving system of approximately 450 m in length that crosses the central axis of the barracks to reach the tram stop. A perimeter ring road is also made to allow the connection of the area with the existing mobility system. The project for the Santa Caterina barracks only provides some bicycle lanes within the intervention area. At the same time, there is no plan to strengthen the public transport system or sustainable mobility to connect the old barracks with the rest of the city.

In both, a differentiated approach is observed in terms of landscape preservation and the use of natural and anthropic resources. Although the original military architectural structures will not be preserved, both projects pay special attention to the natural component, which favors the creation of large green areas. In the case of the Lupi di Toscana barracks, a complex green structure is proposed that includes 22,487 m^2 of green belt parallel to the bike path and pedestrian perimeter to the intervention area, a park of 55,912 m^2 that stems from the recovery of much of the green areas within the barracks compound, a 16,000 m^2 linear central park that crosses the central part of the new building and the urban gardens of 13,204 m^2, with a total of more than 100,000 m^2 of green spaces. On the other hand, the second case will focus on preserving existing green areas and adding more than 80,000 m^2 of parkland.

As for the integrated and complementary roles, both cases introduce substantial changes to the original morphology of their spaces. The intervention at the Lupi di Toscana barracks is presented as an "urban surgery" project, which seeks to integrate social housing with commercial, cultural, and recreational uses by creating a new urban fabric. On the other hand, the conversion of the other barracks will involve the demolition of most of the existing buildings, replacing them with an L-shaped structure intended for archives and cultural purposes, while preserving the green areas, which also means a significant change in the space's dynamics.

Regarding the enhancement of the historical and documentary heritage, both choose to preserve the architectural heritage partially. In the Lupi di Toscana barracks, the Military Command Building, declared a cultural interest site in 2014, will be maintained. In contrast, only the historical fortification in the Santa Caterina barracks will be preserved**11**. However, neither of the projects contemplates the preservation of military memory, which could be interpreted as a loss of the historical identity of these spaces. Social inclusion is another aspect considered. In Florence, the characteristics of social housing have not yet been specified, and it remains unclear whether social housing will be available in the Santa Caterina barracks. Additionally, there is no data available on sale and rental prices. In October 2024, the average rental and sale prices of homes in Florence**12** are €14.18/m^2 and €4,316/m^2,

11 http://www.ifortiassociazione.com/index8.html
12 https://www.immobiliare.it/mercato-immobiliare/toscana/firenze/

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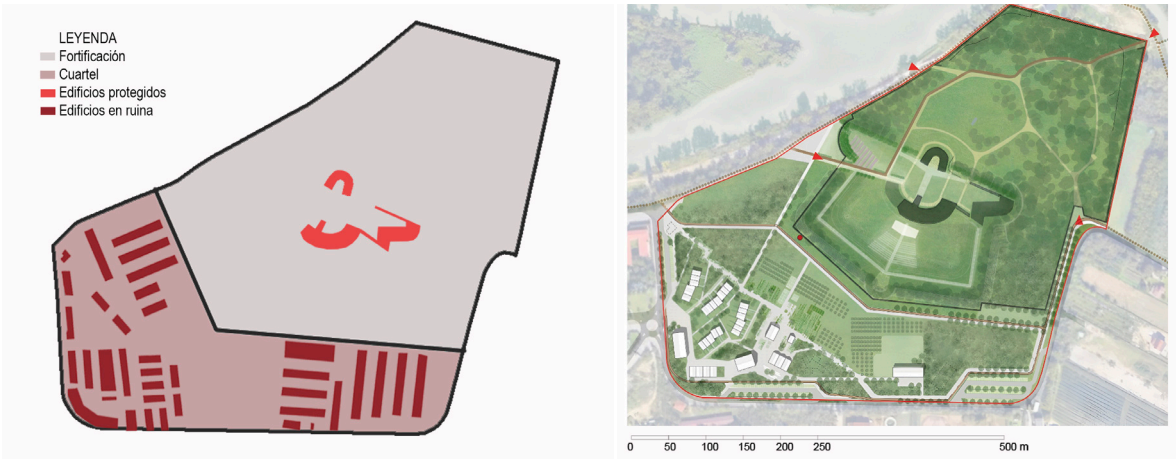

Figure 4. Planimetry of the Santa Caterina area (above) and the proposal of the Master Plan (below). Source: Prepared by the authors based on the material provided by the Verona City Council.

respectively. While in the area of the Lupi de Toscana barracks**13**, these figures reach €14.98/m^2 and €3,763/m^2, respectively. In the case of the Santa Caterina barracks**14**, the rental and sale prices of its area are €9.73/m^2 and €1,957/m^2, respectively, which are lower than the city's average**15** of €11.54/m^2 and €2,583/m^2.

As for the public facilities, the Lupi di Toscana barracks will focus on offering a wide range of cultural services in the Command Building, including an auditorium, library, coworking spaces, and areas for creative and hands-on craft activities. Meanwhile, the conversion of the Santa Caterina barracks, although less defined in this area, aims to create a new cultural centrality for Verona.

Finally, regarding the shared management of common goods and the use of renewable energies, the Lupi di Toscana barracks proposes innovative solutions, such as urban gardens, and community participation in the management of cultural and service spaces. Both projects foresee the installation of photovoltaic panels and the implementation of energy efficiency standards in the new buildings, which will contribute to improving the sustainability of these interventions. However, in the case of Santa Caterina, less information is available on community participation in managing the spaces.

VI. DISCUSSION

The compilation of the results allows a discussion based on various aspects, revealing four key factors that have contributed to determining the new uses.

The first consideration is whether it is possible to regard the prolonged abandonment as an "agent" that has contributed to the ruin of almost all the buildings built, implying a radical morphological change of the barracks between the current state and the project. In the field of architectural-urban studies, authors such as Turri (2014) have highlighted the importance of old barracks as heritage, regardless of their age. In general, it is recognized that these places are significant components of the built environment due to their architectural, engineering, technological, urban, and symbolic qualities, which can offer numerous opportunities for conversion with civil society. However, the barracks, built in the 1940s and 1950s according to a functionalist model, have suffered a prolonged period of underutilization and abandonment, resulting in severe deterioration of both the open and built spaces, as demonstrated by Cacciaguerra and Gatti (2009).

The second and third key factors triggering the conversion were, respectively, the transfer of ownership of the barracks through the ***federal demaniale*** mechanism and the state public funding granted in 2021. The

13 https://www.immobiliare.it/mercato-immobiliare/toscana/firenze/legnaia-soffiano/
14 https://www.immobiliare.it/mercato-immobiliare/veneto/verona/borgo-venezia-santa-croce/
15 https://www.immobiliare.it/mercato-immobiliare/veneto/verona/

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particularity of the Italian context, as far as this type of vacuum is concerned, contributed to blocking the operations. In fact, the continuous change of decisions of the Ministry of Defense on the management of its properties implied its underutilization for a decade, to end up in its definitive abandonment that coincides with a context of acute crisis of the real estate sector, which is why the same Ministry has not been able to achieve the sale of these assets through public auctions. Given this impossibility, both assets were transferred free of charge to the respective local administrations that began to consider their conversion.

Finally, there is the integrated approach of the projects. The conversion of military lands located in peripheral areas of cities requires comprehensive urban-scale planning based on a medium- or long-term future development scenario. In fact, the analysis demonstrates the implementation of this approach and highlights that the old barracks can contribute to defining more inclusive, safe, resilient, and sustainable urban environments. However, several issues remain to be defined in greater detail, among which energy efficiency and the guarantee of the right to the city, through the allocation of truly accessible housing to the population with fewer resources, stand out. When comparing the average rental and sale prices of the city and the area where the old barracks are located, the case studies are more affordable. Faced with this situation, municipal administrations have the possibility of offering a solution based on surveys dedicated to finding out the reality of housing demand at the urban level to meet the needs of the weakest segment of the population, who, although they do not fall within the parameters for accessing social housing, need access to the market.

VII. CONCLUSIONS

The research carried out is a first step towards gaining a deeper understanding of the urban regeneration actions implemented in the peripheries of Italian cities. The work also provides a first attempt to categorize these projects.

This study demonstrates how the qualitative evaluation of 10 relevant elements, in terms of urban regeneration and sustainable development, leads to a deeper understanding of the characteristics of the conversion processes of former military barracks. This assessment can be applied to other types of abandoned areas in other national contexts, regardless of the original use. The evaluation allows for a more detailed assessment of the capacity that the new uses can have, as well as the process that sustains them, to achieve greater sustainability of the intervention and ensure a better integration of this old military piece into its context. In the case of the Lupi di Toscana barracks, the higher score (15/20) shows that the process is better directed towards a more sustainable urban development than the Santa Caterina barracks (9/20), which does not sufficiently address fundamental issues for urban regeneration, such as social aspects and public participation.

It is recognized that comparative research between two cities is complex and has numerous aspects that require further review, such as the condensation of a large amount of information and the selection of a few bibliographic references for each case study. It is also true that the qualitative interpretation of large urban projects that have not yet been carried out reduces the relevance of their evaluation. Even so, this research is considered an important step towards developing a comparative analytical framework for evaluating the conversion processes of military facilities, applicable to other urban empty types, particularly those characterized by inclusive, green, and good governance cities. In addition, this study provides the possibility of applying this framework in other geographical contexts, such as Latin America, where barracks also occupy strategic and socially sensitive spaces.

VIII. CONTRIBUTION OF AUTHORS CRediT:

Conceptualization, F.C.; Data curation, R.C.H.; Formal analysis, F.C.; Acquisition of financing, R.C.H.; Research, F.C. and R.C.H.; Methodology, F.C. and R.C.H.; Project Management, F.C.; Resources, R.C.H.; Software, R.C.H.; Supervision, F.C.; Validation, R.C.H.; Visualization, F.C.; Writing - Original draft, F.C. and R.C.H.; Writing - proofreading and editing, F.C. and R.C.H.

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