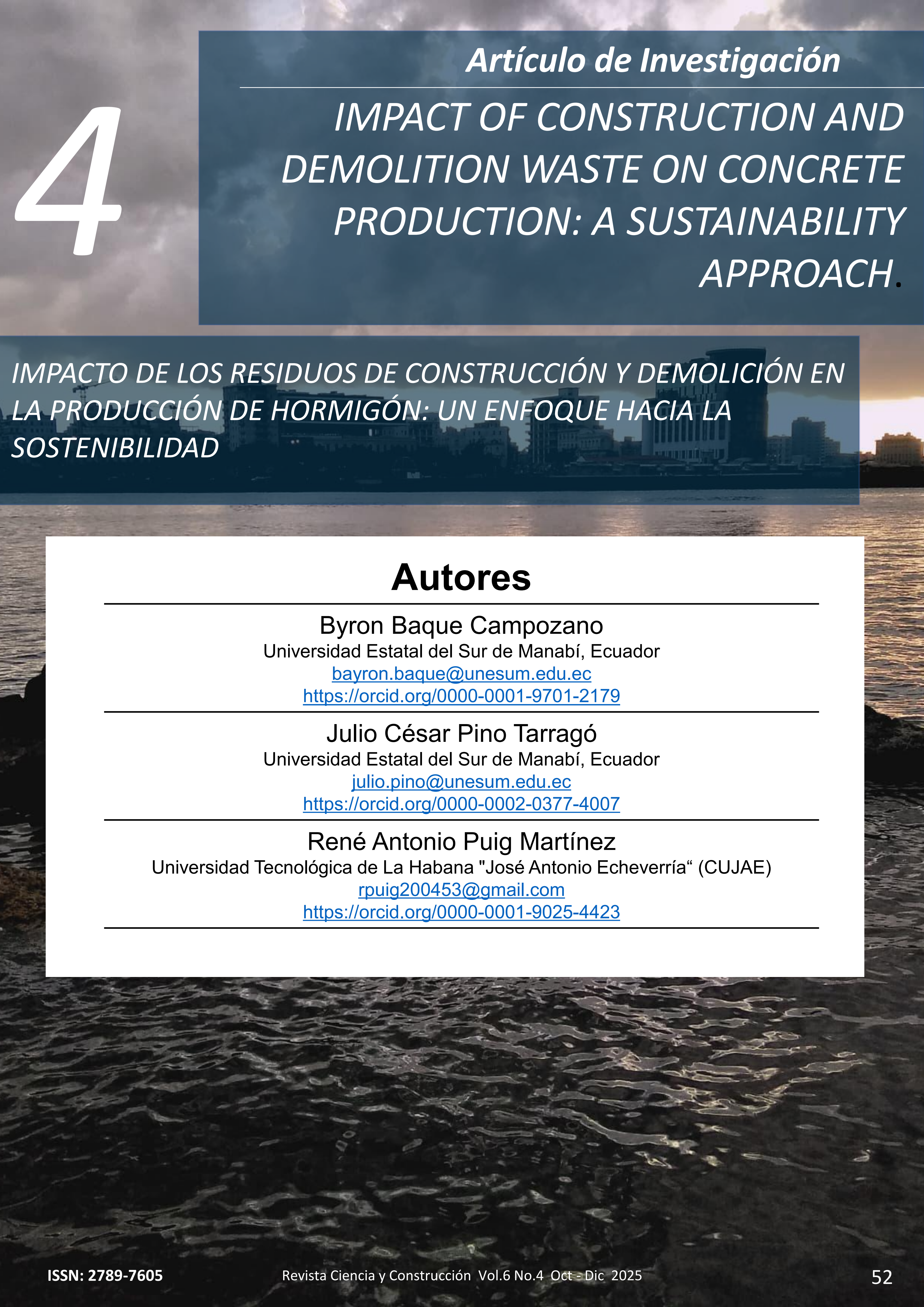

Artículo de Investigación

4

IMPACT OF CONSTRUCTION AND DEMOLITION WASTE ON CONCRETE PRODUCTION: A SUSTAINABILITY APPROACH.

IMPACTO DE LOS RESIDUOS DE CONSTRUCCIÓN Y DEMOLICIÓN EN LA PRODUCCIÓN DE HORMIGÓN: UN ENFOQUE HACIA LA SOSTENIBILIDAD

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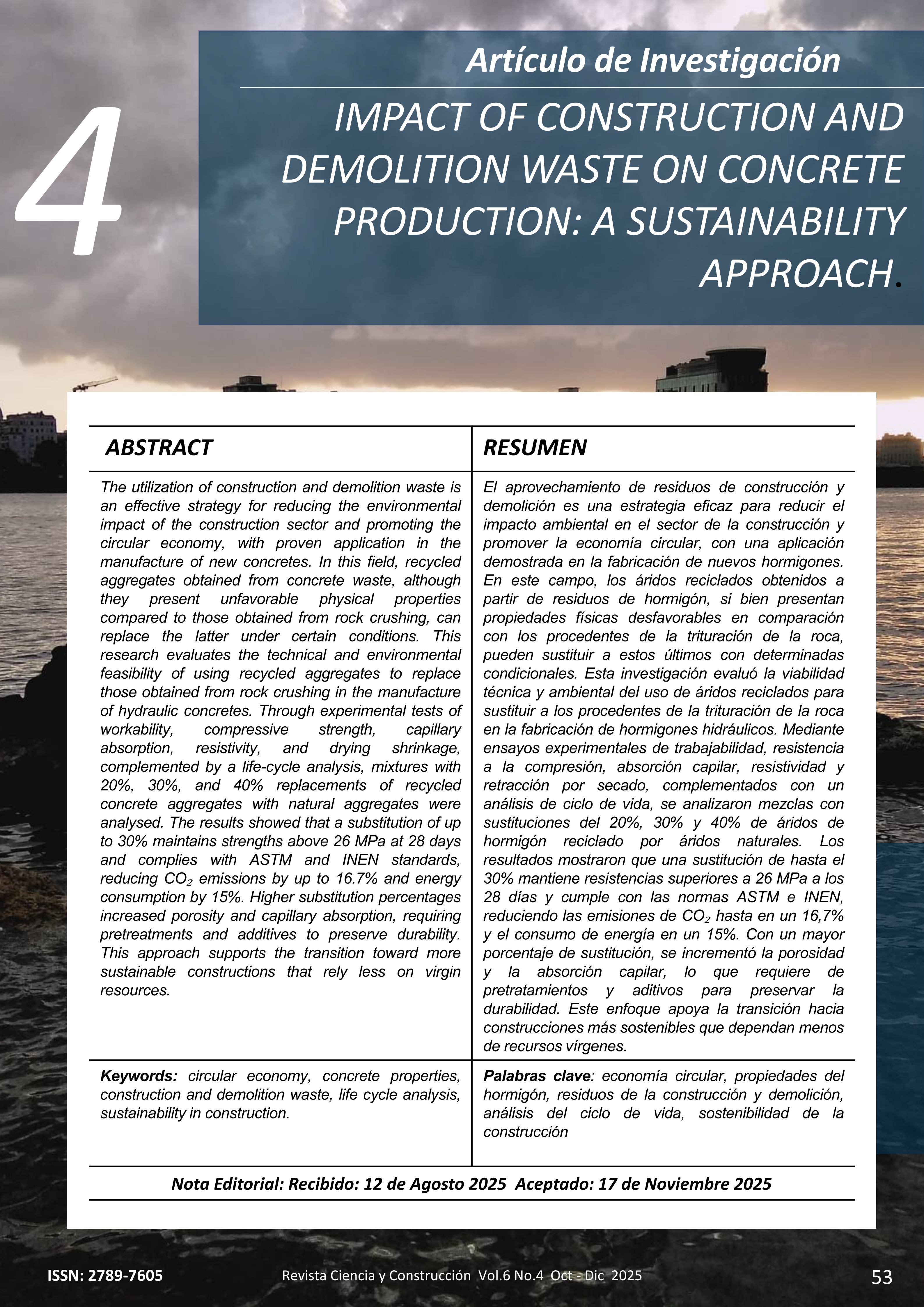

Artículo de Investigación

4

IMPACT OF CONSTRUCTION AND DEMOLITION WASTE ON CONCRETE PRODUCTION: A SUSTAINABILITY APPROACH.

ABSTRACT

The utilization of construction and demolition waste is an effective strategy for reducing the environmental impact of the construction sector and promoting the circular economy, with proven application in the manufacture of new concretes. In this field, recycled aggregates obtained from concrete waste, although they present unfavorable physical properties compared to those obtained from rock crushing, can replace the latter under certain conditions. This research evaluates the technical and environmental feasibility of using recycled aggregates to replace those obtained from rock crushing in the manufacture of hydraulic concretes. Through experimental tests of workability, compressive strength, capillary absorption, resistivity, and drying shrinkage, complemented by a life-cycle analysis, mixtures with 20%, 30%, and 40% replacements of recycled concrete aggregates with natural aggregates were analysed. The results showed that a substitution of up to 30% maintains strengths above 26 MPa at 28 days and complies with ASTM and INEN standards, reducing CO_2 emissions by up to 16.7% and energy consumption by 15%. Higher substitution percentages increased porosity and capillary absorption, requiring pretreatments and additives to preserve durability. This approach supports the transition toward more sustainable constructions that rely less on virgin resources.

Keywords: *circular economy, concrete properties, construction and demolition waste, life cycle analysis, sustainability in construction.*

RESUMEN

El aprovechamiento de residuos de construcción y demolición es una estrategia eficaz para reducir el impacto ambiental en el sector de la construcción y promover la economía circular, con una aplicación demostrada en la fabricación de nuevos hormigones. En este campo, los áridos reciclados obtenidos a partir de residuos de hormigón, si bien presentan propiedades físicas desfavorables en comparación con los procedentes de la trituración de la roca, pueden sustituir a estos últimos con determinadas condicionales. Esta investigación evaluó la viabilidad técnica y ambiental del uso de áridos reciclados para sustituir a los procedentes de la trituración de la roca en la fabricación de hormigones hidráulicos. Mediante ensayos experimentales de trabajabilidad, resistencia a la compresión, absorción capilar, resistividad y retracción por secado, complementados con un análisis de ciclo de vida, se analizaron mezclas con sustituciones del 20%, 30% y 40% de áridos de hormigón reciclado por áridos naturales. Los resultados mostraron que una sustitución de hasta el 30% mantiene resistencias superiores a 26 MPa a los 28 días y cumple con las normas ASTM e INEN, reduciendo las emisiones de CO_2 hasta en un 16,7% y el consumo de energía en un 15%. Con un mayor porcentaje de sustitución, se incrementó la porosidad y la absorción capilar, lo que requiere de pretratamientos y aditivos para preservar la durabilidad. Este enfoque apoya la transición hacia construcciones más sostenibles que dependan menos de recursos vírgenes.

Palabras clave: *economía circular, propiedades del hormigón, residuos de la construcción y demolición, análisis del ciclo de vida, sostenibilidad de la construcción*

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1. INTRODUCTION

The construction industry is one of the main consumers of natural resources and generators of solid waste worldwide. This sector uses more than 50% of the natural resources extracted globally and produces approximately 35% of the waste that ends up in landfills. It also contributes more than 11% of global CO_2 emissions due to the intensive use of energy and virgin materials [1,2]. The extraction, transportation, and processing of construction materials account for between 5% and 8% of these emissions [3]. In Latin America, rapid urbanization has increased the generation of construction and demolition waste (CDW), most of which lacks proper management, causing negative impacts on soils, water bodies, and air quality [4,5]. In Ecuador, limited recycling infrastructure and the absence of specific regulations exacerbate the informal disposal of this waste [6]. However, its recovery represents a strategic opportunity to boost the circular economy. In this context, advances in self-healing concrete —a topic also addressed in research by the authors [7]— gain relevance, especially when considering emerging techniques detailed in recent reviews and studies demonstrating the durability of concrete with recycled aggregates in humid climates similar to the Ecuadorian coast [8].

International experience confirms the potential of this strategy. In Europe, countries such as Germany and the Netherlands have implemented policies that allow the reuse of up to 30% of recycled aggregates in public projects, reducing landfill disposal and generating economic benefits [3,6]. In Asia, Japan and South Korea have achieved recycling rates above 90% thanks to separation technologies and chemical treatments that improve the quality of recycled aggregates [9, 10]. In contrast, in developing countries such as India and Brazil, the lack of specific regulations and the high variability of CDW limit their use to non-structural applications [5].

In Ecuador, the use of recycled aggregates in concrete is still incipient. However, initiatives such as the "Sustainable Construction Ecuador" project of the Ministry of Urban Development and Housing (MIDUVI) and studies developed by universities such as UNESUM and EPN demonstrate their potential to reduce costs and mitigate environmental impacts [2,7]. Life cycle assessment (LCA) has demonstrated, in international research, reductions in concrete's carbon footprint of between 20% and 30% when natural aggregates are replaced with recycled ones [3,11]. Furthermore, technologies such as alkaline activation, the use of pozzolanic admixtures, and superplasticizers have significantly improved the durability and strength of recycled concrete [12,13].

The physical and mechanical properties of CDW —including porosity, mortar adhesion, and water absorption— determine their performance in structural applications [14]. Tests such as particle size distribution and electrical resistivity allow for the optimization of mixture designs and the application of treatments to mitigate their adverse effects. The adoption of international standards such as ASTM C192M or INEN 1573 can serve as a basis for developing national standards that strengthen the circular economy [2,15].

Within this framework, this research aims to position Ecuador among the best international practices in sustainable CDW management, by evaluating the technical and environmental viability of hydraulic concrete made with recycled aggregates. To this end, experimental tests and a life cycle analysis were conducted to quantify the environmental and economic benefits. This is intended to provide scientific evidence for the formulation of regulations and public policies that support sustainability in construction, based on the hypothesis that it is feasible to replace up to 30% of natural aggregates with CDW without affecting their physical, mechanical, and durability properties.

2. MATERIALS AND METHODS

This study was conducted using an experimental approach, with the purpose of evaluating the mechanical and physical properties and environmental impact of concrete made with CDW used as recycled aggregates. The methodology was designed to ensure the reproducibility and validity of the results, and was structured in six stages.

2.1. STAGE 1: MATERIAL SELECTION AND CHARACTERIZATION

Crushed natural aggregates and recycled aggregates were used in the manufacture of the concrete, along with Portland cement, water, and additives, as detailed below:

- Crushed natural aggregates: From the Picoazá quarry, owned by MEGAROK S.A., located in Portoviejo, Manabí, Ecuador. This company, through its own laboratory (an accredited institution), certifies the quality of the aggregates it produces in accordance with the Ecuadorian standard NTE INEM 872; therefore, their characterization is not included in this research. Two types of aggregates were used: crushed sand classified in the 4.75-0.15 fraction; and number 6 gravel, corresponding to the 19-9.5 fraction. Table 1 shows their main physical properties.

Table 1- Main physical properties of crushed natural aggregates

Property	Unit of measurement	***Crushed sand** 4.75-0.15*	Gravel 19-9.5
Specific gravity (current)	g/cm^3	2.55	2.53
Loose unit weight	kg/m^3	1376	1370
Compacted unit weight	kg/m^3	1558	1530
Finer than 200 mesh sieve	%	2.45	0.67
Water absorption	%	1.67	2.11
Clay content	%	0	0
Los Angeles abrasion test	%	-	35
Flat and elongated particles	%	-	4.33

- Recycled Aggregates: Obtained from rubble from demolished buildings in the province of Manabí, they were cleaned to remove impurities and separated from reinforcing steel bars, as well as classified by sieving according to ASTM C136. Two fractions were selected, according to the research objective: a fine fraction in the form of sand; and a coarse fraction in the form of gravel, both characterized as part of the research.
- Cement: Portland cement type IP for general use, in accordance with the requirements of ASTM C150.
- Additives: Superplasticizer, used to improve workability and simultaneously contribute to the strength and durability of the concrete.
- Water: Potable, meeting the quality requirements established in ASTM C1602.

As a preliminary step in mix design, the physical and particle size distribution properties of the recycled aggregates were determined to estimate their impact on water demand, workability, and the mechanical and durability properties of the concrete.

Table 2 shows the physical properties of the recycled aggregates (determined according to ASTM C127 for coarse aggregates and ASTM C128 for fine aggregates.

Table 2- Physical properties of recycled aggregates

Property	Unit of measurement	Recycled fine aggregate	Recycled coarse aggregate
Specific mass	g/cm^3	2.35	2.45
Water absorption	%	6.2	5.8
Porosity	%	12.4	10.7

Notes: Specific mass and absorption determined according to ASTM C128 (fine fraction) and ASTM C127 (coarse fraction).

Porosity obtained by mercury intrusion (MIP) on representative fractions of the recycled aggregates.

The reported values correspond to average results; the coefficient of variation in specific mass was ≤ 2%.

The recycled aggregates come from C&D waste from buildings in the province of Manabí, Ecuador, after mechanical cleaning and particle size classification (ASTM C136).

Source: Prepared by the authors (2025), based on laboratory tests performed according to the ASTM standards indicated.

It can be observed that they presented the expected physical behavior: lower specific mass, and higher water absorption and porosity than natural aggregates, mainly due to the presence of adhered mortar and greater surface roughness. This behavior increases the water absorption capacity and reduces the density of the concrete, which can affect durability and workability in structural applications [12,16] and is critical for adjusting the water/cement ratio and the dosage of superplasticizing additives, as well as for anticipating possible effects on permeability and shrinkage. The coefficient of variation in density (2%) indicated good experimental consistency. These results are consistent with studies in tropical regions, where humidity favors the adherence of the residual mortar [6], and suggest the relevance of pretreatments such as sealing impregnations to improve performance.

In Figure 1, the granulometric curves corresponding to the two recycled aggregates can be seen (determined according to ASTM C136).

When evaluating the granulometric curves, it is significant to note that both aggregates meet the specifications established in Ecuador for this property, although the fine aggregate is characterized by a particle size distribution very close to the maximum fineness limit, which is explained by the grinding process using an industrial plant with a jaw mill and the high percentage of adhered mortar. The fineness modulus of the fine aggregate reaches a value of 2.33, very close to the minimum established in Ecuadorian regulations (2.3). Like the crushed aggregates from rock crushing, the coarse recycled aggregates are classified as gravel 19-9.5 and the fine recycled aggregates as sand 4.75-0.15.

2.2. STAGE 2: MIX DESIGN

Four mixes were prepared: one control (0% recycled aggregates) and three with partial replacement of natural aggregates with recycled aggregates at percentages of 20%, 30%, and 40% of each fraction, based on the total aggregate mass. The mix design was performed according to ACI 211.1, for a required 28-day average compressive strength of 25 MPa, with adjustments made through test mixes to maintain workability with the use of the superplasticizer admixture, as well as to prepare specimens for mechanical and durability testing. The water/cement ratio was optimized to 0.47 to maximize strength and durability.

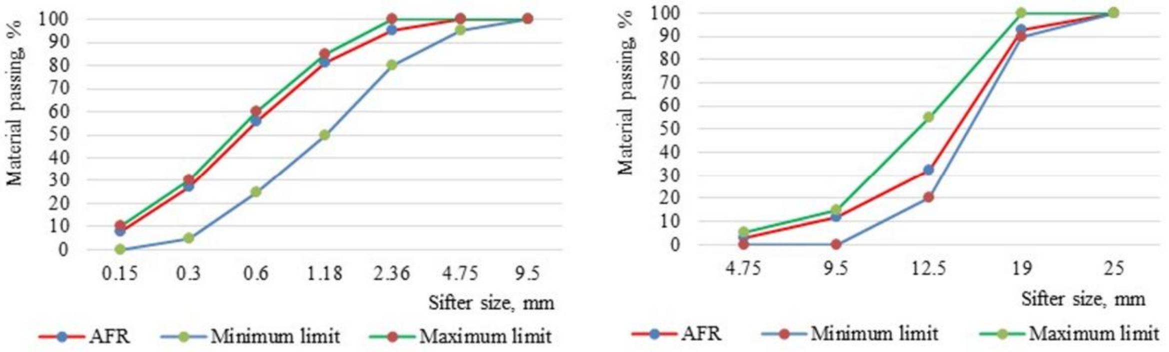

Fig. 1- Granulometric curves of fine and coarse recycled aggregates

The dosage per cubic meter and for the different 40 L test mixes can be seen in Table 3. The increase in the proportion of superplasticizer additive required can be seen as the proportion of recycled aggregates increases to achieve the same workability, which is in line with the physical results obtained, in particular, the high fineness of the particles due to the adhered mortar.

Table 3- Concrete dosages for the experiment

Materials	**Unit of measurement**	**Dosages**				
		Cubic meter	**Substitution levels, %**			
			0	**20**	**30**	**40**
Portland cement (GU)	**kg**	400	16.00	16.00	16.00	16.00
Water	**L**	188	7.56	7.56	7.56	7.56
Pucoazá sand	**kg**	704	28.16	22.53	19.71	16.90
Picoazá gravel	**kg**	1057	42.28	33.82	29.60	25.37
recycled sand	**kg**	-	-	5.63	8.45	11.26
recycled gravel	**kg**	-	-	8.46	12.68	16.91
Plastocrete additive	**L**	3.4	0.14	0.20	0.25	0.29

2.3. STAGE 3: RESEARCH DESIGN

The proportion of recycled aggregates to be replaced with natural aggregates was selected as the independent variable of the experiment. An equal proportion of fine and coarse aggregate was replaced at each dosage (see Table 3). To select the replacement levels, the percentages most commonly used by the scientific community were followed [3,11,12,13], choosing 20%, 30%, and 40%.

The following were measured as output or dependent variables of the experiment: compressive strength at 7, 14, and 28 days to evaluate the behavior of this property over time; capillary absorption, resistivity, and drying shrinkage, the latter only at 28 days. The specimens were kept in a curing tank until the testing age. Additionally, as complementary tests, workability, unit mass, and fresh air content were measured. One main test and two replicates were performed on each batch, which is considered adequate and statistically representative.

To determine compressive strength, three specimens were prepared for each test age in each text mix, totaling nine specimens per text mix. Three batches were prepared for each mix design, including the control mix, resulting in 27 specimens per mix design. Since there were four different mix designs based on the aggregate substitution percentage, a total of 108 specimens were prepared for the compressive strength test. The resistivity test was performed on the same specimens used for the 28-day compressive strength test, before failure. For the absorption test, one additional cylindrical specimen was prepared per text mix, for a total of nine. Finally, for the shrinkage test, prismatic specimens were prepared according to ASTM C157, three per text mix, i.e., nine for each substitution percentage and 36 in total.

The following standards were used to determine the properties of the fresh concrete: slump using the Abrams cone test (ASTM C143), unit mass (ASTM C138), and air content (ASTM C231). Hardened properties were determined using: compressive strength in cylindrical specimens at ages of 7, 14, and 28 days (ASTM C39), capillary absorption (ASTM C1585), electrical resistivity using the four-electrode method (Wenner), and drying shrinkage (ASTM C157).

2.4. STAGE 4: LIFE CYCLE ASSESSMENT (LCA)

A life cycle assessment was carried out to quantify the environmental impact of the mixtures, following the following stages:

- **Objective and scope:** To compare greenhouse gas (GHG) emissions, energy consumption, and waste reduction between mixtures with recycled aggregates and the control mixture.
- **Life cycle inventory:** Data collection from the extraction and processing of CDW to concrete production.
- **Impact assessment:** ReCiPe 2016 method, implemented in SimaPro v9.3 software with an Ecoinvent 3.8 database.

2.5. STAGE 5: STATISTICAL EVALUATION

The following procedures were applied:

- Analysis of variance (ANOVA): To determine whether or not there were statistically significant differences between the levels of substitution of crushed aggregates with recycled aggregates in each of the properties compared to the standard.
- Post hoc tests: Tukey HSD, to identify the groups between which there were significant differences ($p < 0.05$).

2.6 STAGE 6: REGULATORY VALIDATION

The results obtained were compared with the requirements established in ASTM, INEN, and ACI standards to evaluate the technical feasibility of using recycled aggregates in structural applications, considering strength, durability, and sustainability parameters.

3. Results and discussion

3.1 FRESH CONCRETE PROPERTIES

3.1.1. WORKABILITY

Slump decreased with increasing recycled aggregates ratio (70 mm in the standard mix versus 50 mm with 40% replacement), necessitating an increase in the superplasticizer admixture ratio to bring each of the control mixes to approximately 120 mm, measured on the Abrams cone (see Table 4). Analysis of variance (ANOVA) showed significant differences without the use of admixtures (p-values = 0.00 < 0.05), confirming that increasing recycled aggregates increases mixing water demand and reduces fluidity [9]. The angular and irregular shape of the recycled aggregates reduces internal cohesion and can cause segregation [12].

Table 4- Properties of fresh concrete

Recycled aggregates ratio, %	Slump, mm		Unit mass, kg/m³	Air content, %
	Without additive	With additive		
0	70	120	2380	2.0
20	61	112	2350	2.2
30	55	114	2330	2.4
40	50	110	2320	2.5
Note: The standard deviation never exceeded 3%.				

Source: Prepared by the authors (2025), based on laboratory tests performed according to the ASTM standards indicated.

3.2. PROPERTIES OF HARDENED CONCRETE

3.2.1. COMPRESSIVE STRENGTH

Table 5 shows the results for the three ages evaluated.

Table 5- Compressive strength

Recycled aggregates ratio, %	Compressive strength, MPa		
	7 days	14 days	28 days
0	22.0	27.5	30.0
20	20.5	26.0	28.0
30	18.0	24.0	26.0
40	16.5	22.0	24.0

Source: Prepared by the authors (2025), based on laboratory tests carried out according to the indicated ASTM standards.

Overall, compressive strength increases with age, consistent with expectations. This increase is proportional regardless of the replacement percentage evaluated. Mixtures with up to 30% recycled aggregates met structural standards (required mean 28-day compressive strength of 25 MPa), reaching strengths ≥ 26 MPa at 28 days (Table 5). Strength decreases with higher percentages, showing a strong negative correlation ($R^2 = 0.91$ in absolute value), indicating that 91% of the strength variability is explained by the recycled aggregate content. This loss could be mitigated with pozzolanic additions or pretreatments to the recycled aggregates [3]. The p-value of the F-test was zero (below 0.05), indicating the existence of statistically significant differences between the standard dosage and the different control dosages. At 28 days, the averages formed four homogeneous groups.

3.2.2 CAPILLARY ABSORPTION

Absorption increased with recycled aggregates content, from 0.09 g/cm² min¹/² (standard) to 0.15 g/cm² min¹/² (with 40% recycled aggregates), representing an increase of 66.7%. The R^2 value of 0.89 indicates a very high positive correlation between recycled aggregates content and absorption. This suggests that porosity and residual mortar in recycled aggregates are determinants of this behavior. One mitigation strategy would be the use of hydrophobic additives or protective coatings [17,18].

3.2.3. ELECTRICAL RESISTIVITY

The resistivity decreased from 18 kΩ.cm (standard) to 10 kΩ.cm (with 40% recycled aggregates), with a negative $R^2 = 0.85$, indicating a strong inverse correlation between recycled aggregates content and resistivity. This decrease is due to the increased number of interconnected and water-saturated pores, which increases ionic conductivity. While the values comply with RILEM TC-154 for moderate environments, they would not be suitable for severe conditions without additional treatments [10].

3.2.4 DRYING SHRINKAGE

Shrinkage increased by 71.4%, from 0.035% (standard) to 0.060% (40% recycled aggregates), attributable to the porosity and lower stiffness of the recycled aggregates. Polymers impregnated in the aggregates could reduce this effect [14].

3.3. ENVIRONMENTAL IMPACT

The environmental impact, determined through Life Cycle Assessment (LCA) following the **ReCiPe 2016** methodology and implemented in **SimaPro v9.3** software using the **Ecoinvent 3.8** database, showed progressive reductions in CO_2 emissions, waste, and energy consumption (Table 6). The system boundaries included aggregate extraction and processing, cement production, transportation, and concrete production. The maximum benefit was achieved with 40% recycled aggregates, with a 21% reduction in CO_2, expressed as CO_2 equivalent (kg CO_2-eq); a 20% energy saving, expressed as primary energy consumed (MJ); and 100 kg/m³ of concrete waste not sent to landfills.

Table 6- Environmental impact per m³ of concrete

Indicator	Unit of measurement	Recycled aggregates ratio, %			
		0	**20**	**30**	**40**
CO_2	kg	420	378	350	330
Waste avoided	kg	0	50	75	100
Energy saved	MJ	600	540	510	480

Source: Own elaboration (2025), based on LCA modelling according to the indicated standards and methodology.

3.4. RESULTS-BASED SUSTAINABILITY STRATEGIES

The findings demonstrate that incorporating up to 30% recycled concrete into structural concrete is technically feasible and environmentally beneficial in the Ecuadorian context. According to the LCA, significant reductions in CO_2 and energy consumption are achieved without compromising structural strength. In this regard, the following strategies are proposed:

- Implement national regulations that establish a mandatory minimum percentage of recycled concrete in public projects, based on demonstrated technical feasibility.
- Promote economic incentives for the use of additives and treatments that improve the durability of recycled concrete.
- Integrate LCA into the design and bidding processes to prioritize solutions with a lower environmental footprint.
- Strengthen the CDW recycling infrastructure through public-private partnerships and technical training.

These measures would allow national construction practice to be aligned with successful experiences such as those of Germany and Japan, where clear policies and advanced technologies have achieved recycling rates above 50% and 90%, respectively [5].

4. CONCLUSIONS

Technical feasibility: The results demonstrate that construction and demolition waste (CDW) can be used as recycled aggregates in hydraulic concretes for structural applications. Mixtures with up to 30% recycled aggregates achieved compressive strengths greater than 26 MPa at 28 days, complying with ASTM and INEN standards. This allows for a reduction in dependence on natural aggregates without compromising mechanical performance. Replacements above 30% require adjustments to the water/cement ratio and the addition of additives to maintain strength and durability levels.

Environmental benefits: The life cycle analysis (LCA) showed that incorporating 40% recycled aggregates in the mix reduces CO_2 emissions by up to 21%, decreases energy consumption by 20%, and avoids the disposal of 100 kg/m³ of waste in landfills. These benefits are consistent with global sustainability goals and certification criteria such as LEED and BREEAM.

Material optimization: The application of pretreatments—such as hydrophobic impregnations, protective coatings, and pozzolanic additions—improves the durability of recycled concrete, reduces capillary absorption, and mitigates the decrease in electrical resistivity. Furthermore, an optimized mix design, combined with superplasticizers, maintains adequate workability even with high recycled aggregates contents.

Limitations and projections: The study was conducted under controlled laboratory conditions; therefore, long-term evaluations under real-life conditions are recommended, considering climatic factors, variable loads, and exposure to aggressive environments. Future research should explore the integration of recycled aggregates with innovative materials, such as self-healing concrete, and its implementation in projects certified under international sustainability schemes.

Applicability and regulatory scope: The findings are applicable to infrastructure projects in regions with high CDW generation, contributing to the circular economy in construction. They also provide a technical and scientific basis for formulating national regulations that regulate and promote the use of recycled aggregates in structural concrete.

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