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## Geometric characterization of solid ceramic bricks for construction in Ecuador

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**Abstract.** In Ecuador, about 95.9% of dwellings are built with masonry, however the local production of bricks does not meet technical standards and there is no scientific research on its geometric characterization and the technical state of their production. The geometric characterization of bricks is essential for the standardization of materials and constructions and allows the design of structures with a higher degree of accuracy. This research, conducted in 12 provinces of the 3 continental regions of the country, where 79% of the buildings are concentrated, studies for the first time the geometric characteristics of solid clay bricks in Ecuador. The results show that 67% of the brick production in Ecuador is artisanal and 98% of the factories do not comply with the technical standards for brick production. The authors present the characteristic dimensions of solid bricks produced in different regions of Ecuador. The results show a high variation in brick dimensions depending on the region, and even in a same province the dimensions depend on the factory, since its production does not comply with any standard. Ecuadorian standards regulating brick geometry need to be updated taking into account the real characteristics of the national brick production.

**Keywords:** clay bricks, geometric characteristics, solid brick dimensions, production technologies, masonry structures

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# Геометрические характеристики полнотелого керамического кирпича, применяемого для строительства в Эквадоре

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**Аннотация.** В Эквадоре около 95,9 % жилых домов построены из кирпичей, однако местное производство кирпича не соответствует техническим стандартам, отсутствуют научные исследования по его геометрическим характеристикам и техническому состоянию его производства. Определение геометрических характеристик кирпича имеет существенное значение для стандартизации материалов и конструкций и позволяет проектировать конструкции с более высокой степенью точности. В исследовании, проведенном в 12 провинциях трех континентальных регионов страны, где сосредоточено 79 % зданий, впервые изучаются геометрические характеристики полнотелого глиняного кирпича, произведенного в Эквадоре. Установлено, что 67 % производства кирпича в Эквадоре является кустарным и только 6 % – промышленным, при этом 98 % заводов не соблюдают технические стандарты производства кирпича и даже не знают об их существовании. Представлены характерные размеры полнотелого кирпича, произведенного в различных регионах Эквадора. Полученные результаты свидетельствуют о большом разбросе размеров кирпича в зависимости от региона, и даже в одной провинции размеры зависят от завода, поскольку производство не отвечает стандартам. Эквадорские стандарты, регламентирующие геометрию кирпича, нуждаются в обновлении с учетом реальных особенностей национального производства кирпича.

**Ключевые слова:** керамический кирпич, геометрические характеристики, размеры полнотелого кирпича, технологии производства, каменные конструкции

## 1. Introduction

In all cultures of the world, both natural and artificial stones have been the most common building material in all historical periods. Natural stone masonry construction dates back to around 12 000 years ago, when nomadic peoples became sedentary and permanent domestic dwellings became common throughout the Mediterranean Levant [1–3]. The pre-Hispanic civilizations of Latin America developed various building techniques for masonry construction, for instance, the Incas built structures with carved natural stones and without mortar, the Mayas built their famous pyramids with adobe bricks covered with natural stones [4–6]. In the American continent, the beginning of the use of fired clay bricks is related to the Spanish conquest and dates back to the 16th century. In Ecuador, the first evidences of the manufacture of ceramic bricks date back to 1565 [7]. Nowadays, the massive use of the steel and reinforced concrete in construction is evident, however, ceramic brick masonry continue to hold a predominant place for building in Ecuador, Latin America and worldwide [8–11].

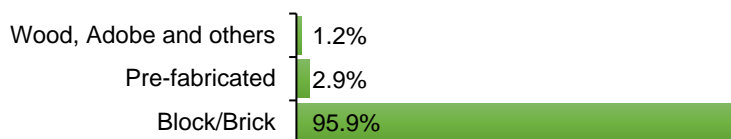
Approximately 70% of dwellings in Ecuador are 1–2 storey houses [12–14] and 95.9% of dwellings are built with the use of masonry (Figure 1). The literature review reveals that there is no research, scientific articles or technical information on the geometric properties of ceramic bricks produced in different regions of Ecuador.

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The few available studies in Ecuador are limited to: determination of the strength of bricks in a given city [15]; mechanical quality levels of bricks produced in a given province [16]; environmental pollution produced by brick factories [17]; and business models of brick factories [18]. These facts evidence the lack of scientific interest in one of the most widely used construction materials in Ecuador.



**Figure 1.** Types of materials used for construction of walls in Ecuador, according to [11]

It is well known that different national standards<sup>1</sup> normalize the brick production. However, the level of technological development in each country is reflected in more precise technical standards, as well as stringent requirements for brick manufacturing and more active research on related topics [19–21]. Since the late 1970s, Ecuador has had technical standards for the geometric, physical and mechanical standardization of building bricks,<sup>2</sup> however, it is observed that local brick production does not meet these technical specifications and there are no scientific studies on the geometric characterization of the most used construction brick in Ecuador. It is important to note that the geometric properties of bricks are an essential parameter for the standardization and mechanical characterization of materials. In this way, it is important to note the results presented in [16], but it is even more important to point out that it is limited to only 1 province, which represents only 2.84% of the buildings at the national level [11].

Given these facts, it is important to determine the geometric characteristics of the most commonly used clay brick in construction in Ecuador in order to obtain real information that will allow structures to be designed with a higher level of precision and safety.

This article presents the first results on the geometric characterization of solid clay brick as the most used brick in construction in Ecuador and on the particularities of its production. The presented results are the first step prior to the mechanical characterization of the bricks, on which the authors will continue to work.

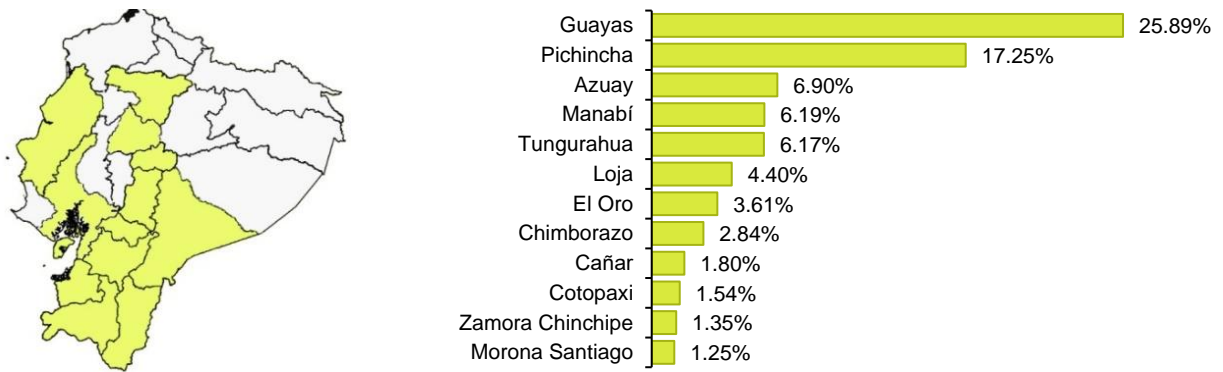
## 2. Methods

This study began with a literature review and field data collection on the geometric and mechanical properties of bricks produced in Ecuador, and the characteristics of their production. Then, a field data collection campaign was organized in different provinces of Ecuador with the collaboration of Civil Engineering students from the Catholic University of Cuenca in the framework of the research project PICVII19-87. For the collection of qualitative data, a semi-structured survey was designed and answered by the representative of each factory visited. The survey questionnaire asked about: the manufacturing process to determine whether the factory's technology is artisanal, semi-industrial or industrial; the types of bricks manufactured in the plant; the types of bricks that are mostly commercialized; compliance with standards in the manufacturing process. In addition, each factory visited was geo-referenced and photographs were taken. For the laboratory study, samples of bricks were taken from each production plant in order to determine their geometrical and mechanical characteristics. The geometry and dimensions were determined using measuring instruments and the results were recorded in a measurement notebook.

For the field data collection, the largest factories with the highest brick production in each study region were identified. Data collection for this study was carried out in 52 brick production factories located in 12 provinces of the 3 continental regions of Ecuador (coast, Andes and Amazon). The provinces studied cover 49% of the Ecuadorian territory where 77% of the national population lives [23] and where 79% of the new buildings in Ecuador are located [11] (Figure 2).

<sup>1</sup> NTE INEN 297. *Ladrillos cerámicos. Requisitos. Normalización técnica ecuatoriana*. Quito; 1977; NTC 4205-1. *Unidades de mampostería de arcilla cocida. Ladrillos y bloques cerámicos*. Bogotá: INCOTEC; 2009; ASTM C62-12. *Standard specification for building brick*. Pennsylvania: ASTM International; 2012; GOST 530–2012. *Ceramic brick and stone. General specifications*. Moscow; 2013. (In Russ.); EN-771-1. *Specification for masonry units. Part 1. Clay masonry units*. European Committee for Standardization; 2003.

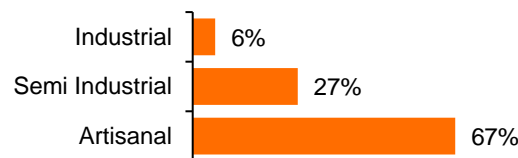
<sup>2</sup> NTE INEN 297. *Ladrillos cerámicos requisitos*. Quito; 1977; NTE INEN 293. *Ladrillos cerámicos definiciones. Clasificación y condiciones generales*. Quito; 2014; NTE INEN 292. *Ladrillos cerámicos. Muestreo (Clay bricks. Sampling)*. Quito; 2015.



**Figure 2.** Map of Ecuador and provinces where field data was collected. Provinces with the highest percentage of new buildings in Ecuador in 2018, according to [10]

### 3. Results and discussion

The results of the field study show that 67% of brick production is mostly artisanal, where the mixing of clay and moulding is done by hand and the firing kiln is rudimentary without technical control of temperature; 27% of brick factories have semi-industrial production processes, in which the clay mixing and moulding is done with machinery and kilning is done in rudimentary kilns or with minimal technology; only 6% of brick factories produce bricks in an industrial way, in which the whole process is done with machinery and the ovens have the appropriate technology for temperature distribution and control (Figure 3).



**Figure 3.** Brick production technologies in Ecuador

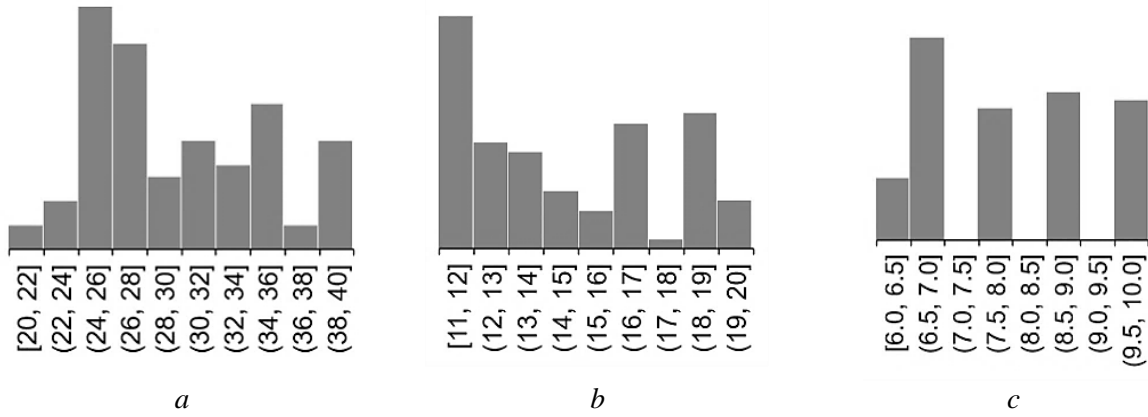
The results of this research show that solid clay brick is the most common type of brick produced in Ecuador. 92% of the factories studied produce solid clay brick, but the dimensions of the units vary depending on the region where it is manufactured, and even in the same province, the dimensions of the same type of brick vary depending on the factory. This variation in dimensions is due to the fact that 98.1% of the factories studied do not comply with any technical standard for production. According to the above, the geometric characterization of solid clay brick produced in Ecuador is a relevant topic that deserves to be studied.

The results of the data collected in the field show a high dispersion of the dimensions of solid bricks at the national level. The dimensions vary from 20 to 40 cm in length, 11 to 20 cm in width and 6 to 10 cm in thickness (Figure 4).



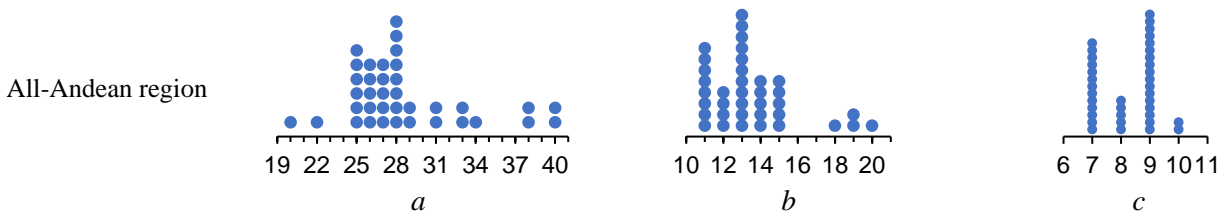
**Figure 4.** Dimensions of solid clay bricks produced in Ecuador

Statistical analysis of the dimensions of bricks produced in the different regions of Ecuador shows a multimodal characteristic (Figure 5). It is observed that at the national level, bricks are: 20–40 cm in length, with a tendency to lengths of 26, 28 and 35 cm; 11 and 20 cm in width, with a tendency to 12, 17 and 19 cm; regard height, it varies between 6 and 10 cm, with a tendency to make bricks of 7 and 9 cm. This multimodal characteristic of the results suggests the need for a more detailed geometric characterization study applied to the different regions of Ecuador (Andean, coastal and Amazonian regions).

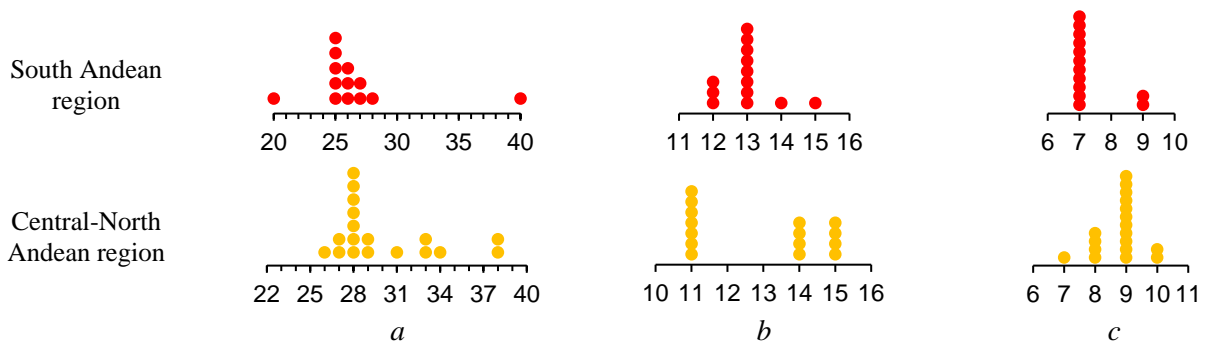


**Figure 5.** Solid brick dimensions distribution in all regions of Ecuador:  
*a* – length, cm; *b* – width, cm; *c* – height, cm

Statistical results for the dimensions in the Andean region show a bimodal behavior (Figure 6). This bimodal behavior is due the fact that in the south Andean region the dimensions of bricks are different than the bricks produced in the central-north Andean region (Figure 7).



**Figure 6.** Dimensions of solid bricks in the Andean region of Ecuador:  
*a* – length, cm; *b* – width, cm; *c* – height, cm

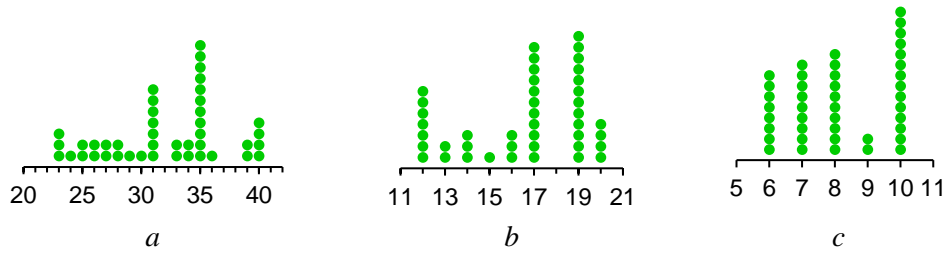


**Figure 7.** Dimensions of solid bricks in the South Andean and Central-North Andean regions of Ecuador:  
*a* – length, cm; *b* – width, cm; *c* – height, cm

The analysis of the results allows us to establish that the production of solid bricks in the Andean region of Ecuador is characterized by bricks of 28.0×11.0×9.0 cm in the central-northern Andes, while in the southern Andes it is 25.7×13.0×7.5 cm with a standard deviation of 0.31, 0.17 and 0.23 cm in length, width and height respectively.



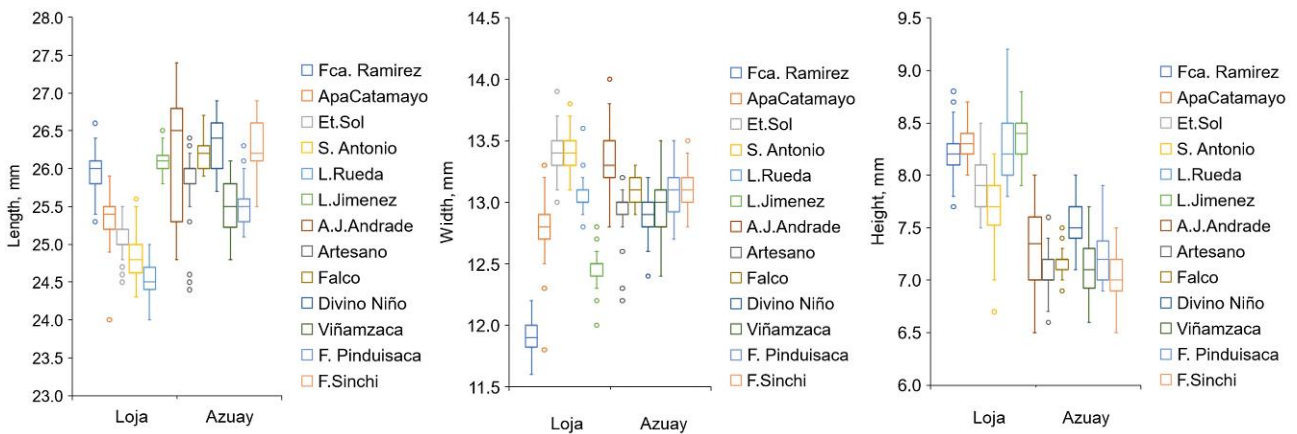
In the coast region of Ecuador, bricks are produced between 23 and 40 cm of length, 12 and 20 cm of width, and 6 to 10 cm of height (Figure 8). The production of solid bricks in the coast region of Ecuador is characterized by bricks of 35×19×10 cm.



**Figure 8.** Dimensions of bricks in the coastal region of Ecuador:  
*a* – length, cm; *b* – width, cm; *c* – height, cm

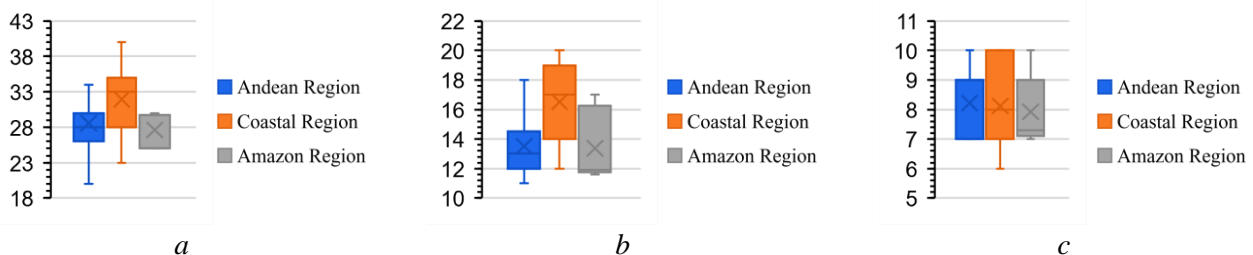
The most densely populated provinces studied in the Amazon region represent only 2.6% of the constructions at the national level. The average dimensions of the solid bricks produced in this region are: 25 cm in length, 12 cm in width and 7 cm in height, with a standard deviation of 0.23, 0.15 and 0.17 cm respectively.

A broader analysis of brick production in the provinces of Azuay and Loja at the south Andean region of Ecuador shows that in the province of Azuay the production tends to be more homogeneous in terms of overall dimensions, although the dispersion in sizes is due to the mainly artisanal and non-standardized nature of production and non-compliance with technical standards. The bricks produced in Azuay are longer and wider, but less thick than in Loja province (Figure 9).



**Figure 9.** Dimensions of bricks in the provinces of Loja and Azuay in the south Andean region of Ecuador

This research establishes that the average length of solid clay bricks manufactured in Ecuador varies between 25 and 33 cm; the average width values are between 12 and 17 cm, and the average height is between 7 and 8 cm (Figure 10).



**Figure 10.** Dimensions of bricks in different regions of Ecuador:  
*a* – length, cm; *b* – width, cm; *c* – height, cm

To contextualize the obtained results, we have compared the data obtained in this research with the regulatory specifications of national technical standard in force in Ecuador. This comparison allowed us to determine the unconformity between the reality of the national production of ceramic bricks and the regulations in force. In Ecuador, standard INEN-317<sup>3</sup> sets the relationships of the modular dimensions of ceramic bricks (Table 1), and the standard INEN-293<sup>4</sup> presents the standard dimensions for bricks (Table 2).

Normal modular dimensions of ceramic bricks according to INEN-317

Table 1

| Length |   | Width |   | Height |
|--------|---|-------|---|--------|
| 2M     | × | 1M    | × | 1M     |
| 3M     | × | 1.5M  | × | 1M     |
| 4M     | × | 2M    | × | 1M     |
| 5M     | × | 2.5M  | × | 2M     |

Dimensions of ceramic bricks according to INEN-293

Table 2

| Type of brick     | Length, cm | Width, cm | Height, cm |
|-------------------|------------|-----------|------------|
| Common (handmade) | 39         | 19        | 9          |
| Machining         | 39         | 19        | 9          |
|                   | 29         | 14        | 9          |
| Repressing        | 29         | 19        | 9          |
|                   | 29         | 14        | 9          |

The obtained results of this research show that only 4.82% of the bricks produced in Ecuador comply with this standard.

#### 4. Conclusion

This is the first study on geometric characterization of solid clay brick in Ecuador. This study was carried out in 12 provinces of Ecuador, where 79% of the country's buildings are concentrated. The results show that the nature of brick production in Ecuador is mainly artisanal and non-standardized. 67% percent of brick production is artisanal, 27% is semi-industrial and only 6% is industrialized. This research show that 98% percent of the factories studied do not meet any technical standards for brick production and are even unaware of the existence of any standards. This fact shows that the Ecuadorian standards that regulate the geometry of brick production have not been adequately developed, socialized and are not applied.

The dimensions of the solid bricks produced in Ecuador show a very high dispersion, however, it has been determined that there is a regional influence that determines the average dimensions of the bricks. There is a clear difference in the dimensions of the bricks produced in the Ecuadorian coast, as well as in the central-north Andean region and the south Andean region. The dimensions of the bricks produced in the studied provinces of the Amazon region are very similar to the dimensions of the bricks produced in the south Andean region.

The authors have determined for the first time the characteristic dimensions of solid bricks produced in different regions of Ecuador. The dimensions ( $l \times w \times h$ ) of the solid bricks produced in the coast region are mainly  $35 \times 19 \times 7$  cm. The dimensions of the bricks produced in the central-north Andean region are  $28 \times 11 \times 9$  cm; in the south Andean region  $26 \times 13 \times 7.5$  cm with a variation of  $CV_{\text{length}} = 0.31$  cm,  $CV_{\text{width}} = 0.17$  cm,  $CV_{\text{height}} = 0.23$  cm. The dimensions of the bricks produced in the Amazon region are  $25 \times 12 \times 7$  cm, with a variation of  $CV_{\text{length}} = 0.23$  cm,  $CV_{\text{height}} = 0.15$  cm,  $CV_{\text{height}} = 0.17$  cm.

It is important to point out that this research has determined that only 4.8% of solid bricks produced in Ecuador complies with the modular dimensions established in the Ecuadorian standards INEN-317 and INEN-293. This fact demonstrates that the Ecuadorian standards on the geometric characteristics of bricks have been developed without considering the real national characteristics of brick production. The related standards require adequate updating for their subsequent socialization and mandatory compliance.

<sup>3</sup> NTE INEN 317. *Coordinación modular de la construcción. Dimensiones modulares de ladrillos cerámicos*. Quito; 2014.

<sup>4</sup> NTE INEN 293. *Ladrillos cerámicos definiciones. Clasificación y condiciones generales*. Quito; 2014.

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