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Recycled Concrete as Circular Material for Sustainable Construction: Applications in Housing Rehabilitation in Guadalajara

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Abstract: The construction sector is one of the largest consumers of natural materials and one of the largest contributors to environmental degradation, particularly in the generation of rubble and waste. Currently, the housing crisis is a global problem, as UN data confirms that nearly 1.8 billion people lack housing, indicating that a solution to this problem must be found; moreover, approximately 80% of Mexican homes require improvement or expansion. This research examines this housing crisis to propose the rehabilitation of housing as a sustainable and strategic alternative to address the shortage and offer solutions to the country's housing problem. Vacant housing in Guadalajara has become an environmental, social, and urban problem in the metropolitan area and affects most Mexican cities, where thousands of homes built in the last 50 years exhibit construction problems related to building materials, poor structural design, and uninhabitability. This research explores how recycled concrete can be a circular and sustainable material and evaluates its potential in housing rehabilitation applications, promoting sustainable construction and urban regeneration; the rehabilitation methodology focuses on and adopts, through a multidisciplinary vision. Additionally, it examines how housing rehabilitation can be a solution to the country's high demand for housing. Far more than the technical contributions of this material, this research positions recycled concrete as a mediator between sustainability and habitability, linking the effects of climate change and housing resilience. Therefore, considering the problem of vacant housing, this research focuses in Tlajomulco de Zúñiga which is the municipality with the most uninhabited housing in all of Mexico; with the aim of rehabilitating it is using recycled concrete, giving it a second life and addressing the housing problem in Mexico. The rehabilitation of vacant housing using recycled materials is a response to the demand for urban regeneration, contributing to the discourse of sustainable construction by proposing and seeking to replicate the model for innovative and sustainable building.

Keywords: Sustainable rehabilitation; Climate change; Recycled concrete; Habitable housing; Low-carbon materials



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1. Introduction

We are in an era marked by the overconsumption of natural resources and diverse social asymmetries; architecture must focus on rethinking not only how it is built, but how it affects and improves ethically and culturally. Climate change is one of the greatest challenges facing humanity today. In addition to affecting biodiversity, climate, and natural resources, it is also having significant repercussions for construction and architecture. The severity of extreme weather events such as hurricanes, floods, wildfires, and droughts is testing the capacity of buildings and cities to withstand the effects of global warming. Reducing energy consumption and waste materials are fundamental elements for environmental protection. In 2015, the United Nations launched the 2030 Agenda for Sustainable Development and introduced the Sustainable Development Goals (SDGs) to tackle global challenges and promote a more sustainable future by 2030. That is why it is important to study how architecture and construction can adapt to climate change and mitigate its effects. Architecture and construction have an important role to play in adapting to global warming. This includes sustainable design and construction techniques, such as the use of more efficient and resilient materials and technologies, and urban planning that minimizes risks and withstands extreme weather events.

By the beginning of 2025, buildings and the construction sector, including the carbon embedded in building materials and their manufacturing, are responsible for generating approximately 34% of CO₂ emissions into the environment, while energy consumption remains at 28% of energy consumption in 2025. Despite modest progress in this sector, it is still far from the goal of limiting or reducing CO₂ emissions. Thus, over the last decade, research related to the architecture, construction, and environmental sectors has advanced exponentially with the aim of mitigating the effects of climate change. The use of new technologies, innovative materials, and sustainability principles has been adopted by various universities, construction companies, and architectural firms to build sustainably. The concept of a circular economy in the construction industry aims to minimize

waste and maximize resource efficiency throughout the entire life cycle of building^[1].

The report *"Not just another brick in the wall: The solutions exist - Scaling them will build on progress and cut emissions fast. Global Status Report for Buildings and Construction 2024/2025,"* developed by the United Nations Environment Programme, highlights that the transition to modern construction must adapt and embrace new approaches to build differently in the coming decades. One of the solutions proposed in this report is adapting existing buildings to current needs. This proposal suggests that adapting buildings can provide habitable space for the community without generating CO₂ emissions. According to official World Bank data, the equivalent of one New York City will be built in the coming years to house the world's population. Based on this premise, this research seeks to understand how housing can be rehabilitated¹ to meet the growing demand for housing in Mexico.

The numbers speak for themselves. According to the 2024 National Institute of Statistics and Geography (INEGI), 133,014,024 people live in Mexico. Compared to other countries, Mexico ranks at the 10 places among the most populous nations in the world. Over the last 70 years, Mexico's population has more than quadrupled. In 1950, there were 25.8 million people; by 2020, that number had reached 126 million^[2]. From 2010 to 2020, the population increased by 14 million. According to recent projections, it is estimated that by 2030 at least 75 percent of our population will live in cities and their metropolitan areas, making new housing, with suitable land and basic infrastructure and services for the population, more crucial than ever.

Housing in Mexico is one of the main economic and social problems. In Mexico, 75% of the constructed land use is for housing, hence its importance. Furthermore, housing is one of the main assets that make up a family's wealth; it is generally considered a form of savings and investment to preserve their resources. From an economic standpoint, housing is a driver of economic activity, based on the construction

¹ Housing rehabilitation is a constructive action carried out with the purpose of recovering or considerably improving some conditions ranging from the habitability of a specific dwelling, through the conditions of structural and constructive safety, protection against humidity, its accessibility.

industry. The national importance of housing to the country's economy lies in the fact that cities generate approximately 2.4% of GDP. In fact, the real economy is largely driven by the urban economy; simply considering the accumulated fixed capital of properties gives us an idea of the value invested in cities, in addition to the importance of the land, housing,

and transportation markets. Therefore, housing is considered a national problem that, unfortunately, from a sustainable and economic perspective, does not receive the attention it deserves due to a lack of consideration. Federal government policies have failed to address the number of people who lack their own homes.



Figure 1. The coexistence of vacant housing and unmet demand reflects systemic planning failures, financial exclusion, and territorial mismatch, producing surplus dwellings disconnected from social, economic, and infrastructural realities.

One of the aspects to highlight regarding this research is understanding the difference between remodeling and rehabilitation, since in general terms

they may sound the same but they are very different concepts, with rehabilitation being a more complex but more beneficial action **Table 1**).

Table 1. Importance of housing rehabilitation over remodeling: structural safety, energy efficiency, and environmental sustainability. *Rehabilitation is more important than remodeling because it not only enhances appearance but also ensures structural safety, energy efficiency, and environmental sustainability, contributing to the responsible use of existing infrastructure and the well-being of inhabitants.*

Aspect	Remodeling	Rehabilitation
<i>Definition</i>	Partial or complete change of appearance, layout, or finishes of a house.	Comprehensive process of restoring and improving the functionality, safety, and efficiency of a deteriorated house.
<i>Main Focus</i>	Aesthetic and functional (interiors, finishes, layout).	Structural, functional, and environmental; preserves the existing infrastructure.
<i>Environmental Impact</i>	Can generate more waste and consumption of new materials.	Minimizes material waste and reduces carbon footprint by reusing existing structures and materials.
<i>Long-term Cost</i>	Lower initial investment but does not always improve durability.	Higher initial investment but extends the lifespan of the house and reduces future maintenance or reconstruction costs.
<i>Social Relevance</i>	Improves aesthetics and comfort, but not necessarily habitability or safety.	Increases safety, habitability, and energy efficiency; contributes to urban regeneration.

2. Research Objective

Evaluate the recycled concrete as a sustainable material and its contributions to housing rehabilitation, highlighting its structural behavior, environmental impact, and contribution to the environment in housing rehabilitation in the Tlajomulco de Zuñiga area. The research seeks to demonstrate low-impact strategies, promoting resilience, increasing habitability through sustainable architectural and structural practices; aiming to establish a replicable methodology that articulates technological, material, urban innovation and sustainability to strengthen habitability in the face of the global housing and resource crisis.

3. State of the Art

Approximately a decade ago, architect Norman Foster remarked, "As an architect, you design for the present, with an awareness of the past, for a future that is essentially unknown. Sustainability is not an option; it is a responsibility." This statement resonates deeply with the context of climate change. In the coming decades, the future of humanity will depend on what we do and how we implement it. In the construction sector, how will we ensure that we build homes that not only provide shelter but also adapt to climate change, homes that endure thanks to recycled and sustainable materials, and homes that honor the generations who inhabit them? Based on this research question, this

article seeks to link and provide solutions regarding the integration of recycled concrete and their contributions to housing and structural efficiency to generate habitable and sustainable housing. But to do so, we must understand sustainability and how it is addressed in this research.

Sustainability is introduced in the paradigm of architecture as a necessity that entails important modifications in designing methods for practitioners; sustainability derives from the Latin word *sustinere*. Which implies lastingness, longevity, preservation and conservation. In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Production of recycled materials often requires less energy than manufacturing new materials, thus reducing carbon emissions. Using recycled materials in resource and environmentally friendly construction techniques aligns with sustainable design principles [3]. Architects are moving towards incorporating repurposed and recycled materials in their projects to promote sustainability, innovation, and environmental responsibility [4]. Recycled concrete is a prime example of sustainable design, and compared to other materials, it is a much better option. Furthermore, there are various laws and regulations worldwide that highlight the importance of this material (Table 2).

Table 2. Key benefits of recycled concrete in sustainable construction. *The table highlights recycled concrete's key benefits: it reduces construction waste by reusing debris, lowers carbon emissions by minimizing new cement production, saves costs on materials and transport, offers structural versatility in pavements and walls, conserves natural aggregates, and supports a circular economy, promoting long-term sustainability in construction projects.*

Advantage	Description	Data / References
Waste reduction	Reuses demolition debris, reducing the amount of construction waste sent to landfills.	According to EPA (2021), up to 70% of construction debris can be reincorporated into new concrete.
Lower carbon footprint	Reduces the need for new cement production, a major source of CO ₂ emissions in construction.	World Green Building Council (2022): using recycled concrete can reduce emissions by up to 30%.
Cost savings	Less demand for new raw materials and reduced debris transportation costs.	Studies in Mexico show 10–20% material cost savings for rehabilitation projects.
Structural versatility	Can be used in pavements, walls, foundations, and non-critical structural elements.	ACI – American Concrete Institute (2018) recognizes safe use in secondary structures and prefabricated elements.
Conservation of natural resources	Reduces extraction of sand, gravel, and other natural aggregates.	UN Environment Programme (2020): aggregate extraction accounts for up to 50% of construction's environmental impact.
Contribution to circular economy	Promotes reuse of materials within the construction chain, supporting long-term sustainability.	Cases in Europe and North America show increasing adoption in sustainable construction policies.

If we analyze the history of construction, we can see that the use of recycled materials is not a contemporary technique. For thousands of years, recycling materials has solved problems and enabled the creation of new projects. Such is the case of the Romans, who systematically reused marble, stones, and fragments from previous constructions to erect new monumental structures. A prime example is the Colosseum (72 AD), which incorporated reclaimed travertine blocks, recycled iron for beams, and structural reinforcements. Another example is the Abbey of Saint-Denis (1135) in France, considered the first Gothic cathedral. Its construction employed Roman stones and columns from older buildings; the use of these reclaimed materials allowed for the redirection of resources and

gave rise to this magnificent cathedral. This approach demonstrates the relationship between historical sustainability and innovation in structural processes. Another important example of material recycling occurred at the beginning of the Industrial Revolution in England: The Coal Brookdale Bridge (1775) in Shropshire, United Kingdom. Its construction was made possible by recycling iron from dismantled ships and machinery. One of its most significant aspects is that it was the first iron bridge ever manufactured, representing a major innovation due to the spans it could cover: 60 meters long and 30 meters high. It thus stands as a prime example of the structural design of that era.

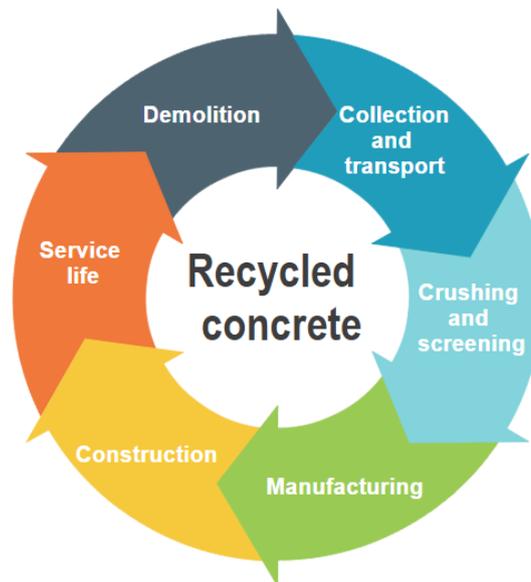


Figure 2. Recycled concrete shows higher porosity and absorption with slightly lower strength yet remains structurally viable for housing while significantly reducing environmental impact through material reuse and waste minimization.

When we talk about recycled concrete², we are referring to the reuse of concrete from demolished

² The negative impact of the production of cement-based materials has been mentioned in many studies. In fact, it is time to be cautious about this issue because the impact is much bigger than ever foreseen. For example, the total world production of aggregates was 48.3 billion tons in 2022. In volume, this amount is 32,200,000,000 m³ (considering 1 m³ of aggregate to be 1.5 tones). This volume is ≈ 180 times bigger than that of the volume of the Great Wall of China (180 million m³ of raw material). In other words, the volume of the aggregates mentioned above can be equal to the volume of an 80 m (height) \times 10 m (width) wall around the circumference of Earth.

structures (**Figure 2**) in new construction or renovation projects. Once concrete reaches the end of its useful life, it can be recycled through a process that involves breaking it up, removing unwanted materials such as dirt and steel, and crushing the remaining mixture to meet preferred specifications. This process can be carried out in a quarry or on-site, and the resulting product is called recycled concrete, which can be used as a base for manufacturing new concrete products. Currently in Mexico, unlike in other countries, construction debris is not given a second life. The design process (**Figure 3**) is structured in different phases, beginning with construction but without

considering recovery, recycling, or reuse. This is necessary to generate sustainable and innovative proposals.

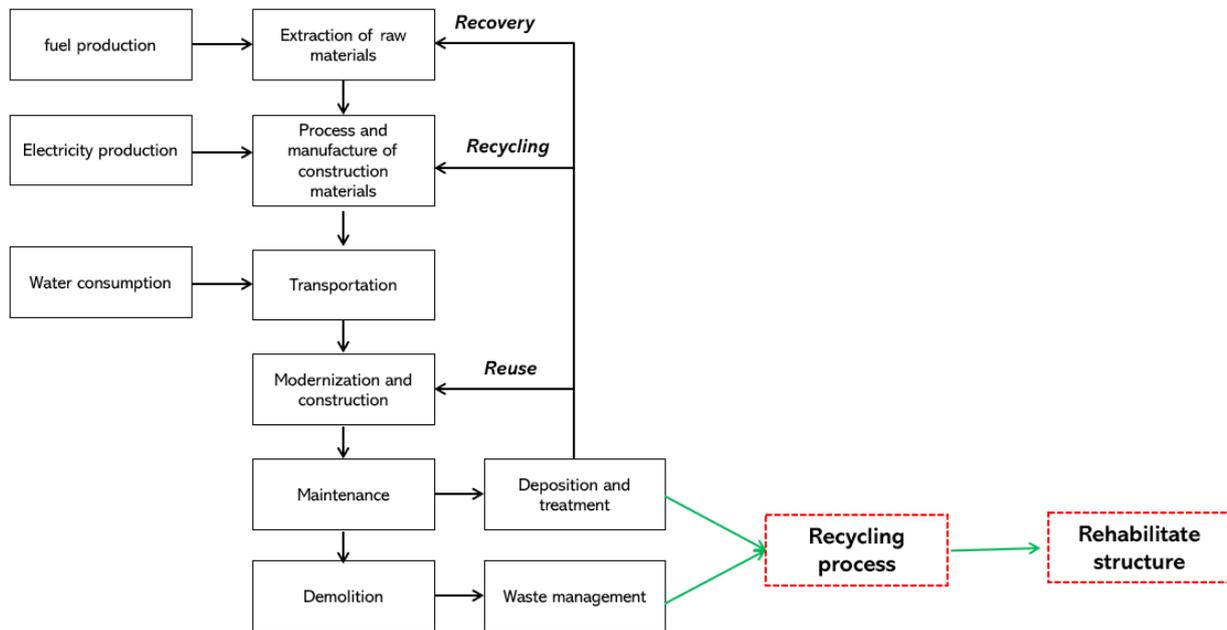


Figure 3. The table outlines construction stages from planning to finishing, highlighting processes for new buildings. Recycling materials enables structural rehabilitation.

4. Recycling Uninhabited Housing in Mexico: A Sustainable Design Opportunity

In the middle of the last century, the famous architect Le Corbusier stated that "the house is a machine for living in" Le Corbusier's vision of housing as a "machine for living" should not be understood merely as a functional object, but as an ecosystem that must respond to urban needs, environmental crises, social inequality, and the changing ways of living today. It is essential to adapt this thinking to recognize that housing must evolve alongside its inhabitants, integrating sustainable materials and technologies, spatial flexibility, energy efficiency, and strategies that allow each person to live comfortably. Currently, and globally speaking, housing is far from being a refuge, being more of an element that generates wealth for those who build it; thus, housing today must adapt to climate change and economic crises in its design process and, for the purposes of this research, in its rehabilitation. The construction industry has undergone a complete transformation over the past 20 years, owing to the high rates of urbanization worldwide and

constant improvement of infrastructure^[5].

Adequate housing is recognized as a right in international instruments, including the Universal Declaration of Human Rights and the International Covenant on Economic, Social and Cultural Rights. Adequate housing must provide more than just four walls and a roof. Several specific conditions must be met before a dwelling can be considered "adequate housing-Habitat estimates that at least 38.4% of Mexico's population lives in inadequate housing; that is, in overcrowded conditions, or in housing built without durable materials, or lacking improved water or sanitation services. According to UN-Habitat, the seven elements (Table 3) of adequate housing for the future should be used to develop housing based on these concepts.

The increase of uninhabited housing is a persistent problem in Mexico. As early as 2015, the Organization for Economic Cooperation and Development (OECD) identified the country as having one of the highest rates of vacant housing in the entire organization, surpassing countries that at that time were recovering from a

housing bubble, such as Ireland and Spain. Housing is one of the core challenges in Mexican cities³, since the 2011 reforms regarding Human Rights, it has been established that the State has the legal obligation to guarantee the right to adequate housing⁴. Human Rights are fundamental rights that all people possess, without exception, in accordance with the provisions of

the Political Constitution of the United Mexican States. Urban peripheries saw their size increase considerably in previous decades, largely due to the construction of new housing on cheap land, but far from urban centers; the State's authority in this matter (with municipalities having these powers) presented areas of opportunity.

Table 3. Multidimensional housing deficits in Mexico based on UN adequate housing criteria. *The table shows how UN adequate housing criteria reveal multidimensional deficits in Mexico tenure insecurity, poor services, low habitability, and peripheral location highlighting the urgent need for sustainable, regenerative housing solutions.*

UN Criteria / Aspect	Definition / Rationale (UN-Habitat / CESCR)	Relevance / Context for Mexico
Security of tenure	Legal or other protection against forced eviction, harassment or other threats guarantees that residents are secure in their housing, free from fear of arbitrary eviction.	In Mexico many low and middle-income households lack formal property titles or secure leases. According to a recent study, nearly one in four dwellings is considered "inadequate," partly due to precarious tenure or informal settlement status.
Availability of services, materials, facilities and infrastructure	Adequate access to safe drinking water, sanitation, energy for cooking/heating/lighting, food storage, waste disposal, drainage essential for health, hygiene, dignity, and functioning daily life.	In Mexico informal settlements and self-built housing frequently suffer from lack of reliable water supply, sanitation, drainage or energy services which perpetuates health hazards, inequity, and vulnerability.
Affordability	Housing cost (rent or mortgage) should be such that it does not compromise ability to afford other basic needs commonly interpreted as housing costs not exceeding ~ 30 % of household income.	For many Mexican households low to middle income, high housing prices and limited access to credit make owning or renting decent housing unaffordable; this forces people into informal or unsuitable housing, or excessive expenditure at cost of other essentials.
Habitability	Housing must provide adequate space, protect inhabitants from climate (cold, heat, rain, humidity), structural hazards—ensuring safety, health, and dignity.	In many Mexican social-housing developments or mass-built housing for low-income groups, construction quality, materials, size and structural safety are often minimal leading to overcrowding, poor ventilation, thermal discomfort, or structural risks.
Accessibility	Housing must consider vulnerable or marginalized groups persons with disabilities, older persons, marginalized communities ensuring access regardless of income, status or ability.	Given social inequalities in Mexico, many vulnerable households (people with disabilities, migrants, low-income families) have limited access to subsidized or adequate housing; policies and social housing often fail to ensure inclusive accessibility.
Location	Housing should be located such that inhabitants have access to employment opportunities, health services, education, transport, commercial and social services, and should avoid environmental hazards or pollution.	In Mexico many affordable or social-housing projects are built on urban peripheries or marginal lands far from jobs, services, or adequate infrastructure; this produces segregation, high transportation costs, social exclusion, and perpetuates inequalities.
Cultural adequacy / Identity and dignity	Housing must allow inhabitants to live in peace and dignity, respect cultural identity, social relations, and provide a sense of belonging — more than just physical shelter.	Standardized mass-housing models in Mexico often ignore cultural, social, and community dimensions resulting in housing that may satisfy minimal technical requirements but fails to respond to social, familial, cultural or community needs of residents.

Over the past 23 years, hundreds of miles of social housing built across Mexico have gone from being abandoned to being illegally occupied. Until a few months ago, the Ministry of Agrarian, Territorial and Urban Development (SEDATU) reported that there were approximately 650,000 abandoned and vandalized homes nationwide. This is worrying considering that, according to federal government figures, the country

³ Housing in Mexico represents a living narrative of social, economic, and political transformation. From colonial tenements to modern urban complexes, this way of living has reflected inequality, dreams of modernity, and efforts to build community.

⁴ Although Mexico transitioned from adobe and tenement housing to massive housing developments and urbanized peripheries, the housing deficit persists millions of homes still lack adequate living conditions (space, ventilation, durable materials), access to services, and a location integrated into the city. Historically, from the workers' housing of the Porfiriato (1876-1911) to the INFONAVIT megaprojects of the 2000s, the problem has been constant: housing is produced without fully considering the actual living conditions of its inhabitants.

currently needs to build 2.8 million new homes and remodel 8.9 million properties in precarious condition; unfortunately, about 68% of these homes have structural problems due to insufficient materials and poor structural calculations.

When discussing home rehabilitation, many concepts must be considered: energy efficiency, installations, ventilation, expansion, and structure. This research focuses on the structural rehabilitation of the home. Structural rehabilitation of homes is essential to guarantee the safety of the inhabitants, prolong the useful life of the property, to incorporate sustainable criteria and techniques to improve the structural and constructive performance of a home in order to adapt the home to current needs.

One of the main ideas for developing this research focuses on the fact that in Mexico one of the most used materials in construction is concrete (**Figure 4**), being a material used in almost 70% of the constructions in the country (a number very similar to that in different nations where cement is the element used par

excellence in construction), so from this perspective the search is to give a second use to this material to

build in a sustainable way and give a second use to this material.

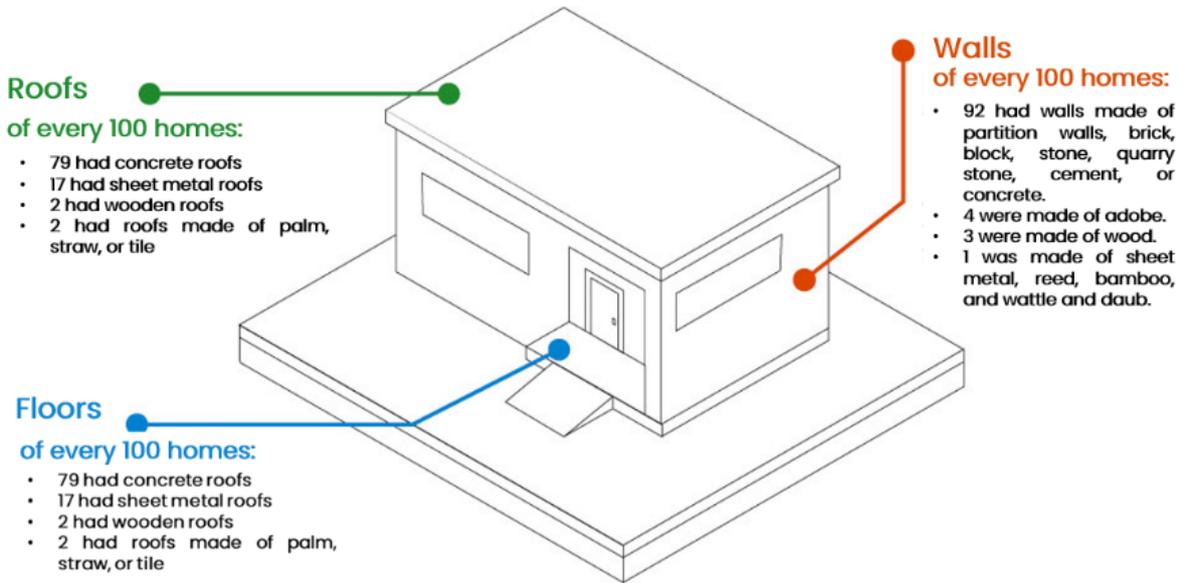


Figure 4. Building Materials for Homes in Mexico 2024, The use of cement in Mexican housing and buildings is notable, prompting an understanding of how this material can be recycled, given its use in various parts of Mexican homes.

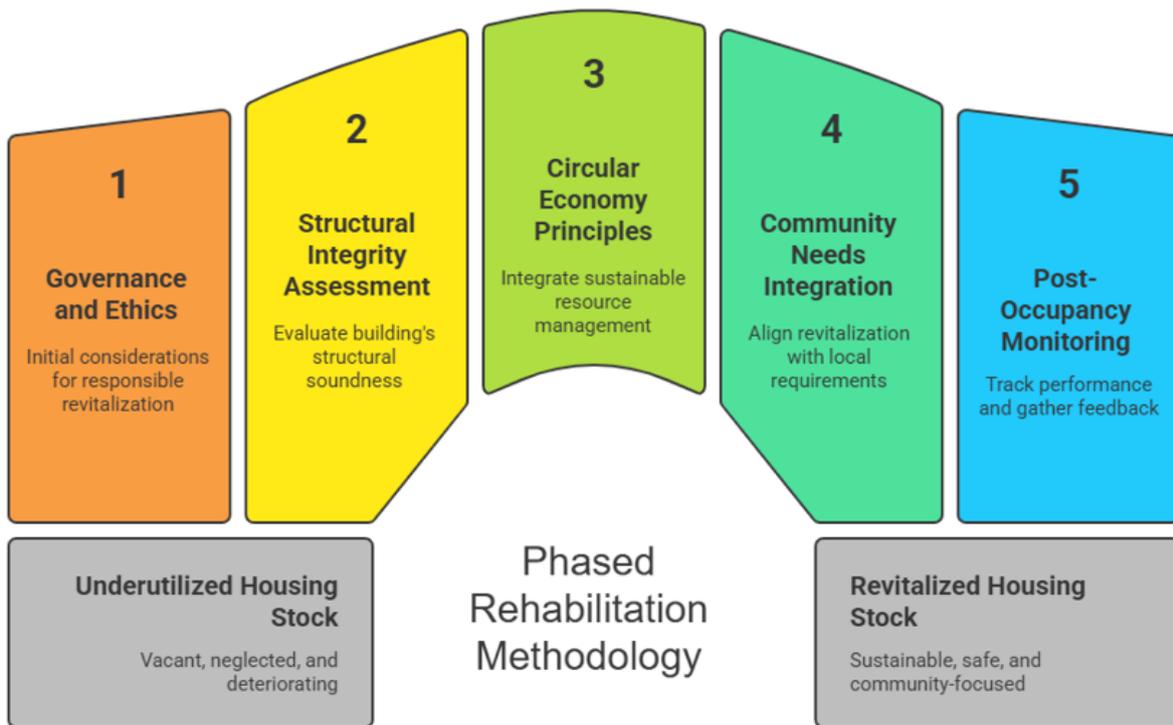


Figure 5. The phased methodology for the sustainable rehabilitation of vacant housing, integrating structural integrity assessments with circular economy principles and community needs. The approach spans from initial governance and ethical considerations to post-occupancy monitoring, ensuring a holistic and adaptable framework for revitalizing underutilized housing stock. Each phase incorporates specific actions, verifiable deliverables, and alignment with relevant Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production).

Recycling has become a new representation⁵ of the sustainability of the place in the face of the inadequacy seen mainly in the city's urban centers and is presented as a sustainable possibility. In Mexico's current situation, the reuse of buildings is largely unknown, and the study of material recycling is even less so. Unfortunately, there are no policies, laws, or incentives to encourage this type of construction, unlike in other countries. To rehabilitate a house, a methodology was developed for this case study, considering various aspects. It is worth noting that the construction systems used in almost all Mexican homes present problems, making this research a potential solution to the problem of vacant housing in Mexico.

5. Case of Study

After Mexico City, Jalisco is the second most populous and important state in the country, and one of the states that contributes the most to the GDP after the capital. In 2024, census studies estimated the total population of Jalisco at 8.9 million inhabitants. The capital of Jalisco is Guadalajara, the second most important and populous city after Mexico City, and it is estimated that due to its growth, the city will receive approximately one million more people per year. Currently, the Metropolitan Area of Guadalajara (MAG) is made up of 10 municipalities (**Table 4**).

Table 4. Population, land area, and housing density in the Guadalajara Metropolitan Area municipalities. *The table summarizes population, land area, and housing density across the main municipalities of the Guadalajara Metropolitan Area, highlighting uneven urban growth and spatial distribution.*

Municipality	Population	Area (km ²)	Density (inhab./km ²)
Guadalajara	1,385,629	893.20	1,491.57
Zapopan	1,476,491	150.20	9,721.36
San Pedro Tlaquepaque	687,127	636.90	862.68
Tonalá	669,913	119.58	4,483.28
Tlajomulco de Zúñiga	727,750	270.00	2,459.97
El Salto	232,852	41.50	4,420.17
Ixtlahuacán de los Membrillos	67,969	184.20	287.98
Juanacatlán	30,855	89.08	201.56
Zapotlanejo	64,806	643.02	106.56
Acatlán de Juárez	25,250	166.68	133.56
MAG Total	5,288,642	2,551.34	2,145.00

Although Guadalajara has areas with high demand for residential developments, there are housing complexes that were never completed and ultimately never inhabited, one of them is the so-called *Mexican Chernobyl* (**Figure 6**). The municipality suffers from significant depopulation in specific peripheral areas,

⁵ Recycling abandoned buildings is an old but little-used technique; there are different methods to rehabilitate these architectural spaces, helping to revitalize sectors or spaces obsolete due to the change of use generated by the expansion of cities.

including Santa Fe. Of these 76,000 homes, 50,000 are located in an expansion zone; that is, they are homes built in the last decade, between 2010 and 2020, that are now being abandoned, creating a serious problem in terms of security and property values. In the case of Guadalajara, it is almost eradicated informal settlements, but the outlying municipalities still face this urban development process, this problem, and there the consolidation processes are much slower because they depend on political initiative and public investment.



Figure 6. It became colloquially known as the Mexican Chernobyl, due to the deterioration of the buildings as well as the total abandonment; in the area you can see gray buildings, graffiti, without windows or doors and surrounded by nature, which contributes to the name that was given to.

Tlajomulco de Zúñiga is the municipality with the most abandoned homes in the México, with 77,000, according to the 2020 housing and population census of the National Institute of Statistics and Geography (INEGI). In Tlajomulco de Zúñiga, the 77,000 homes, some abandoned, others unfinished, are scattered throughout the municipal territory of 637 square kilometers. The Institute for Planning and Management of Development in the Guadalajara Metropolitan Area (IMEPLAN) estimates that the population will exceed one million by 2040.

Between 2025 and 2040, an additional 250,000 people are expected to be added, per year according to a diagnostic report prior to the consultation to renew the Municipal Development Plan and the Metropolitan Territorial Planning Program. This population increase would generate a demand for 590,697 new homes over the next 15 years throughout the Guadalajara Metropolitan Area; of these, a third (approximately 195,000) would have to be in Tlajomulco.

5.1 Application in Tlajomulco de Zúñiga

Recycled materials are revolutionizing how we conceive of architectural projects. They are no longer seen as a secondary solution, but as a priority option that meets the highest quality standards. Incorporating recycled materials into construction helps decrease the consumption of natural resources and reduce waste. With the demand for more sustainable buildings, the use of these products is changing the landscape of contemporary architecture.

The construction industry is one of Mexico's most

powerful economic drivers, but it also has a significant environmental impact. Every building erected or demolished leaves behind tons of materials that lack proper management beyond simply being disposed of elsewhere. Recycling construction materials is practically nonexistent in public discourse, and it is urgent that it be made a priority. Currently, it is estimated that around 3% of construction and demolition waste is recycled in Mexico, reflecting a worrying lag compared to regions like Europe, where the reuse of recycled materials is mandatory and reaches levels exceeding 70%. The difference between the adoption of recycling and the reuse of these materials in new construction projects lies in the regulatory framework and the cultural certainty that recycling and recycled products are effective.

Furthermore, in Mexico, the lack of construction waste recycling is a problem of inefficient infrastructure and regulation. Mexico lacks a standardized regulatory framework that integrates circularity as a central principle for shaping a genuine market for secondary materials. While laws and regulations exist such as the General Law for the Prevention and Management of Waste and *NOM 161*, their application varies from state to state, and the informal nature of the sector limits traceability. There has been progress, such as *NACDMX-007-RNAT-2019* in Mexico City, which promotes circularity, and states like Nuevo León and Jalisco are working on their own initiatives, but these efforts remain insufficient to drive a profound transformation across the country.

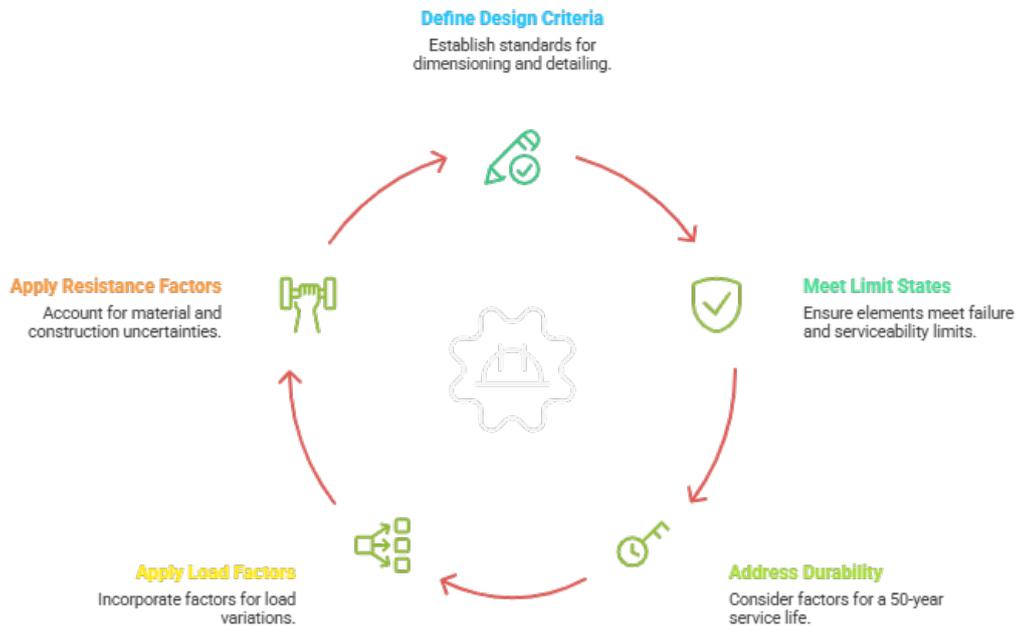


Figure 7. The construction regulations of the state of Jalisco outlines the design criteria for dimensioning and detailing structural elements, ensuring they meet failure and serviceability limit states as defined in the Building Code for Mexico and associated standards. It also addresses durability considerations to achieve a minimum service life of 50 years.

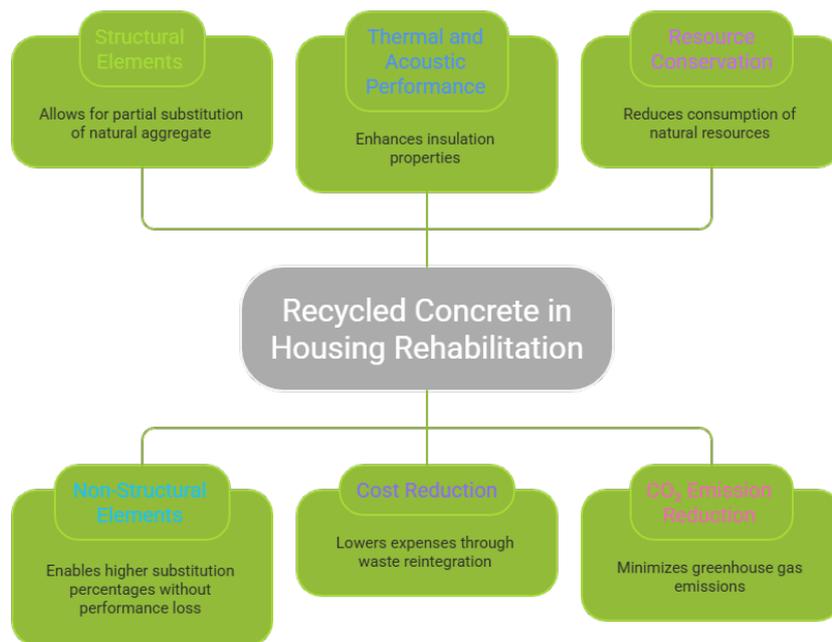


Figure 8. Recycled concrete is emerging as a viable alternative for housing rehabilitation, both in structural and non-structural elements, by integrating technical and sustainability criteria. Several studies demonstrate that the partial substitution of natural aggregate with recycled aggregate, in proportions of 20–30%, allows for compressive strengths of 20–30 MPa, sufficient for use in columns and beams of low- and mid-rise housing.

The Jalisco state building code does not explicitly prohibit the use of recycled materials; however, it does specify that materials with sufficient mechanical strength for structural applications must be used. Nationally, cement-based structural systems are

regulated by standard *NMX-C-021-ONNCCE-2015*, entitled "*CONSTRUCTION INDUSTRY - MASONRY CEMENT (MORTAR) - SPECIFICATIONS AND TEST METHODS.*" This standard establishes the specifications and test methods that masonry cement

(mortar), whether manufactured domestically or imported, must meet when sold within Mexico. This Mexican standard applies to all masonry cements (mortars) sold in Mexico.

Based on Mexican and Jalisco state regulations, the use of recycled concrete is a viable solution for housing rehabilitation in Guadalajara, and more specifically in the Tlajomulco de Zúñiga area. Regarding this, the municipal government modified its laws in mid-2025 to allow for the rehabilitation of vacant homes in the municipality, with the aim of providing new housing for the area. Given the housing needs and demands in this municipality, the use of recycled cement can be a great solution for making homes habitable and sustainable. It is worth noting that, in this sense, housing rehabilitation is much more important than building new homes, since rehabilitation can save approximately 65% of natural resource consumption and 87% of economic resources.

5.1.1 Methodology for rehabilitating housing using recycled concrete

The methodology for conducting a literature review of recycled materials in modern architecture and civil engineering focused on their uses, advantages, and challenges. The study analyzed the present research level in this field by setting defined goals, including identifying successful case studies, understanding the benefits and limitations of the materials, and analyzing creative methods in the industry.

The employment of recycled concrete from construction and demolition waste is a key factor to move the field of construction towards sustainable

development. Its use as a raw material replacing conventional aggregate would reduce the consumption of natural resources. In this regard, many researchers have worked to analyze the structural behavior of recycled concrete, that is, a concrete where the conventional aggregate has been partially replaced by recycled concrete [6].

The concept of rehabilitation in urban environments was born in the 1950s at the International Congresses of Modern Architecture, where European urban planners, particularly Italians, criticized the prevailing model of urban growth that was constant, indefinite and disrespectful of the pre-existing city. It is the rehabilitation that is now being implemented, with increasing intensity, alongside the emphasis on the process of generating a new urban fabric. It is commonly used within the context of urban transformation as processes of reinvention and improvement of urban areas, which are often degraded. For the development of the methodology, a qualitative approach is still followed, focusing on the search, collection, consultation, and analysis of information from bibliographic sources. Considering the deductive nature of this research, as well as its theoretical character.

The methodology arises from understanding the current housing needs, not only in the present but also with a vision for the future. This methodology aims to rehabilitate both structural and non-structural elements. Based on the mechanical analysis of recycled concrete and the study of building codes, the elements that can be rehabilitated (Table 5) are divided into structural and non-structural.

Table 5. Applications of recycled aggregate concrete in structural and non-structural housing elements. *The table outlines how recycled aggregate concrete is applied to structural and non-structural housing elements, ensuring safe rehabilitation, improved performance, and sustainable material reuse in residential buildings.*

Element	Type	Rehabilitation strategy (How)	Use of recycled concrete (RC)	Engineering justification
Columns	Structural	Jacketing of existing columns, section enlargement, added confinement reinforcement	Structural RAC with 20–30% recycled coarse aggregate, f_c 20–30 MPa	Restores axial capacity and ductility; RC is suitable when mix design and reinforcement are properly controlled
Beams	Structural	Section enlargement, partial replacement, or addition of tie beams	Structural RC with adjusted steel reinforcement	Improves load redistribution, stiffness, and structural continuity
Load-bearing walls	Structural	Concrete overlay or shotcrete strengthening layer	Structural or semi-structural RC	Increases shear capacity and lateral stiffness
Slabs	Structural	Topping slab, leveling layer, or partial replacement	Structural RC with controlled self-weight	Enhances diaphragm action and seismic performance
Partition walls	Non-structural	Replacement or reinforcement with prefabricated or cast-in-place panels	RC with higher recycled content (>50%)	Adequate mechanical performance for non-load-bearing elements
Masonry blocks / partitions	Non-structural	Substitution with RAC blocks or hollow units	RC blocks with high recycled aggregate content	Reduces material demand and improves circularity
Sidewalks and exterior pavements	Non-structural	Removal and recasting of deteriorated concrete surfaces	High content RC	Low structural demand allows high recycled content
Architectural and prefabricated elements	Non-structural	Replacement with modular RAC components	RC optimized for workability and durability	Facilitates fast rehabilitation and material standardization

5.2 Material-level results and system-level structural results

Industrialization and urbanization had emerged at its peak due to an increased population and they resulted in depletion of natural resources. Perhaps, it leads to a shortage of natural resources and the generation of a huge number of solid wastes. Approximately 20 to 40 billion tons of natural resources were being procured and used as raw materials by the construction industries every year. Also, the technological advancement necessitated the production of concrete close to 25 billion tons per year and nearly one-third of it end up as wastes. Upon scarcity, the necessity on aggregates reached its peak in the field of construction. Researchers have been pioneered in finding alternative material to be used as aggregates in concrete.

Concrete and asphalt heavily rely on non-renewable resources, mainly natural aggregates, leading to significant ecological footprints from excessive

resource extraction, production, transportation processes, carbon emissions, and energy use during construction. The use of construction waste and the production of new materials from waste materials is considered recycling. Concrete is the most important and necessary element in building construction; the quality of a structure also depends on it. Recycled concrete is used as coarse aggregate; its main characteristic is that it consists entirely of waste and elements of concrete that have been destroyed. The advantages of using recycled concrete are that it saves on some construction costs and reduces the extraction of rocks. Currently, some concrete elements are partially destroyed, and in some cases, the entire structure is demolished. This is due to the end of its useful life or age. The demolition of a structure generates a large amount of solid waste that can be reused and employed in the production of new concrete.



Figure 9. The table summarizes the recycled concrete recycled production process.

One of the primary aspects of this research and its application in the construction sector in Mexico and achieving good structural efficiency. The efficiency of recycled concrete varies depending on several factors, but one of the most important is the quality of the recycled concrete and the control of the crushing, screening, and homogenization processes. While it exhibits different characteristics (such as higher

porosity of 14-18%), water absorption (5-8%), and a slightly lower density than traditional concrete (2150-2280 kg/m³), it is worth noting that these values do not compromise its performance when water-reducing admixtures are incorporated. Based on this and following mechanical tests, it is concluded that recycled concrete achieves compressive strengths between 25 and 31 MPa, placing it within the appropriate structural

ranges and construction systems permitted in Mexico with a moderately lower modulus of elasticity (19-23 GPa), resulting in stability under loads. In addition to compressive strength, the tensile strength of recycled concrete has also been extensively studied.

However, with appropriate design adjustments, including the use of supplementary cementitious materials or chemical admixtures, the tensile strength

of recycled concrete can be improved. The modulus of elasticity, which relates to the stiffness of the material, is another important mechanical property. Studies have shown that the incorporation of recycled concrete generally leads to a reduction in the modulus of elasticity, but this reduction can be minimized by adjusting the water–cement ratio and utilizing high-quality recycled concrete [7].

Table 6. Physical and mechanical characteristics of recycled concrete and their implications for housing applications. *Recycled concrete shows higher porosity, absorption, and lower strength due to adhered mortar and microcracks. Despite reduced mechanical performance, it remains suitable for housing applications and offers significant environmental and resource-efficiency benefits.*

Parameter	Recycled Concrete (RC)	Natural Concrete (NC)	Scientific/Engineering Notes
Sample ID	RC-01 / RC-02 / RC-03	NC-01 / NC-02 / NC-03	Three batches prepared under identical mix design except aggregate type.
Aggregate Source	Recycled aggregate from demolished housing structures; pre-crushed and graded	Virgin limestone/gravel aggregate	RC presents adhered mortar, higher porosity, and variable angularity.
Water Absorption (%)	5.2–7.8%	1.1–1.8%	RC shows higher absorption due to microcracking and old mortar residue.
Bulk Density (kg/m ³)	2150–2250	2350–2450	Reduced density is linked to the lower specific gravity of recycled aggregates.
Slump (mm)	60–95	75–115	RC mixes require water-reducing admixtures to maintain workability.
Compressive Strength (MPa, 28 days)	25.4–31.7	32.8–38.5	Strength reduction ranges from 10–20%, depending on aggregate quality.
Tensile Strength (MPa)	2.1–2.4	2.8–3.2	RC has lower tensile capacity due to weaker interfacial transition zones (ITZ).
Elastic Modulus (GPa)	19–23	26–30	RC microstructure induces reduced stiffness under linear loading.
Flexural Strength (MPa)	3.1–3.8	4.2–4.8	Flexural behavior is more sensitive to aggregate bonding discontinuities.
Ultrasonic Pulse Velocity (m/s)	3200–3600	3900–4300	Higher void ratio and microcracks in RC reduce wave propagation speed.
Porosity (%)	14–18%	8–10%	Increased porosity results from adhered mortar and recycled aggregate texture.
Particle Size Distribution (mm)	4.75–19.0 (well-graded)	4.75–19.0 (controlled grading)	RC requires additional screening to ensure granulometric stability.
ITZ Condition (Qualitative)	Heterogeneous, microcracked, partially remolded	Dense, continuous	The ITZ is the critical zone affecting global mechanical behavior.
Environmental Benefit	Saves 40–60% natural aggregate; reduces demolition waste	Requires extraction of virgin aggregate	RC contributes to circular construction strategies and lower embodied carbon.

Although tests show a 10-20% reduction in strength compared to conventional concrete, recycled concrete offers significant structural advantages, such as predictable behavior under axial loads and good adhesion to steel reinforcement under tension and compression. However, one of its most relevant contributions is its environmental, economic, and functional benefit, as it reduces the extraction of natural aggregates, minimizes demolition waste, and allows for the development of more sustainable structural rehabilitation strategies. For the purposes of this research, it can be used to modernize uninhabited housing. Applying the concrete recycling methodology can consolidate a viable alternative that incorporates superior sustainable, environmental, and economic aspects for housing construction and rehabilitation.

6. Further Work

This research has demonstrated that structural housing rehabilitation using recycled concrete, rehabilitation methodologies, and participatory processes is a viable, sustainable, and socially relevant solution to address the current housing crisis in various Mexican cities, specifically in Tlajomulco de Zúñiga. This municipality is a key area for housing rehabilitation due to its high percentage of vacant homes. Furthermore, the results have generated new avenues for research, development, and application that should be explored further to replicate, scale up, and consolidate the proposed model nationwide. Therefore, future work will be structured around three main axes: (a) socio-environmental integration and public policy, (b) scalability and replication in different cities across the country, and

(c) in-depth analysis of the structural, technical, and material aspects of different states.

Regarding scalability, future research should guide different design methodologies toward adapting the developed model to various urban contexts across the country that face similar problems of housing abandonment (unfortunately, this phenomenon occurs in almost every city in the country), structural deterioration due to materials, and urban sprawl. To address this problem, a flexible methodological framework must be developed that can adapt to the country's diverse climatic, social, construction, and economic conditions. The systematization of this approach could then lead to a technical guide for the structural rehabilitation of existing housing, which should be implemented by local governments, universities, academic institutions, and social organizations.

From a Mexican government policy perspective, this research highlights the need to link its findings to national and international agendas, but primarily to the UN Sustainable Development Goals (SDGs), specifically SDG 11 (Sustainable Cities and Communities), SDG 9 (Industry, Innovation and Infrastructure), and SDG 13 (Climate Action). Given that the structural rehabilitation of vacant housing aligns closely with the approaches of the 2030 Agenda, housing rehabilitation using low-carbon materials and techniques can become a strategic tool for reducing the environmental footprint of the construction and engineering sector. Furthermore, it can address housing demand and curb Mexico's uncontrolled urban sprawl. In this sense, this research concludes with the development of, and encourages the development of, different evaluation, design, economic, and governmental methodologies that allow for the short-, medium and long-term measurement of the effects of structural housing rehabilitation, with the aim of increasing habitability and sustainability.

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