

## **USE OF MACHINE LEARNING TO DETERMINE MECHANICAL PROPERTIES OF NON-ENGINEERED MASONRY HOUSING IN COLOMBIA**

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### **Abstract**

*In Colombia, more than half of residential structures have been built informally, commonly using unreinforced masonry (URM) systems. The understanding of the mechanical properties of such materials are essential to assess the vulnerability of these buildings within the framework of the National Seismic Risk Model. This research presents the development of an application with a graphical user interface that integrates the collection of laboratory test results and the analysis of a mechanical property database, along with a neural network designed to predict the mechanical properties of informal masonry. The neural network estimates compressive strength and modulus of elasticity based on the strength of the mortar, the masonry unit, and certain geometric characteristics of the wall or the masonry units themselves. To conduct the study, experimental data were gathered from various types of prisms and masonry panels, which were classified according to the material and geometric shape of the masonry unit. Dedicated neural networks were developed for each type of masonry panel. In addition, simplified equations were derived to estimate the mechanical properties of masonry using these neural networks. This integrated approach provides a practical and efficient tool for evaluating informal URM structures in the field of structural engineering, updating predictive models to reflect current construction practices.*

**Keywords:** Unreinforced masonry, Informal construction, Mechanical properties, Neural networks

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## 1 INTRODUCTION

The study of masonry structures has gained significant attention in recent years due to their widespread use in residential and commercial construction. However, research remains concentrated on specific masonry types and controlled environments, often overlooking informal and self-built structures that dominate many urban and rural areas. Building codes establish critical parameters such as wall height, length, reinforcement, and material properties to ensure structural integrity and seismic resilience. Nonetheless, deviations from these codes—whether due to economic constraints, lack of technical knowledge, or construction informality—can lead to severe structural deficiencies, particularly in seismic-prone regions like Colombia. A significant portion of the country’s housing stock consists of self-built masonry structures, often constructed without professional oversight, making them highly vulnerable to earthquakes. To address these challenges, there is an urgent need to refine predictive models for masonry properties, incorporating data from both laboratory tests and in-site case studies. Advanced numerical simulations and machine learning techniques are proving invaluable in assessing the structural behavior of masonry under dynamic loads, offering insights that can improve both design standards and retrofitting strategies. Furthermore, understanding the engineering methodologies—whether formal or informal—that influence construction practices in Colombia is essential for developing effective policies and technical guidelines tailored to local building realities. Bridging the gap between traditional masonry practices and modern engineering approaches is crucial for enhancing the safety, sustainability, and resilience of masonry structures in seismic regions.

Informal masonry refers to self-built constructions that do not meet the country's minimum technical standards, compromising their structural performance [1]. In urban areas, these houses are often densely clustered in informal settlements, whereas in rural zones, they tend to occupy larger plots and are usually single-story [2, 3, 4]. In both cases, informal housing represents a significant portion of the country’s total building inventory, accounting for over 40% at the national level [4, 5, 6, 7]. Studies have shown a high incidence of informal housing in urban centers due to socioeconomic factors such as forced migration and limited financial resources [4, 5, 6, 7]. These factors lead to construction delays, and residents often live in the buildings during the construction process [8], increasing their vulnerability due to the lack of structural and construction requirements. This research aims to develop a predictive model based on artificial intelligence (AI) to improve the estimation of compressive mechanical properties of informal housing in Colombia. After training the model with variables that influence these properties, a statistical filter is applied to identify the most relevant ones. Although the lack of data limits model development for certain types of masonry units, those models created for horizontally perforated clay units and concrete units allow predictions that are close to experimental values. These results enable further studies on the retrofitting, vulnerability, and fragility of informal masonry in the country. Additionally, a graphical application is developed to facilitate the use of the model, allowing users to input data and predict the mechanical properties of masonry panels. The application also enables interaction with the study’s database and supports the addition of new information.

## 2 INFORMAL MASONRY CONSTRUCTION IN COLOMBIA

Informal masonry housing in Colombia exhibits significant variation, particularly in the types of masonry units used, reflecting regional preferences and the availability of materials. For instance, horizontally perforated clay units (HHCL), commonly referred to as “*Unit #5*”,

are prevalent in urban and densely populated areas due to their cost-effectiveness and large dimensions [8]. However, their geometry hinders the option to place internal vertical reinforcement within these units. In coastal regions of the country, vertically perforated concrete units (VHCR) are commonly used [9]. Solid clay bricks (SOL), as well as vertically perforated clay units (VHCL), are also found, although less frequently in informal masonry.

Considering the construction methods used in informal housing, it is reasonable to state that the lateral and gravity load-resisting system comprises all masonry walls in the structure. In some houses, a type of wall confinement can be observed; however, it does not follow the recommendations [11] and guidelines set forth by the Colombian Seismic Design Code NSR-10 [12]. This is evident when vertical tie-columns (*small columns*) are spaced at lengths greater than those recommended, due to their small cross-sectional dimensions [13], or when bond beams or confinement beams lack adequate reinforcement [11]. Floor systems in informal masonry houses typically fall into one of three categories: (1) thin solid slabs, (2) ribbed slabs, and (3) composite slabs. Solid slabs vary in thickness but typically consist of a thin concrete slab with steel reinforcement [14]. Ribbed slabs are larger and incorporate lightweight filler materials, typically made of masonry units [14]. Alternatively, some houses use composite floor systems made of steel, concrete, and masonry -often referred to as “*Easy slab*” - which use hollow masonry units and steel joists to support a thin concrete slab [15].

Informal masonry houses generally have shallow foundations [11] composed of concrete footings, strip footings, or slabs. When slab foundations are used, they may lack adequate reinforcement to prevent cracking and differential settlement [16]. Regardless of the foundation type, the ground is often not properly prepared to ensure appropriate load transfer to the soil. Roof systems in these houses typically consist of zinc or fiber-cement sheets with a simple or gable slope. Some houses have concrete slab roofs that allow for a terrace on the top floor; however, in many cases, the terrace is only used temporarily while the construction of that floor is completed.

Several predictive models for masonry properties are currently proposed with variability depending on the materials and influencing factors. This study reviews models relevant to the region, highlighting material variability, particularly in clay units. Meli [17] proposed a model for predicting the properties of masonry panels based on linear regression of experimental results. More advanced predictive frameworks incorporate variables such as mortar compressive strength and geometric features of the wall. For instance, Arango [18] introduced a model based on Hilsdorf’s masonry strength equation [19], focusing on clay units. Yamín and García [16] proposed simplified models to assess low-cost clay masonry in Colombia. The current masonry design code in Colombia [12] integrates elements from these previously mentioned models, adding absorption factors for the units and specifying confinement and reinforcement requirements.

### 3 MATERIAL PROPERTIES DATABASE

A materials database (DB) was created to characterize masonry in Colombia using experimental results from various studies conducted in accordance with technical standards [20], such as the Colombian Technical Standards (NTC) or ASTM standards. Once organized, the database consists of 44% data from the laboratory at Universidad de los Andes, 34% from these conducted at other Colombian universities, and the remaining portion from available reports or studies on masonry in Colombia. The data in the DB underwent a standardization process to

ensure consistency and facilitate analysis and direct use. The database includes results from different types of tests, such as masonry prism compression tests [21], diagonal tension tests on masonry panels [22], bond strength in flexural masonry tests [23], compression tests on mortar cubes [24], tension tests on mortar specimens [25], compression tests on masonry units [26, 27], quasi-static tests on masonry walls, and scaled shaking table tests. However, the study methodology focuses on tests related to compressive properties of masonry units, mortar, and prisms.

The developed database includes information from all available tests related to informal masonry; however, advanced analyses or tests of masonry are less frequently found. Due to this limitation in data availability, the database specializes in the characterization of linear properties of masonry, such as compressive strength and modulus of elasticity of mortar, masonry units, and masonry prisms or panels. During prism compression testing, multiple masonry units and mortar cubes are characterized, and the average result from each test is recorded as a single compressive strength value for each prism. When the reported tests provide complete characterization of the prism but lack full data on the units or mortar, the data are still included in the database, but excluded from the analysis to enable accurate comparisons between experimental results and predictive models. Shear mechanical properties are not addressed in this publication, considering ongoing collaborative work between Universidad de los Andes and Universidad Militar Nueva Granada [28].

#### 4 AI-BASED PREDICTIVE MODELS

This study uses neural networks (NNs) to model the complex behavior of masonry due to their exceptional ability to learn and abstract features from intricate patterns in the input data. Various interdependent factors influence the mechanical properties of masonry, such as material composition, construction techniques, and environmental conditions. Neural networks are well-suited to handle these nonlinear interactions, providing reliable predictions for engineering decision-making [29]. Their ability to fine-tune processing during training [30] enables accurate adaptation to masonry-specific data. For this reason, neural networks offer a more robust and adaptable approach for modeling the properties of informal masonry [31, 32, 33]. With a straightforward training and tuning process [30], feedforward neural networks simplify model development and facilitate practical implementation. The developed algorithm identifies the optimal neural network architecture for the problem, defining the number of hidden layers and neurons. It evaluates various combinations (from one to three layers), with the number of neurons ranging from the number of input variables up to three times that number. Input selection is based on experimental variables, assessing functional relationships similar to those used in previous predictive models. Metrics such as RMSE, MSE,  $R^2$ , and a Conservativeness Factor (CF) are employed to select the optimal architecture. In a second phase, additional parameters such as transfer functions and convergence algorithms are tuned for the selected architecture. This procedure is carried out for each masonry category, allowing the model to be specifically tailored to each type, acknowledging that the properties of the masonry units in the database are simplified.

#### 5 RESULTS

Artificial intelligence-based predictive models have been developed to estimate the compressive mechanical properties of informal masonry structures using experimental data. These models are essential for informing and guiding decisions regarding the structural behavior of housing. However, neural networks require large datasets to avoid overfitting. Predictions for the HHCL category, which includes more data, are more accurate than those for the VHCL and

VHCR categories. The SOL category results in unreliable analysis due to its limited number of samples and is therefore excluded from the evaluation. Since the neural networks were trained using fully characterized masonry specimens, the input data are processed by the networks and directly compared to the measured compressive strength of each prism. In this context, the proposed model shows a strong agreement with actual resistance for the HHCL category, where the general trend of the experimental-to-predicted ratio ( $f'_{me}/f'_{mp}$ ) tends toward 1, as shown in Table 1. Similar results are observed for the VHCR and VHCL categories in terms of compressive strength ( $f'_m$ ) and modulus of elasticity across all three categories, although these networks were trained with fewer data points.

	HHCL	VHCL	VHCR
RMSE	0.41	1.20	1.07
R <sup>2</sup>	0.69	0.42	0.65
MAPE	0.17	0.10	0.22
$f'_{me}/f'_{mp}$	1.02	1.01	0.99

Table 1: Statistical results of the developed models for predicting  $f'_m$ .

To compare the developed model with other predictive models, Table 2 presents the ratio between the predicted and the experimental values of the compressive strength ( $f'_{mp}/f'_{me}$ ) for both the literature-based models and the NN model. This table simultaneously shows the accuracy and variability of each model through the statistical mean and dispersion of the  $f'_{me}/f'_{mp}$  ratio. The results show that the developed models provide more accurate predictions for the HHCL and VHCR categories than existing models, which tend to overestimate  $f'_m$  values. The proposed models yield consistent results, with low dispersion and a mean close to 1, without overestimating the outcomes. In contrast, existing models for VHCL are more conservative and tend to overpredict the mechanical properties of masonry. However, the limited data available for  $f'_m$  in the VHCL category may introduce some bias into the analysis.

Category	RN		Meli [ref]		Yamin [ref]		Arango [ref]		NSR-10 [ref]	
	$\mu$	$\beta$	$\mu$	$\beta$	$\mu$	$\beta$	$\mu$	$\beta$	$\mu$	$\beta$
HHCL	1.02	0.24	1.07	0.49	1.19	0.54	1.59	0.72	1.29	0.60
VHCL	1.01	0.15	0.93	0.44	1.04	0.49	1.07	0.31	0.95	0.40
VHCR	0.99	0.34	1.60	0.84	1.33	0.70	1.29	0.47	1.33	0.64

Table 2:  $f'_{me}/f'_{mp}$  Comparison for the studied models.

This study aims to provide a tool that simplifies the evaluation of informal housing behavior by recalibrating existing models to improve the estimation of key parameters. The model proposed by Meli [17] was selected to calculate  $f'_m$  for the HHCL category, while the NSR-10 model [12] was chosen for the VHCL and VHCR categories. Equations (1) and (2) present the calibrated, proposed, and simplified expressions to compute the compressive strength for HHCL and VHCR, respectively. Additionally, the study has developed a graphical user interface application named COLBRICK [34] to implement and apply the study’s findings in an accessible manner. COLBRICK facilitates access to the information compiled in the materials database (DB), incorporates the developed neural network models, and allows for the addition of new experimental data. To access COLBRICK app please go to: <https://cimoc.uniandes.edu.co/software>

$$f'_m = 0.4f'_{cu} \quad (1)$$

$$f'_m = 0.59 \cdot \min\left(\frac{2h}{75+3h}f'_{cu} + \frac{50k_p}{75+3h}f'_{cp}; 0.8f'_{cu}\right) \quad (2)$$

## 6 CONCLUSIONS

This study introduced artificial intelligence models to predict the compressive properties of masonry in informal constructions in Colombia, demonstrating improvements over existing models. The neural network (NN) models showed good accuracy in estimating compressive strength, with correlations reaching up to 83%, and offer more precise predictions than current approaches. However, they face limitations due to insufficient data, particularly for certain types of masonry, which may introduce biases into the predictions. A robust database was created, along with a graphical tool called COLBRICK, to facilitate access to both models and data. Additionally, existing equations were recalibrated to better align with the conditions of informal masonry in Colombia, resulting in improved prediction accuracy. Despite these advancements, the study highlights ongoing challenges related to data scarcity and suggests future enhancements to incorporate additional parameters and further refine the models.

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