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Original Article

Impact of Construction and Demolition Waste Concrete on the Safety and Durability of Two-Story Houses

Impacto del concreto de Residuos de Construcción y Demolición en la seguridad y durabilidad de viviendas de dos pisos

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Abstract

Introduction: the construction industry faces a significant challenge in using construction and demolition waste (CDW) as coarse aggregate in structural concrete. The incorporation of these recycled materials can impact the safety and durability of structures, highlighting the need to investigate their viability in concrete mixtures.
Objective: the objective of this study is to evaluate the safety and durability of concrete modified with CDW through a comparative structural analysis. The aim is to establish the relationship between compressive strength indices and steel percentages based on different proportions of CDW in the mix.
Methods: compression tests were conducted based on a conventional concrete mix design according to the ACI-6318 method. Variations in the water/cement (w/c) ratio were made, and the coarse aggregate (¾”) was partially replaced with CDW in percentages of 5%, 10%, and 15%. Different types of collected bricks (#4, structural, and paver) were used, resulting in a total of 102 specimens evaluated at 7, 14, and 28 days post-molding.
Results: the results indicate an effective relationship that meets the minimum requirements of the Colombian Seismic Resistant Construction Rule (NSR-10 - Title B). The comparison of a two-story house model shows that using #4 brick type at percentages below 10% provides significant benefits in terms of structural safety and durability.
Conclusion: it is concluded that the use of construction and demolition waste as aggregate in concrete can be an effective strategy to enhance sustainability in construction without compromising the safety or durability of structures, especially when appropriate bricks are used in controlled proportions.

Resumen

Introducción: la industria de la construcción enfrenta un desafío significativo al utilizar residuos de construcción y demolición (RCD) como agregado grueso en el concreto estructural. La incorporación de estos materiales reciclados puede impactar la seguridad y durabilidad de las estructuras, lo que plantea la necesidad de investigar su viabilidad en mezclas de concreto.
Objetivo: el objetivo de este estudio es evaluar la seguridad y durabilidad del concreto modificado con RCD mediante un análisis estructural comparativo. Se busca establecer la relación entre índices de resistencia a la compresión y porcentajes de acero en función de diferentes proporciones de RCD en la mezcla.
Métodos: se realizaron pruebas de compresión basadas en un diseño de mezcla de concreto convencional según el método ACI-6318. Se variaron las proporciones de agua/cemento (w/c) y se sustituyó parcialmente el agregado grueso (¾”) con RCD en porcentajes del 5%, 10% y 15%. Se utilizaron diferentes tipos de ladrillos recolectados (#4, estructurales y de paver) y se evaluaron un total de 102 especímenes a los 7, 14 y 28 días después del desmoldeo.
Resultados: los resultados indican una relación efectiva que cumple con los requisitos mínimos de la Normativa Colombiana de Construcción Sismo Resistente (NSR-10 - Título B). La comparación de un modelo de vivienda de dos pisos demuestra que el uso de ladrillo tipo #4 en porcentajes inferiores al 10% ofrece beneficios significativos en términos de seguridad estructural y durabilidad.
Conclusión: se concluye que el uso de residuos de construcción y demolición como agregado en el concreto puede ser una estrategia efectiva para mejorar la sostenibilidad en la construcción, sin comprometer la seguridad ni la durabilidad de las estructuras, especialmente cuando se utilizan ladrillos adecuados en proporciones controladas.

Keywords: construction and demolition waste (CDW), compressive strength, aggregate and compression test**.**

Palabras clave: residuos de construcción y demolición (RCD), resistencia a la compresión, agregado y ensayo a compresión.

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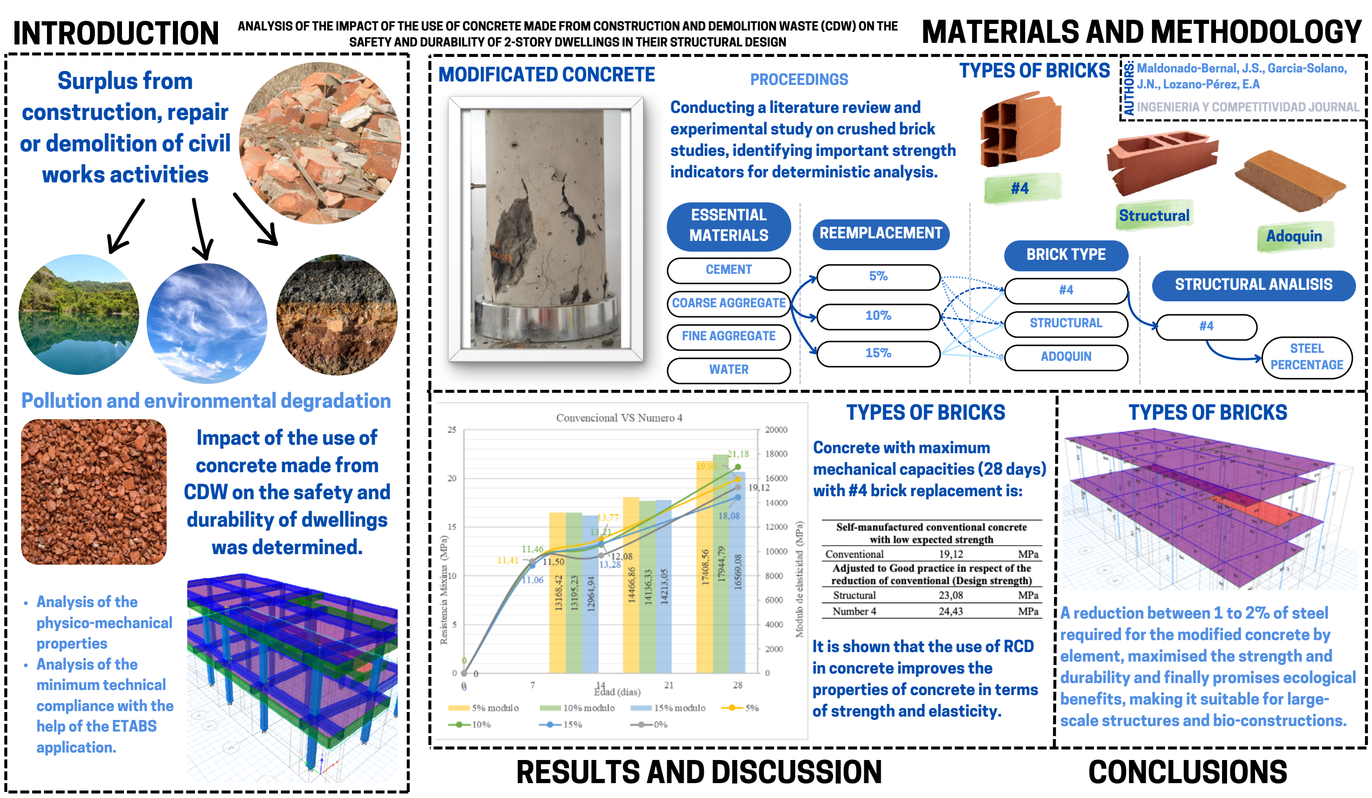
Why was it conducted?:
This study provides an evaluation of the most used methodologies for assessing the wind energy generation potential in various geographical regions. The research focused on identifying and analyzing the technical, environmental, legal, administrative, and logistical conditions necessary for the successful implementation of wind energy projects. Due to the inherent high intermittency of wind energy, it is crucial to conduct preliminary investigations to understand the technical and economic feasibility, as well as the energy potential, of such projects in specific areas. This approach helps reduce uncertainty and optimize the planning and execution of wind energy projects, thereby contributing to sustainable development and the global energy transition.

What were the most relevant results?
The study determined that although wind energy has significant potential for sustainable electricity generation, its successful implementation depends on various factors. These factors include the availability of favorable wind conditions; the minimization of environmental and aeronautical restrictions; optimal site conditions; and robust economic and logistical support. The bibliometric analysis revealed a growing trend in wind energy research, with notable contributions from countries such as the United States, China, Turkey, and Iran. Additionally, the importance of integrating multiple renewable energy sources to mitigate the intermittency issues associated with wind energy was identified. This approach allows for a more precise evaluation and more efficient planning of wind energy projects, optimizing their technical and economic feasibility.

What do these results contribute?
The results provide crucial information on the optimal conditions and methodologies for the implementation of wind energy projects. They highlight the need for preliminary studies to assess site suitability and the potential benefits of integrating wind energy with other renewable sources. The findings of the study will help guide policymakers, researchers, and investors in decision-making for the development and investment in wind energy projects. Additionally, the bibliometric analysis offers a detailed view of current research trends, enriching the global knowledge base and facilitating future studies in the field.

Graphical Abstract



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Introduction

According to (1), CDW as defined by Decree 1713 of 2002 as leftover of construction, renovation, repair, or demolition of civil engineering works or related activities, this material represents a source of pollution and environmental deterioration that negatively influences water bodies, air, or soil. Therefore, there is great interest in implementing modified designs that reduce the ecological impact through reuse to promote sustainable construction and in this way ensuring economic efficiency through evaluated technical concepts (2) and (3). According to the National Council for Economic and Social Policy (CONPES) 3874 of 2016 and the Superintendence of Public Utilities (SSPD), in Colombia will have 13.8 million tons of CDW annually for the year 2035, as Bogotá currently generates around 14,027,000 m³ of CDW per year (4) due to massive demolitions. Hence, it is necessary to reuse materials as viable technical, economic, social, and environmental alternatives (5), (6), considering research conducted on these materials where they are tested and concluded to comply with local regulations (2), (7).

For the above reasons, at a national level the management of CDW has been proposed as expressed by the UN and UNDP, emphasizing the need to incorporate policies for the management of CDW in future housing with the help of international regulations to minimize energy, water, and non-renewable resource consumption; from less machine hours for the extraction material, decreasing ecological imbalance, and mitigating ecosystem threats (8). These materials have been capable of withstanding live, dead, and seismic loads (9), (10), (11), although the structural elements for these cases of modified concrete must be checked in all their characteristics what ensure an optimal mix for the stability of structures using concrete (12), These influencing characteristics include geometry (cross-sectional area), air content, flexural strength, compressive strength, durability, and the structural system (13).

One of the major issues impacting the deficit in CDW management is specified by (14), who point out that in Colombia, the interest of public entities in managing these wastes has increased due to the lack of a consolidated methodology for reusing rubble in concrete elements (15) or massive treatment. Being a recycled material, it is influenced by hardness (16), porosity (12), and permeability (3%), which produce different w/c ratios, so this also affects workability (15), (12), since an optimal ratio avoids obstacles due to quality variations of CDW depending on its type and origin (17), thereby improving the internal and external characteristics of concrete elements (15). In additional, using clay counteracts damage due to temperature variations and increases compressive strength by up to 45% (18). Another important factor for the safety of the frame model is the steel required to regulate tension when the concrete is subjected to axial forces (19). CDW reduces material costs (20) and theoretically in housing projects for low-income families (21), as it does not require material extraction, but it does require transportation, classification, and selection (size of the coarse aggregate) (8), (22).

The research to determine the impact of using concrete manufactured with CDW on the safety and durability of two-story houses in their structural design, also includes an analysis of the physical-mechanical properties provided by clay blocks of type #4, pavers, and structural bricks, as these have specifications according to (23) (24), (25), (26), (12) respectively. All the above to analyze the behavior by verifying compliance with minimum technical and regulatory standards using the ETABS application; employed as a structural analysis software for finite elements focused on building behavior. This software allows for a structural check and design to ensure the stability, safety, and durability of a building (21). As the subject of study is a "green" house constructed with modified concrete using crushed brick for a two-story housing model, parameters were established according to the NSR-10 (19).

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Methodology

The research focuses on evaluating the impact of using CDW on the safety and durability of a two-story house as a measure for reintegrating crushed brick and housing optimization. Therefore, an experimental study was conducted based on a literature review of studies involving crushed brick, in which the strength indicators of importance for the deterministic analysis to estimate the advantages gained by structures with modified concrete designs, such as achieving strengths above 21 MPa.

To begin, the material specifications that make up the mix design were defined, followed by a comparative analysis of the properties enhanced by the modified concrete. Accordingly, a house was selected for the analysis of the model elements, which was modelled according to real dimensions. The comparison between conventional and modified concrete regarding the percentage of reinforcement required per element was carried out, after analyzing the technical compliance of the structural system (frames) using ETABS. This defined the safety constant and the details of structural durability for the final presentation of results and conclusions on the benefits of including CDW immersed concrete technology.

Results

According to the results of the experimental development, as well as the deterministic analysis of the model in ETABS, so the impact generated by using crushed brick was determined due to it has high hardness and permeability. The types of brick varying in functionality based on characteristics such as size, holes, type of clay, and firing, are used to determine which composition offers the greatest resistance advantages for the required structural system.
Structural bricks and pavers were selected using a sieve corresponding to a size of 19 mm, complying with the normal specification given by NSR-10, which requires a size bigger than the standard (27). Table 1 presents the w/c ratios used for concrete mixes that exceed a strength of 21 MPa (27), taking into account than for each of the following three mixes they maintained an amount of water (200 kg with a density of 1000 kg/m^3), cement (432.10 kg with a density of 2940 kg/m^3), and sand (776.74 kg with a density of 2701 kg/m^3) (28). In parallel manner, the water/cement/sand ratio was 0.463/1000/1.798, requiring only the variation of the weight of gravel and brick.

Table 1. w/c ratio with different dosages (5, 10 and 15%)

5% coarse aggregate replacement			10% coarse aggregate replacement			15% coarse aggregate replacement		
Aggregate	Gravel	Brick	Aggregate	Gravel	Brick	Aggregate	Gravel	Brick
Mass (kg)	901.88	47.47	Mass (kg)	854.41	94.93	Mass (kg)	806.94	142.40
Density (kg/m^3)	2597	-	Density (kg/m^3)	2597	-	Density (kg/m^3)	2597	-
Ratio	2.087	-	Ratio	1.977	-	Ratio	1.867	-

In the way the data obtained from concrete with “Paver” brick were excluded, as they exhibited lower than expected strengths and were not useful for the analysis, therefore, the verification of the model was reduced to the strengths of “Number 4” and “Structural” bricks. These failed specimens, with a curing age (29) and a diameter of 18 cm (measured after curing), provided maximum load values of interest and were subsequently used for the calculation of maximum strength (Equation 1) and modulus of elasticity (Equation 2) derived from (30):

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Equation 1. Maximus resistance

$$F'c = \frac{P\ max.}{A}$$

Equation 2. Modulus of elasticity

$$Ec = 3900 * \sqrt{F'c}$$

For better illustration, the figures 1 and 2 shows the data calculated and corrected with the percentage deviation mentioned below with respect to 21 MPa:

Compressive strength up to 28 days with respect to different dosage rates

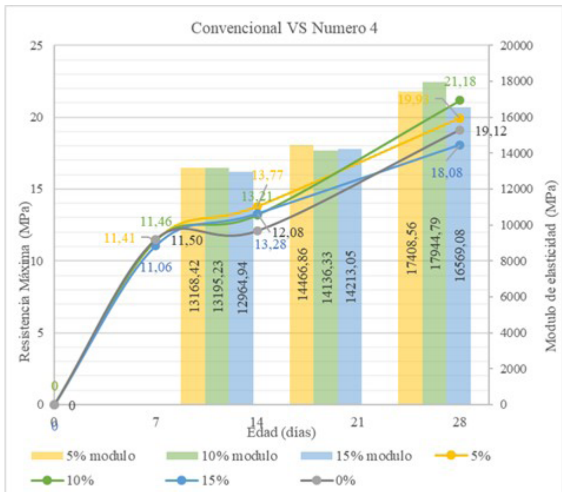

Figure 1. Strength and modulus of elasticity curve between conventional and brick #4 modified concrete.

Note: This graph shows the capacities of modified concrete with #4 brick at the ages of 7, 14, and 28 days compared to conventional concrete. As a secondary graph, the elasticity values acquired by each concrete are expressed.

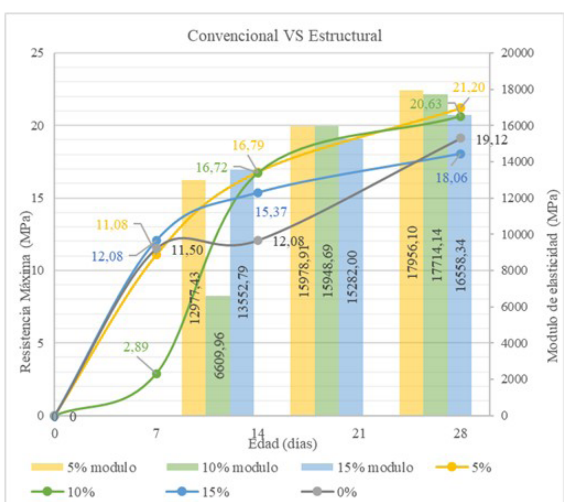

Figure 2. Strength and modulus of elasticity curves between conventional and structural brick modified concrete.

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Note: This graph shows the capacities of modified concrete with structural brick at the ages of 7, 14, and 28 days compared to conventional concrete. Like the previous graph, the secondary graph refers to the elasticity acquired by each concrete. These are averaged data from 3 specimens for each percentage of CDW replaced.

The increase in capacity, both in compression and in the modulus of elasticity, compared to conventional concretes, made it possible to select the maximum strength for the model in ETABS from the non-averaged data. (table 2)

Table 2. Maximum resistance (f'c).

Concrete with maximum mechanical capacities						
Brick type	**Age**	**Replacement**	**f`c**	**Und**	**E**	**Und**
Estructural	28	5%	21,20	MPa	17956,10	MPa
Numero 4	28	10%	22,55	MPa	18519,67	MPa

Note: The Structural brick type (Structural brick type (5%) with 28 days of age) offers better strength and elasticity indices among the averaged data, while the Number 4 brick was more advantageous in terms of strength without averaging.

Simultaneously, the expected maximum strength value (21 MPa) and the maximum strength value of conventionally manufactured concrete show a 9% difference (1.88 MPa) due to influential environmental factors (31) and (20), such as temperature variation, acid rain, and microbial agents (32). Therefore, the differential percentage of conventional concrete was added to the modified concretes for the deterministic analysis. (table 3)

Table 3. Desing strength

Self-manufactured conventional concrete with low expected strength		
Conventional	19,12	MPa
Adjusted to Good practice in respect of the reduction of conventional (Design strength)		
Structural	23,08	MPa
Number 4	24,43	MPa

The impact of modified concrete on structural elements of green homes by being a bioconstruction, quantifies the positive effect of incorporating CDW at 10%, promising advantages in mechanical (33) behavior for adaptation to large-scale structures with ecological benefits. Therefore, the numerical design adapted the characteristics shown in Table 4.

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Table 4. Project Description: Characteristics of a house

Country house in the village of Vanguardia-Villavicencio		
House type	**Model Home**	**Modified housing**
Type Use of building	Group I	
Materials of the main structure	Reinforced Concrete	Modified Concrete
Roofing materials	Lightweight plate	
Number of Building Levels	Two (2)	
Seismic resistance system	Reinforced concrete frames	CDW modified concrete portal frames

From the breakdown, the minimum area of the columns was verified using NSR-10 section C.21.6.1.1, with a height of 30 cm and a base of 30 cm, validated as they exceed the minimum required. Column dimensions for the ETABS model are a base of 35 cm and a height of 35 cm, with a cover of 4 cm (resulting in an effective height of 31 cm). Furthermore, the adapted frames for each floor comply with NSR-10 provisions, although is important to clarify that the Shell elements were discretized. Additionally, the structural configuration (columns, beams, and lightweight slabs) was adopted for the roof mezzanine shown in Figure 3, Figure 4.

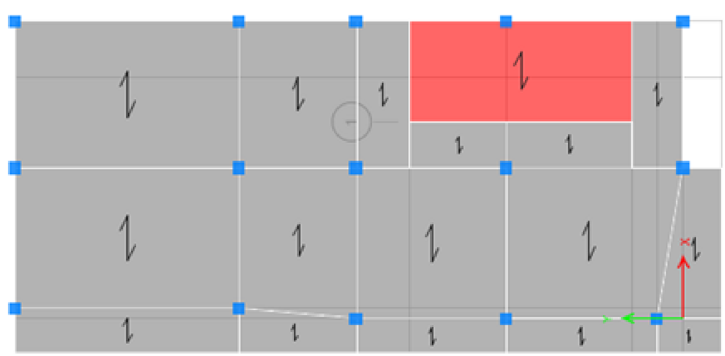

Figure 3. Mezzanine floor plan N+3.73

Note: The figure above shows the structural system in plan of the mezzanine floor with uniform column distribution.

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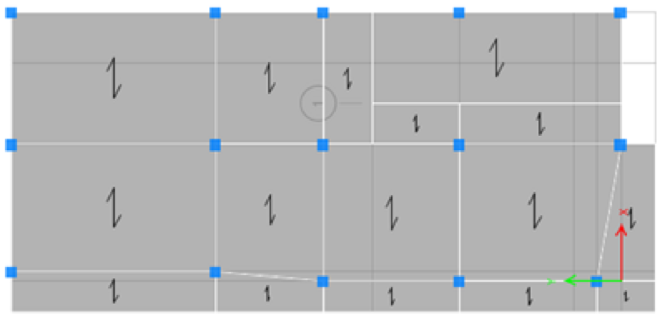

Figure 4. Mezzanine floor plan N+7.51

Note: The figure above shows the planar structural system of the roof with uniform column distribution.

Other specifications required for conventional concrete, modified concrete, and reinforcing steel for the numerical model (performed in ETABS software), calculating the modulus of elasticity (Ec) according to compressive strength (f'c) for the concretes, resulted in the conventional concrete having an Ec of 17,872.05 MPa and the modified concrete having an Ec of 19,276.85 MPa. Additionally, the normal capacity of steel Ec was taken as 200,000 MPa. Before examining the model, the increased loads and load combinations were assigned to the model as specified by NSR-10 in Title B, as these influence the verification of the structural support based on a uniform distribution of columns, since they are all the same size (30x30 cm). (figure 5)

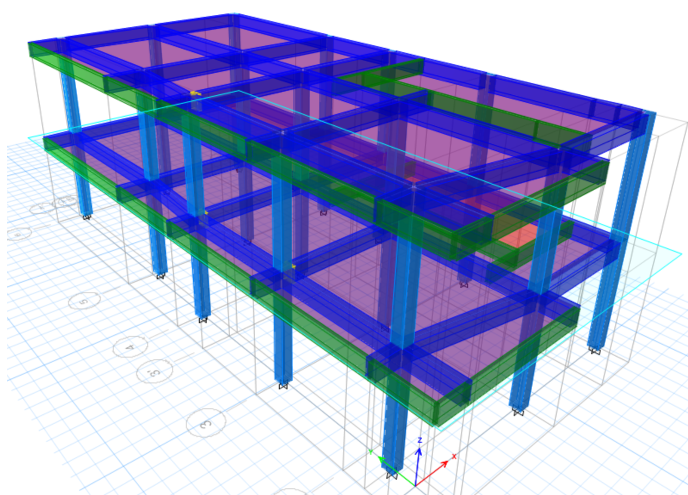

Figure 5. 3D view of the mathematical model

Note: the modelled structure is equal both geometrically and in its load distribution.

In addition, the labels of each element are identified as shown in Figure 6 in order to detail the elements that require more or less steel.

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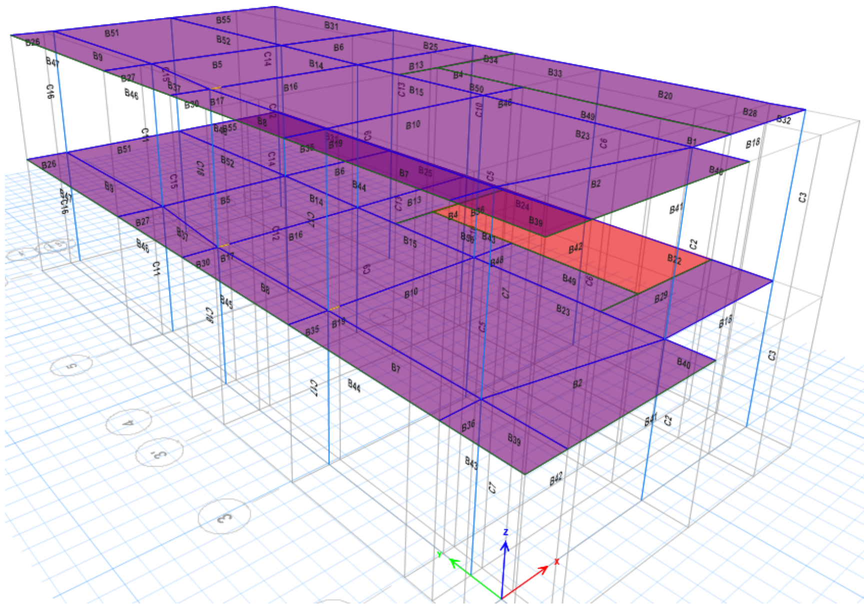

Figure 6. Identification of the labels of each element of the model - 3D view

In comparative terms between the advantages or disadvantages produced by the modified concrete with respect to the required reinforcement and conventional concrete per element, advantages were identified based on the concept of compression, since this analysis was conducted by substituting the coarse aggregate and examining the structural system's strength. The reduction of coarse aggregate and the inclusion of CDW in the mix effectively reduced the required reinforcement percentage, such visual comparison was made possible through the longitudinal and transverse sections generated by the software, considering the axes shown in the plan with an elevation of N+3.73m in Figure 7 and the plan with an elevation of N+7.51m in Figure 8.

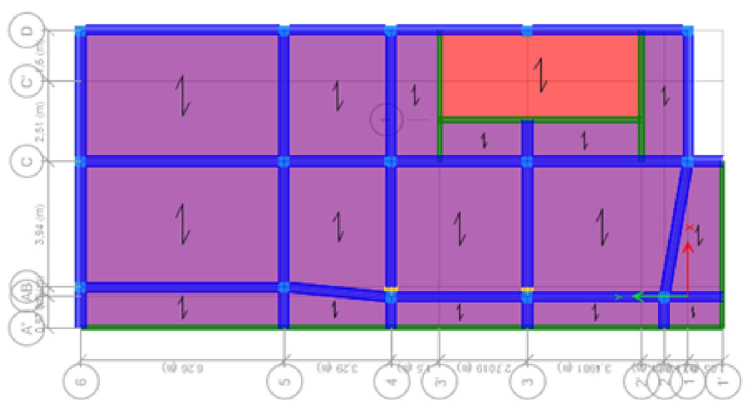

Figure 7. General floor plan with characterization of axes at level N+3.73m

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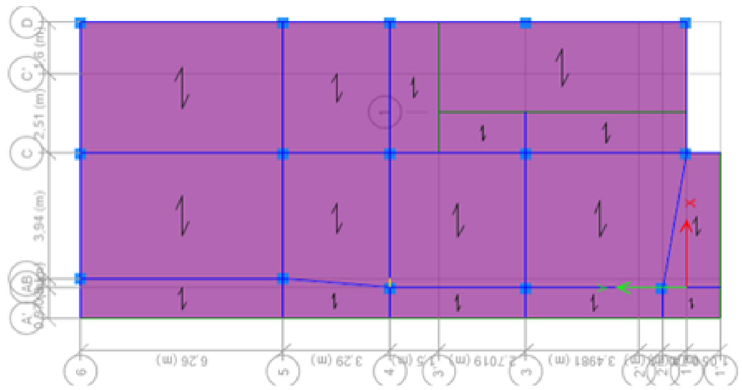

Figure 8. General floor plan with characterization of axes at level N+7.51m

From the tabulated quantum comparison, the average percentage of steel required for the mezzanine and roof is presented in Table 5 and Table 6. These tables were organized by left upper end reinforcements (EIS-LU), center bottom reinforcements (CB), and right upper end reinforcements (EDS-RU). Since the elements at each axis and elevation had steel in the same positions, these values were taken and averaged with respect to all elements according to their position, height, and axis of the steel.
Axes transverse to the model

Table 5. Percentages of the amount of the model with conventional and modified (transverse axes).

Axis	Elevation	Conventional			Modified		
		LU	CB	RU	LU	CB	RU
1′	N+3.73	0,35%	0,31%	0,35%	0,35%	0,30%	0,34%
	N+7.51	0,30%	0,30%	0,33%	0,30%	0,29%	0,33%
1	N+3.73	0,71%	0,58%	0,91%	0,72%	0,57%	0,92%
	N+7.51	0,59%	0,49%	0,52%	0,59%	0,49%	0,52%
2	N+3.73	0,30%	0,30%	0,42%	0,29%	0,29%	0,41%
	N+7.51	0,30%	0,30%	0,40%	0,29%	0,29%	0,39%
2′	N+3.73	0,21%	0,67%	0,18%	0,00%	0,00%	0,00%
	N+7.51	-	-	-	-	-	-
3	N+3.73	0,49%	0,30%	0,56%	0,49%	0,29%	0,56%
	N+7.51	0,29%	0,30%	0,46%	0,29%	0,29%	0,45%
3′	N+3.73	0,18%	0,64%	0,18%	0,19%	0,63%	0,17%
	N+7.51	0,18%	0,54%	0,00%	0,17%	0,53%	0,00%
4	N+3.73	0,45%	0,34%	0,55%	0,42%	0,34%	0,38%
	N+7.51	0,33%	0,30%	0,32%	0,33%	0,29%	0,31%
5	N+3.73	0,49%	0,32%	0,53%	0,39%	0,32%	0,54%
	N+7.51	0,34%	0,30%	0,39%	0,34%	0,29%	0,38%
6	N+3.73	0,61%	0,56%	0,75%	0,67%	0,56%	0,74%
	N+7.51	0,45%	0,32%	0,40%	0,44%	0,32%	0,40%

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Axes longitudinal to the model

Table 6. Percentage amounts of the model with conventional and modified (longitudinal axes)

Axis	Elevation	Conventional			Modified		
		LU	CB	RU	LU	CB	RU
A’	N+3.73	0,40%	0,33%	0,39%	0,39%	0,32%	0,39%
	N+7.51	0,35%	0,32%	0,36%	0,34%	0,32%	0,36%
A	N+3.73	0,53%	0,30%	0,51%	0,53%	0,29%	0,51%
	N+7.51	0,42%	0,30%	0,42%	0,34%	0,29%	0,38%
B	N+3.73	0,75%	0,47%	0,68%	0,74%	0,47%	0,69%
	N+7.51	0,60%	0,48%	0,37%	0,60%	0,47%	0,36%
C	N+3.73	0,70%	0,46%	0,71%	0,72%	0,46%	0,71%
	N+7.51	0,54%	0,44%	0,53%	0,53%	0,43%	0,53%
D	N+3.73	0,73%	0,50%	0,71%	0,73%	0,49%	0,71%
	N+7.51	0,39%	0,37%	0,40%	0,39%	0,37%	0,40%

Regarding the comparisons of the required reinforcement percentage by level, a reduction of one to two percent was observed in the percentage required per element. However, it is important to emphasize that when averaging the information, a significant overall reduction per level with a positive impact is evident.

Finally, for the evaluation of the safety and durability of the structural system, data from the last three specimens (exposed to the elements) that failed were managed. These were analyzed for their strength, which increased and maintained a composition that, although it did not comply with curing according to the regulations for these last specimens, demonstrated durability against extreme factors such as the avoidance of curing processes, exposure to high temperatures, and rain over 56 days (Table 7). It was shown that the specimens did not suffer wear greater than one percent. Considering this, it is simultaneously recognized that such environmental factors can generate both internal and external pathologies in the concrete or chemically change the material conditions (32). However, with the inclusion of CDW, no significant changes regarding durability were observed.

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Table 7. Specimens exposed to weathering

Exposed to the elements								
Age at failure (days)	% replacement	Diameter (m)			Cylinder area (m2)	Max. load (kN)	Max. strength (MPa)	Calculated Max. Resistance (N/ mm2)
Concrete with structural brick								
Outside								
28	5%	0,151	0,151	0,151	0,018	395,98	22,18	22,11
Curing								
28	5%	0,151	0,151	0,151	0,018	399,98	22,63	22,34
Concrete with Brick Number 4								
Outside								
28	10%	0,150	0,149	0,151	0,018	390,48	16,80	22,10
Curing								
28	10%	0,150	0,148	0,149	0,017	394,42	17,14	22,64
Conventional concrete								
Outside								
28	0%	0,149	0,159	0,149	0,018	345,14	19,34	19,05
Curing								
28	0%	0,151	0,151	0,152	0,018	348,63	19,73	19,38

Discussion of the results

The results of this research are unique and have not been carried out before, while in several investigations they only related the characteristics of concrete that offer good resistance indicators (46) and others include modified concrete in the structural analysis (15) but none focused on the positive effects in terms of concrete-dependent variables in housing, due to the adaptation of RCD that effectively manages to overcome minimum resistance values, but what had not been taken into account is the functionality that the housing actually offers when using modified concrete and the variables involved; reduction of percentage reduction, which is a dependent variable of concrete strength, for seismic resistance capacity, durability and use for green housing (47, 48, 49), so much so that this analysis was carried out using the ETABS application and allows us to determine the efficiency of the use of crushed brick immersed in the concrete mix (50, 51).

Conclusions

The results indicate that the analyzed two-story house achieves safety and durability using crushed brick within the composition of CDW-modified concrete, contributing to its strength as it exceeds the 21 MPa resistance threshold (34). Therefore, the following statements can be made about its effectiveness. In first place, its properties gain physical-mechanical advantages in compression tests (axial forces) (35), due to the reduction of coarse aggregates and the utilization of CDW (36), of way

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that its maximum resistance increases, the structural system's safety also increases. In second place, it is viable to include this material in large-scale projects (37) under the concept of reducing the required quantum percentages. Lastly, the ETABS model with standardized dimensions, loads, and combinations, shows that the internal forces generated by ultimate loads are effectively supported by the modified concrete.

Furthermore, the impact of using CDW on the safety and durability of a house, especially in its structural system, as well as the function and indices of concrete with the w/c ratio of conventionally used concrete (38), is of interest to most architectural projects (39). This is because it requires a smaller amount of aggregate, which reduces costs and environmental repercussions such as the pollution of surface water sources, air, soil, and landscape (40), (41). Additionally, increased compressive strength is observed in concrete with ages greater than 28 days.

In fact, if we correct the errors in the preparation, values exceeding 21 MPa are obtained, which represents a significant difference in terms of the house's safety. Although it may not reduce the steel area, it effectively decreases the required reinforcement percentage. Therefore, it is recommended to verify reductions in the steel area only when resistance values exceed 29 MPa. It should also be noted that according to the concrete's capacity (f'c), elasticity varies, so benefits can also be seen in the elasticity of elements that exceed these safety indices.

Collecting all these observations, the mix with the best conditions is given by the CDW categorized as brick #4 at 10% at an age of 28 days, with a maximum compressive strength (f'c. Max.) of 22.55 MPa. This ensures, according to the NSR-10 and its minimum parameters, good behavior against seismic movements and the capacity to support design loads (42), as it exceeds quality standards (43). Although at earlier ages it only meets the requirements for 1- and 2-story houses, it is necessary to adapt to ages greater than 28 days to meet the minimum requirements of Colombian regulations (23).

Finally, to conclude the analysis of the structural model of a two-story house concerning the safety of the green structure and its specifications with modified concrete, it guarantees the same safety and the benefit of reducing the reinforcement percentage per concrete element (44), so that it is considered that the number of reinforcing bars can be reduced only when the f'c exceeds 8 MPa; otherwise, the relatively usable percentage will be low. The durability of the modified concrete exposed to environmental conditions and the vulnerability of the cylinders demonstrated that the consistency over time did not suffer wear or changes in strength due to its exposure to harmful environmental factors for 56 days. When exposed to the elements, they maintained optimal strength for buildings.

A final additional point: durability is a significant factor for structures, and as it is not a simple factor to calculate, it becomes a dependent variable, so that the durability analysis yielded concrete compositions with suitable coating and permeability (45), without wear and with strength above 21 MPa despite external effects. This indicates effective durability in aggressive environments due to the greater porosity offered by the CDW aggregate.

References

(1) A. Shafica, "Evaluación del manejo de residuos de construcción y demolición (RCD) en seis proyectos de viviendas de interés prioritario, como contribución a la revisión del panorama de gestión de RCD en la ciudad de Medellín"., Medellin, 2014. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.colmayor.edu.co/wp-content/uploads/2019/10/31_alma_cadavidevaluacin_manej.pdf&ved=2ahUKEwjLwMCbms

doi: 10.25100/iyc.v26i1.13762

qHAxWnTTABHbh-AhMQFnoECBIQAQ&usg=AOvVaw2MlZYZYlMeKbFHhlr2lQXe

(2) J. Remolina, “Determinación de parámetros físico-mecánicos y de durabilidad en concreto reciclado con residuos de construcción y demolición (RCD),” (undergraduate thesis), Universidad de la Costa, 2018.https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://repositorio.cuc.edu.co/handle/11323/247&ved=2ahUKEwi76Omam8qHAxXBfTABHf_-NTEQFnoECBYQAQ&usg=AOvVaw2Qz3ei0tPBTUkMjUxXqYx1

(3) E. Romero, “Residuos de construcción y demolición,” España, 2006. (Online). Available: https://www.uhu.es/emilio.romero/docencia/Residuos%20Construccion.pdf

(4) UAESP, Plan de gestión integral de residuos sólidos, U. A. E. de S. P, 2020.https://www.uaesp.gov.co/images/pgirs_mesas/DOCUMENTO%20TECNICO%20SOPORTE%20-%20DTS.pdf

(5) EMPRESA METRO DE BOGOTÁ S.A., “METRO BOGOTÁ,” 2021. (Online). Available: https://www.metrodebogota.gov.co/?q=noticias/demolición.

(6) F. Debieb and S. Kenai, “The use of coarse and fine crushed bricks as aggregate in concrete,” Construction and Building Materials, vol. 22, no. 5, pp. 886-893, 2008.https://www.researchgate.net/profile/Farid-Debieb/publication/229105942_The_Use_of_Coarse_and_Fine_Crushed_Bricks_as_Aggregate_in_Concrete/links/55cb5d0f08aea2d9bdce2602/The-Use-of-Coarse-and-Fine-Crushed-Bricks-as-Aggregate-in-Concrete

(7) A. F. Romero Quintero y J. C. Hernández Rico, “Diseño de mezclas de hormigón por el método ACI y efectos de la adición de cenizas volantes de termotasajero en la resistencia a la compresión,” Research Work, Universidad Santo Tomás, 2014.https://repository.usta.edu.co/bitstream/handle/11634/915/Diseno%20de%20mezclas%20de%20hormigon%20por%20el%20metodo%20a.c.i..pdf?sequence=1

(8) M. Carrascal y A. Martelo, «Determinación de la viabilidad técnica y económica para el uso del concreto tipo RCD en la conformación de estructuras de estabilizacion de taludes (gabiones),» Cartagena, 2020.https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://repositorio.unicartagena.edu.co/e/11227/13511&ved=2ahUKEwiKotbGo8qHAxVjRjABHfyzJRIQFnoECBgQAQ&usg=AOvVaw3Myt5e36TVBQeU2DLmJPBh

(9) M. Sánchez, Verificacion del cumplimiento de la norma Sismo Resistente NSR-10 vigente en Colombia en la estructura “Dotacion cultural filipenses”. (undergraduate thesis),. Universidad Católica de Colombia, 2018. https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://repository.ucatolica.edu.co/items/1255ebf7-204a-4240-a7fb-3566efe234ce&ved=2ahUKEwiZiqbbo8qHAxU2fTABHcpjDBoQFnoECBcQAQ&usg=AOvVaw0i6QL4ZMc7OJQNKBmo1-L_

(10) F. S. Klak, H. Saleh, and A. S. Tais, “Recycling of crushed clay bricks as fine aggregate in concrete and cement mortar,” Australian Journal of Structural Engineering, vol. 24, no. 1, pp. 67-76, 2023.https://www.researchgate.net/profile/Haifa-Saleh/publication/361874249_Recycling_of_crushed_clay_bricks_as_fine_aggregate_in_concrete_and_cement_mortar/links/62de130af3acdd5dc2182b78/Recycling-of-crushed-clay-bricks-as-fine-aggregate-in-concrete-and-cement-mortar.pdf?origin=journalDetail&_tp=eyJwYWdlIjoiam91cm5hbERldGFpbCJ9

doi: 10.25100/iyc.v26i1.13762

(11) C. J. Flores Crispín y E. F. Nieto Cabana, "Análisis comparativo estructural del sistema confinada y aporticado de una vivienda multifamiliar de 5 pisos, San Juan de Lurigancho 2022," 2022. (Online). Available.https://repositorio.ucv.edu.pe/bitstream/handle/20.500.12692/105240/Flores_CCJ-Nieto_CEF%20-%20SD.pdf?sequence=1

(12) K. Masías Mogollón, "Resistencia a la flexión y tracción en el concreto usando ladrillo triturado como agregado grueso," Universidad de Piura, vol. 2, p. 125, 2018.https://docplayer.es/216469580-Facultad-de-ingenieria-y-arquitectura.html#google_vignette

(13) C. Barragan y M. Trujillo, Elaboración de guías de laboratorio de estructuras de la Universidad Catolica de Colombia. (undergraduate thesis). Universidad Católica de Colombia, 2018.https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://repository.ucatolica.edu.co/e/10983/16687&ved=2ahUKEwj2oNL7o8qHAxU1mYQIHVrpCXkQFnoECBAQAQ&usg=AOvVaw2crF3LpTrD_Kwaqmp8OyvQ

(14) J. O. Castaño, R. Misle Rodríguez, L. A. Lasso, A. Gómez Cabrera, and M. S. y Ocampo, "Gestión de residuos de construcción y demolición (RCD) en Bogotá: perspectivas y limitantes," Tecnura, vol. 17, no. 38, pp. 121-129, Sep. 2013.https://revistas.udistrital.edu.co/index.php/Tecnura/article/view/6933

(15) J. M. Guarín Salinas, "Posibilidades de diseño con el concreto arquitectónico, utilizando agregado grueso de ladrillo triturado reciclado," Magister dissertation, Universidad Nacional de Colombia, 2012.https://scholar.googleusercontent.com/scholar?q=cache:p8cfJRcjjMkJ:scholar.google.ciclado.+%5BArt%5D.+Universidad+Nacional+de+Colombia,+2012.&hl=es&as_sdt=0,5

(16) Z. Duan, A. Singh, J. Xiao, y S. Hou, "Combined use of recycled powder and recycled coarse aggregate derived from construction and demolition waste in self-compacting concrete," Construction and Building Materials, vol. 254, art. 119323, 2020. (DOI: 10.1016/j.conbuildmat.2020.119323) https://www.sciencedirect.com/science/article/abs/pii/S0950061820313283

(17) A. Aliabdo, A.-E. Abd-Elmoaty y H. Hassan, "Utilization of crushed clay brick in concrete industry" Alexandria Engeneering Journal, vol. 53, pp. 151-168, 2014.https://www.sciencedirect.com/science/article/pii/S1110016813001269

(18) W. E. López Enriquez, "Diseño de concreto refractario utilizando residuos de ladrillos de barro cocido," undergraduate thesis, Universidad de San Carlos de Guatemala, 2016.http://www.repositorio.usac.edu.gt/4253/1/Wilmer%20Estiven%20López%20Enriquez.pdf

(19) D. L. Acosta Rodríguez, "Análisis estructural con ETABS, aplicando reglamento colombiano de construcción sismo resistente (NSR-10)," monograph, Universidad Santo Tomás.https://repository.usta.edu.co/bitstream/handle/11634/2677/2016davidacosta.pdf?sequence=1

(20) M. A. Calle Delgado, "Influencia de la granulometría y el tipo de cemento en la contracción por secado de morteros estructurales," 2018 https://pirhua.udep.edu.pe/item/0f26551d-33c1-4445-87b5-64b0c1bf2675

doi: 10.25100/iyc.v26i1.13762

(21) L. Berredjem, N. Arabi, and L. Molez, "Mechanical and durability properties of concrete based on recycled coarse and fine aggregates produced from demolished concrete," Construction and Building Materials, vol. 246, art. 118421, 2020. https://hal.science/hal-02490854/file/Berredjem%20et%20al-20202Mechanical%20and%20durability%20properties%20of%20concrete%20based%20on%20recycled%20coarse.pdf

(22) J. Nobre, M. Bravo, J. de Brito, and G. Duarte, "Durability performance of dry-mix shotcrete produced with coarse recycled concrete aggregates," Journal of Building Engineering, vol. 29, Article 101135, 2020.https://www.sciencedirect.com/science/article/abs/pii/S2352710219317334

(23) O. F. Jimenez y L. A. Jiron, "Análisis Sísmico de Vivienda Multifamiliar de 5 Pisos, Empleando Concreto con Ladrillo Recocho Triturado, Santa Teresa de Vitarte, Ate, 2019," Degree Theses, Universidad César Vallejo, Lima, 2019.https://hdl.handle.net/20.500.12692/48966

(24) Ladrillera Santafé, "Bloque #4," Ladrillera Santafé S. A., 2017. (Online). Available: https://assets.website-files.com/5e5004d54227fd8b0ec4803a/5ec2b0cc7c1f28e6c1c8a870_Ficha%20_%20Bloque%20%234.pdf.

(25) San Benito S.A.S, "Ladrillo adoquín rectangular," 2023. (Online). Available: https://ladrillerasanbenito.com/catalogo/ladrillo-adoquin-rectangular/.).https://ladrillerasanbenito.com/catalogo/ladrillo-adoquin-rectangular/

(26) San Benito S.A.S, «Ladrillo estructural,» 2023. (Online). Available: https://ladrillerasanbenito.com/catalogo/ladrillo-estructural-65x12x24/. (Accessed: 11-jun-2024).

(27) R. Matallana, El concreto fundamentos y nuevas tecnologías. Constructora Conconcreto, Corona, 2019.https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://conconcreto.com/wp-content/uploads/2023/02/EL-CONCRETO-Fundamentos-y-nuevas-tecnologias..pdf&ved=2ahUKEwiVmurSqcqHAxUnTTABHTiKCE8QFnoECBQQAQ&usg=AOvVaw3EcbPz-ZXnXzvmtGuPGOJq

(28) D. Sánchez, Tecnologia del concreto y del mortero, Bogotá: Biblioteca de la construcción, Quinta edición 2001. (Online). Available in: https://books.google.com.co/books?id=EWq-QPJhsRAC&printsec=copyright#v=onepage&q&f=false

(29) H. Sarta-Forero y J. Silva-Rodríguez, "Análisis comparativo entre el concreto simple y el concreto con adición de fibra de acero al 4% y 6%," 2017. (Online). Available in: https://repository.ucatolica.edu.co/entities/publication/5f59a07b-e03e-40de-aa22-2d284a675b84

(30) J. Segura Franco, Estructuras en concreto, 7ª ed. (Online). Available in: https://www.yumpu.com/es/document/view/62782881/estructuras-en-concreto-jorge-segura-franco-7ed-pdf.

(31) A. Bran Bedoya, "Propuesta para el manejo integral de los residuos de la construcción y la demolición: caso de aplicación Medellín, Antioquia," 2011.https://bibliotecadigital.usb.edu.co/entities/publication/384f33e0-2a23-462a-9d17-47f3a016dc71

(32) I. C. Rivera Devia, "Autocuración del concreto a partir de la encapsulación del Bacillus Subtilis en un biopolímero de almidón," 2015.https://repository.udca.edu.co/entities/publication/87410668-003f-4da5-a072-c5b04b98bd7b

doi: 10.25100/iyc.v26i1.13762

(33) G. Bai, C. Zhu, C. Liu, y B. Liu, "An evaluation of the recycled aggregate characteristics and the recycled aggregate concrete mechanical properties," Construction and Building Materials, vol. 240, art. 117978, 2020. (DOI: 10.1016/j.conbuildmat.2019.117978)https://www.sciencedirect.com/science/article/abs/pii/S0950061819334312

(34) W. Jiménez y A. López, "Análisis mecánico de la utilización de concreto reciclado como agregado grueso en un concreto de alto desempeño (6000 psi ó 42 MPa)," Trabajo de grado, Universidad Católica de Colombia, Bogotá, Colombia, 2017. (Online). Available in: https://repository.ucatolica.edu.co/server/api/core/bitstreams/cbfbe96f-9147-4872-81c0-e44ab38ed4bf/content

(35) Á. V. P. Rojas, "Uso de triturado de ladrillo reciclado como agregado grueso en la elaboración de concreto," Ingenium, vol. 13, no. 26, pp. 116-125, 2012.https://dialnet.unirioja.es/descarga/articulo/5038429.pdf

(36) "¡No me saque la piedra! Verifique primero la NTC 174," YouTube, 2021. (Online). Available in: https://www.youtube.com/watch?v=NLs5lvZ_esc.

(37) I. Mendoza and S. Chávez, "Residuos de construcción y demolición como agregado de concreto hidráulico nuevo," Revista de Ingeniería Civil, vol. 1, no. 2, pp. 9-14, 2017.https://www.ecorfan.org/republicofperu/research_journals/Revista_de_Ingenieria_Civil/vol1num2/Revista_de_Ingeniería_Civil_V1_N2_4.pdf#page=16

(38) "Specifications for concrete with recycled aggregates," Materials and Structures, vol. 27, pp. 557–559, 1994. (Online). Available: https://doi.org/10.1007/BF02473217.

(39) J. M. Susunaga-Monroy, "Construcción sostenible, una alternativa para la edificación de viviendas de interés social y prioritario," Research Work, Universidad Católica de Colombia, Facultad de Ingeniería, Programa de Ingeniería Industrial, Bogotá, Colombia, 2014.https://repository.ucatolica.edu.co/bitstream/10983/1727/1/I%25C3%2593N%2520SOSTENIBLE,%2520UNA%2520ALTERNATIVA%2520PARA%2520LA%2520EDIFICACI%25C3%2593N%2520DE%2520VIVIENDAS%2520DE%2520INTERES%2520SOCIAL%2520Y%2520PRIORITARIO.pdf

(40) Ministerio de Ambiente y Desarrollo Sostenible, "Resolución No. 0472 'Por la cual se reglamenta la gestión integral de los residuos generados en las actividades de construcción y demolición - RDC y se dictan otras disposiciones,' Resolución No. 0472: 11," 2017. (Online). Available: https://www.minambiente.gov.co/wp-content/uploads/2021/10/resolucion-0472-de-2017.pdf.

(41) K. Kapoor, S. P. Singh, and B. Singh, "Durability of self-compacting concrete made with recycled concrete aggregates and mineral admixtures," Construction and Building Materials, vol. 128, pp. 67-76, 2016.https://www.sciencedirect.com/science/article/abs/pii/S0950061816316385

(42) J. Carrillo, S. M. Alcocer, and W. Aperador, "Propiedades mecánicas del concreto para viviendas de bajo costo," Ingeniería, Investigación y Tecnología, vol. 14, no. 2, pp. 286-298, 2013.https://www.scielo.org.mx/pdf/iit/v14n2/v14n2a12.pdf

(43) ICONTEC, "MÉTODO DE ENSAYO PARA DETERMINAR EL ASENTAMIENTO DEL CONCRETO, Norma NTC 396:2024, Método de ensayo para determinar el asentamiento del concreto", 2024. https://tienda.icontec.org/gp-ntc-metodo-de-ensayo-para-determinar-el-asentamiento-del-concreto-ntc396-2024.html

(44) J. M. Aid Civil Matt, "Concepto de cuantía y cuantía balanceada en una viga de concreto reforzado," YouTube, 2019. (Link: https://www.youtube.com/watch?v=W1Hc_WSndTE)

(45) ACI 201, «Guía para la Durabilidad del Hormigón,» 1997.ACI 201, Guía de Buenas Prácticas en el Uso de Agregados Reciclados en Concreto, 2021. (Online). Available in: https://www.inti.gob.ar/publicaciones/descargac/218.

(46) J. A. M. Macías, F. M. V. Coox, A. N. B. Ponce, W. E. R. Párraga, y M. S. G. Alcívar, "Determinación de la resistencia a la compresión de bloques, utilizando para su construcción, una mezcla de cemento, arena y triturados de ladrillos artesanales," Revista de Investigaciones en Energía, Medio Ambiente y Tecnología: RIEMAT, vol. 4, no. 1, pp. 19-24, 2019. ISSN: 2588-0721. https://revistas.utm.edu.ec/index.php/Riemat/article/download/1941/2111

(47) F. Villa, "Construcciones verdes," Alarife: Revista de arquitectura, no. 17, p. 41-54, 2009https://dialnet.unirioja.es/descarga/articulo/3195183.pdf

(48) L. E. Arriaga Tafhurt, "Utilización de agregado grueso de concreto reciclado en elementos estructurales de concreto reforzado," 2014. https://repositorio.escuelaing.edu.co/handle/001/118

(49) S. P. M. Pérez, D. M. D. Sánchez, E. E. G. Capuñay, and J. A. C. Bustamante, "La influencia de los RCD en reemplazo de los agregados para la elaboración de concreto: una revisión de la literatura," Ecuadorian Science Journal, vol. 5, no. 2, pp. 107-120, 2021. https://journals.gdeon.org/index.php/esj/article/download/111/124

(50) L. J. Maldonado Leal and H. A. Villamil Cortes, "Evaluación del uso de sistemas estructurales aporticados, para zonas de amenaza sísmica alta y baja en Colombia, en un edificio tipo de geometría regular y altura de entrepiso de tres 3 metros," 2016. (Online). Available in: https://ciencia.lasalle.edu.co/ing_civil/54.

(51) IMCYC, "Determinación de la resistencia a la compresión de cilindros de concreto - método de prueba," in Problemas, causas y soluciones, pp. 67-71, 2008. (Link: http://www.imcyc.com/ct2008/nov08/PROBLEMAS.pdf)

doi: 10.25100/iyc.v26i1.13762