Improvement of a traditional construction system using gravel made from mining waste: an alternative for waste reuse and increased constructive productivity

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Abstract. *According to a research done in 2015 by the Brazilian Architecture and Urbanism Council (CAU, in Portuguese) and Datafolha, more than 85% of the country's population build without hiring an architect or an engineer. The self-construction sector brings problems related to low building performance and high rate of material losses. Having this scenario in mind, this paper proposes the improvement of the traditional building elements adding three main characteristics to their process: faster execution of the walls through a specific joint system between bricks that would eliminate the need of mortar; loss reduction by creating a complete family of bricks that covers the main specificities of the wall-laying process and the improvement of the interaction with hydro sanitary and electrical systems. The developed system is made of concrete with aggregates obtained from non-toxic mining waste. As a theoretical background, the traditional process of brick production in Brazilian industry is analyzed and the national regulations that rule this process are also addressed. The target audience and attributes of the product are defined and then, the elements developed in this work are finally presented. The result is a group of five types of bricks (standard , half, corner blocks 1 and 2, and bond beam block) that work with a specific joint system between blocks in the same row and in subsequent ones. It is concluded that the developed product has reached the desirable characteristics related to its formal aspects, presenting not only the reduction of losses mentioned previously but also a greater agility in the wall-laying process. The last aspect is achieved thanks to the fact that the building elements have an approach to dry construction, without the use of mortar due to the adoption of a specific joint system.*

Keywords. *Wall system, dry construction, joint system.*

1 Introduction

According to a research done in 2015 by the Brazilian Architecture and Urbanism Council (Conselho de Arquitetura e Urbanismo do Brasil - CAU, in Portuguese) and Datafolha, more than 85% of the country's population build without hiring an architect or an engineer. The self-construction practice in Brazil brings along a series of problems caused by the lack of proper technical supervision during the works, such as a high level of material loss, extra costs due to a poorly executed work and, consequently, the need to fix damages that wouldn't normally occur if a technical professional was in charge of the process. Buildings that are built without an architect and/or an engineer also show a low performance during its lifetime when compared to buildings that had a project before the works started. There aren't many new researches showing updated data regarding the material loss produced by this sector, but according to a research requested by the Brazilian Association of the Construction Materials Industry (Associação Brasileira da Indústria de Materiais de Construção), the self-construction sector represents 77% of the annual housing production in Brazil (Construção Mercado, 2006), which

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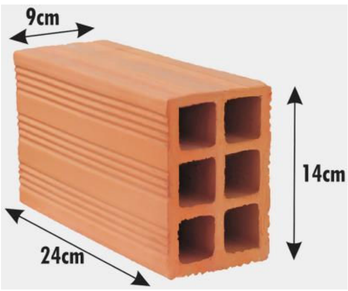
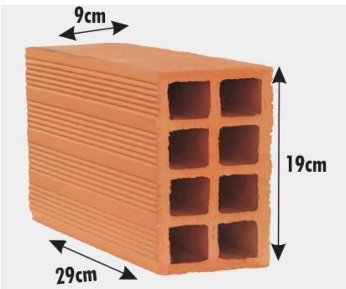
implies that the amount of material loss in these construction sites is considerably high.
Having this scenario in mind, how would be possible to increase the construction productivity, reduce the losses and keep the possibility of use of this product in the self-construction field? In order to achieve such results, it is necessary to adopt a technology that allows itself to be produced in a large scale and also takes into account the several factors that impact the building process at the construction site, such as the interface between the technique and secondary systems, such as water and electrical ones for example. The aim of this work is to develop a complete set of concrete blocks with a tongue-and-groove joint system in order to eliminate the use of mortar between elements and increase the construction productivity. This product also aims to reduce the material losses at the construction site by offering five types of blocks that adapt to the main common situations while assembling a wall (interactions between walls and windows/doors, for instance). Finally, the blocks offer a higher adaptability to water and electrical systems by providing space for horizontal and vertical pipe fitting.

2 Theoretical Background

2.1 Traditional Construction

Figures 1 and 2 show the most common non-load bearing ceramic bricks used in Brazilian construction.

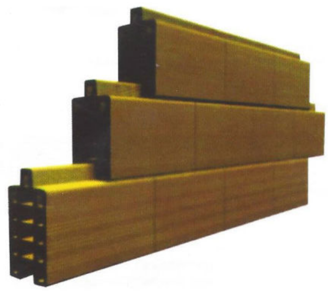


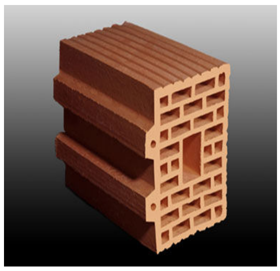


Figures 1 and 2: 6 and 8-hole ceramic bricks. (Source: ceramicafelisbino.com.br). 2016.

Figure 3 shows a complete family of load bearing and non-load bearing elements. Figures 4 and 5, on the other hand, show ceramic bricks with specific top-bottom joint systems.

Figure 3: Concrete blocks. (Source: iporablocos.com.br). 2016





Figures 4 and 5: Ceramic bricks with joint system. (Source: massasparana.com.br). 2016.

Regarding the materials used to assemble the brick formworks, there is a variety of them available in the market, with different life spans. Figures 6, 7 and 8 represent each of the materials mentioned above.

Figure 6: Wood formwork (Source: wikihow.pt). 2016

Figure 7: Steel formwork. (Source: isfel.com.br). 2016.

Figure 8: Plastic formwork.
(Source: nacionalformas.com.br). 2016.

The main advantage of using wood to build brick formworks is the fact that it is a renewable material (when coming from reliable sources) and it is easily handled. Its main disadvantage, though, is the vulnerability against water and its consequent expansion (what brings another issue: the lack of accuracy of the bricks produced by it). Steel formworks don't have this problem and they can actually reach a respectable accuracy, in addition to having a larger lifespan. However, their main disadvantage is related to the cost: steel formworks are considerably more expensive than wood ones. Finally, plastic formworks have similar advantages to the steel ones and one of their disadvantages is the deformability.

2.2 Brazilian Regulations

There is a variety of regulations that rule the bricks production in Brazil, presenting criteria that range from size of the elements and requirements for the production process to resistance and thermal tests that need to be run in order to ensure that the products follow specific structural requirements. These documents also provide information regarding the maintenance of the equipments used during the production process.
Below, there is a short list of the main Brazilian standards related to brick manufacture. They cover structural and non-structural blocks.

- **NBR 6136:2008** – Hollow concrete blocks for concrete masonry - Requirements;
- **NBR 7184:92** – Hollow concrete masonry blocks - Compressive Strength Testing - Method of test;
- **NBR 8215:1983** - Prism of hollow concrete structural masonry blocks - Test to compression - Method of test;
- **NBR 12118:2011** – Hollow concrete blocks for concrete masonry - Test Methods;
- **NBR 15270-1:2005** – Hollow ceramic blocks for non load-bearing masonry - Terminology and requirements;
- **NBR 15270-2:2005** - Structural ceramic block, perforated block, load-bearing masonry - Terminology and requirements;
- **NBR 15575-2 e 4: 2013** - Housing Buildings - Performance - Parts 2 (load-bearing systems) and 4 (external and internal wall systems).

The main goal of this study is to have a notion of the available knowledge regarding quality control of the brick manufacture in Brazil and also what type of requirements the available products in the market are supposed to meet. For this work, the documents mentioned above will serve as references to some specific aspects as listed: minimum thickness of brick internal walls, blocks dimensions (height, width and length) and appearance of the final product.
After analyzing the regulations mentioned previously, some relevant information was gathered, as follows:

- The bricks have their dimensions based on a minimum value: 100 mm. So, each type of brick has dimensions that are multiple of 100 mm, including 10 mm for the mortar applied between elements;

- The internal walls of the bricks should be at least 7 mm thick (as shown in figure 9);
- The mixture to be used to produce the bricks must have a homogeneous and plastic appearance;
- The bricks, as a final product, must present a homogeneous appearance as well, without irregular surfaces or defects;
- As for some of the requirements, the bricks must comply to some values related to water absorption, structural loads (for both non load-bearing and load-bearing bricks), deformation, crack resistance and thermal / acoustic insulation.

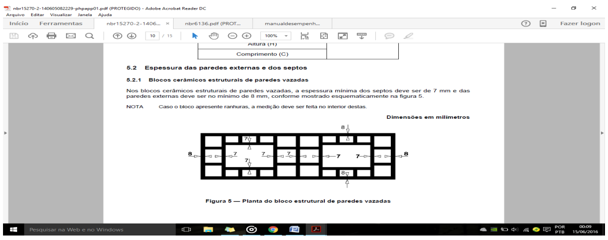


Figure 9: Structural block and its internal walls dimensions, in mm. (Source: NBR 15270-2:2005).

.2.3 Target audience and product's attributes

As part of the product development, it is necessary to come up with the target audience that it intends to reach and which attributes it will offer the public in comparison to the competitors. Bearing this in mind, some characteristics related to these topics have been defined.

Table 1: Definition of User vs. Client and product attributes

USER x	**CLIENT**
Who uses it • Physical persons; • Contractors; • Town halls, public entities.	Who buys it • Owners of building material stores; • Contractors; • Town halls; • Physical persons.
ATTRIBUTES	
Regarding the use (More objective)	**Regarding the appraisal** (More subjective)
• Faster assembly; • Load-bearing bricks; • Reduces the losses during construction; • Joint system without mortar = Dry construction;	• Faster assembly due to the absence of mortar; • Cleaner construction site; • Easy assembly; • Aesthetic aspect.

(Made by the author)

As the next step, the strategies related to the production of the prototypes can be drawn. The main points to follow during the development of the formworks are listed below:

- Think about the drawing of the formworks to ensure that the blocks produced by them comply with Brazilian regulations;
- Define the raw material to be used to produce the formworks, taking into account which one best adapts to their requirements. Other advantages such as cost, ease of handling and availability in the market are also considered;
- Consider the lifespan of the material that will be used in the production of the formworks and what will be done with it after this period.

3 Technology development

3.1 Specifications

The family of bricks developed in this work aims to improve some aspects that are commonly found during the construction process, such as:

- Optimization of the production process;
- Excessive losses due to block breaks;
- Compatibility with complementary systems (electrical and hydro sanitary systems);
- Improvement of the joint systems.

In order to achieve such progress, the following strategies were adopted:

- Optimization of the process by adopting a specific joint system that follows a similar logic to puzzle pieces, excluding the need of mortar between elements;
- Loss reduction by creating five types of bricks with a joint system that is adaptable to several situations. When the need of breaking a joint comes (in a door opening, for instance), the area to be broken is also delimitated, avoiding any excessive losses;
- The developed bricks use their internal spaces and adaptability of their joints to enable an easier pipe fitting, in both vertical and horizontal directions;
- The joint system: the bricks are put together, in vertical and horizontal directions, by a tongue-and-groove joint system.

As to the requirements seen in the regulations, some other specifications are also added to the products to be shown in this work:

- Rules regarding modular coordination: as mentioned before, in the traditional construction techniques involving bricks, their dimensions are multiples of a basic value M (M = 100 mm) and 10 mm of it is reduced as it corresponds to the mortar joint between elements (for instance, a brick that would be 400 mm long is actually 390 mm long - the missing 10 mm representing the mortar joint). As the technology developed in this study presents strategies to eliminate the need of mortar, the bricks will follow that same basic value without the reduction of size;

- Brazilian regulations define that the internal walls of the bricks should be at least 7 mm thick. However, as it was not possible to run structural tests with the produced prototypes and to assure that these elements could have a load-bearing capacity, the internal walls of the bricks were oversized to 20 and 25 mm thick.

The mixture used to produce the prototypes at the laboratory was basically the traditional one: cement, sand and aggregates (in the ratio 1:2:2). However, instead of using traditional gravel, the aggregate used in the concrete mix came from clayey waste that went through a process called flash calcination (controlled burning that reaches temperatures ranging from 650 to 800 ºC). The name of the byproduct used in these aggregates is *metacaulim*. It is important to emphasize that this does not play a decisive role in the bricks performance.

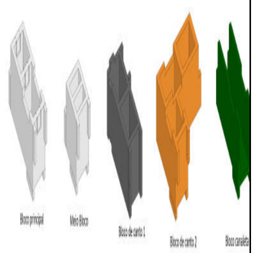
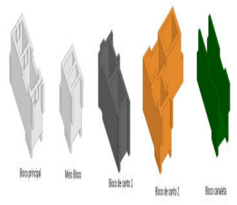
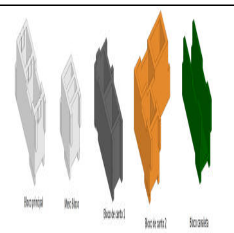
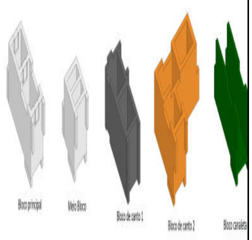
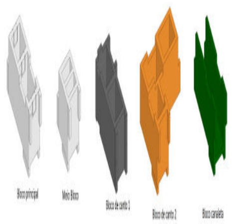
3.2 Developed Family and Production of the Prototypes

The family developed in this work is composed by five elements that aim to improve the issues in the construction process that were previously mentioned. These elements are:

- Standard block;
- Half block;
- Corner block 1 (between two walls);
- Corner block 2 (between three and four walls);
- Bond beam block.

The following table presents further descriptions about them. All of the elements are 15 cm wide and 20 cm high. Plus, all of their joints have grooves that limit and facilitate the process of adaptation whenever necessary.

Table 2: Concrete blocks developed.

CONCRETE BLOCKS DEVELOPED	
	**Standard Block:** The standard block had its joints adapted in order to facilitate joining between subsequent elements and between rows. It was used as the basis for the other elements and, just like them, this block has grooves in its joints so that the delimited area can be broken whenever adaptation is necessary. Plus, it has also got grooves in its inner walls in order to free space for horizontal pipe fitting. **Dimensions:** 400 x 150 mm
	**Half Block:** It follows the same logic as the standard one, except for the part that this element does not have grooves in its inner walls for pipe fitting. Its inner wall is extended by 3 cm downwards in order to provide extra locking of the brick in the row in which it is placed. **Dimensions:** 200 x 150 mm
	**Corner Block 1:** Used in the corners between two walls. It has top joints for blocks of the same type and adaptable (breakable) fittings on the sides for standard blocks. **Dimensions:** 350 x 150 mm
	**Corner Block 2:** With an L shape, this element was created to be placed in the corner between three and four walls. When placed between three walls, it is used in alternate rows with the standard blocks; when placed between four walls, only this type is used as it is placed normally in the first row and in an inverted position in the next one. **Dimensions:** 400 x 350 mm; 150 mm wide e 200 mm high.
	**Bond Beam Block:** Used in the same way as its traditional counterpart. **Dimensions:** 400 x 150 mm

(Made by the author)

Figure 10 illustrates a 3D model simulating a situation where all the developed blocks would be used, including their interaction with doors, windows and complementary systems, such as water installations.

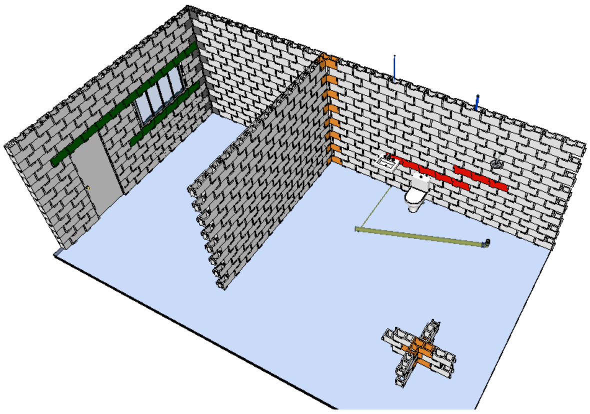


Figure 10: A 3D model with all the blocks being used. (Made by the author)

Figure 11 shows a detail of the last one, where the red blocks represent the standard bricks that were modified in order to allow the passage of water pipes.

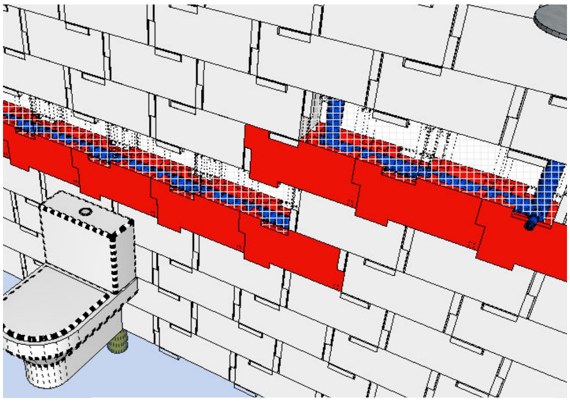


Figure 11: Detail showing how the standard blocks provide space for the water pipes and how they come out of the wall through the hole created by breaking one of the joints. (Made by the author)

3.2.1 Making the formwork

Regarding the formworks, after studying the available materials used for this purpose, it was possible to notice that the best option in terms of higher productivity, better results and reduction of work labor would be the steel formworks. However, due to financial issues and availability of cutting equipment and work labor, the chosen material was 6-mm plywood boards. The reduced thickness was motivated by the fact that the material was cut by a Laser Cutter that could only work within that size limit.

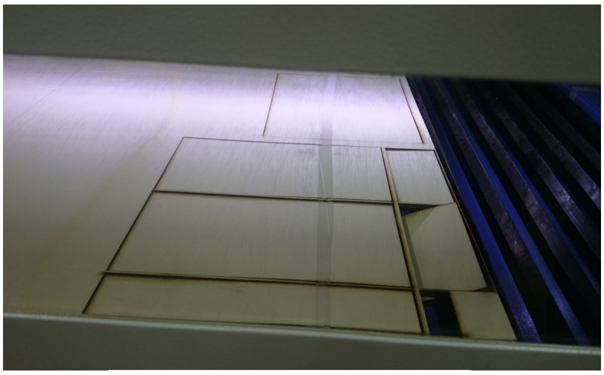


Figure 12: One of the boards in the Laser Cutter. Picture taken by the author.

To reduce the water absorption and dilatation, the plywood boards were waterproofed with marine varnish. The following pictures show the formworks before and during the process of being coated with marine varnish. As the family presents five types of bricks, five types of formworks were made, as shown in picture 13.

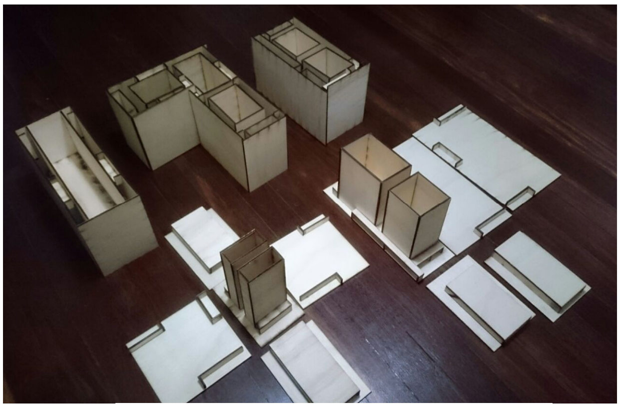


Figure 13: Finished formworks before being coated with varnish. Picture taken by the author.

The reason for not using marine plywood was due to the unavailability of such with that specific thickness (they usually were thicker than 6 mm). In total, two 180 x 220 cm plywood boards were used in the process.

Figure 14: Waterproofing process. Picture taken by the author.

3.2.2 Preparing the mixture and filling the formwork

The production of the prototypes was done in a laboratory at UFMG Sustainable Production Center. The formworks were assembled and their inner faces were coated with an oil similar to diesel fuel to enable an easier removal of the blocks after the curing time. The reason for using this material was because the majority of release agents are sold in considerable quantities and due to the limited scale of this work (as it was intended to produce only prototypes), a different alternative was put in place. After that, the formworks were assembled and locked with the help of formwork clamps and duct tape. Table 3 quantifies the materials used in the concrete mix.

Figure 15: Formworks assembly at the lab. Picture taken by the author.

Table 3: Materials proportion for the concrete mix used to produce the prototypes

MATERIAL	QUANTITY
Nominal proportion = **1:2:2**	
Cement	9 kg
Sand	18 kg
Gravel (obtained from the clayey waste)	18 kg
Water (in volume)	0,00588 m^3 (ou 5,88 L)

(Made by the author).

The following images illustrate the process of preparing the concrete mix and filling the formworks.

Figure 16: From left to right: Aggregate sifting; preparation of sand and concrete; inclusion of the aggregates and mass mixing. Picture taken by Cléber Eustáquio.

Figure 17: Formworks filled with the mix. Picture taken by Cléber Eustáquio

3.2.3 Finished prototypes

After the curing time, which lasted about a week, the first set of blocks started to be removed from the formworks. However, it was noted that the wood formworks ended up being damaged while removing the blocks due to basically two reasons: the oil used as a release agent was not as effective as expected and the wood pieces got stuck to the bricks; and the plywood boards didn't have enough resistance because of their reduced thickness. For these reasons, the formworks could only be used once and, consequently, only one set of bricks could be produced. As this quantity is insufficient to properly run laboratory tests, they will be done in future works. In an ideal situation, it is recommended to produce at least six sets of bricks with a 28-day curing time and at least two sets with a 7-day curing time to be able to run tests properly.

Figure 18: Standard block finished. Picture taken by Cléber Eustáquio.

Figure 19: Corner block 2 finished. Picture taken by Cléber Eustáquio

Figure 20: Corner block 2 - top view. Picture taken by Cléber Eustáquio.

Figure 21: Standard and bond beam blocks - top view. Picture taken by Cléber Eustáquio.

Figure 22: Half block finished. Picture taken by Cléber Eustáquio.

After removing the blocks from the formworks, it is possible to notice that some of elements got damaged during the process. Because of that, all the blocks had their joints rebuilt afterwards, presenting a slightly better finish. Figure 23 shows the complete set.

Figure 23: Complete set of bricks. Picture taken by the author.

4 Results Analysis

As soon as the blocks were finished, they presented the following characteristics:

- The majority of them had smooth and homogeneous surfaces. The concrete mix used to produce them allowed a low rate of air bubbles, creating blocks with reduced porosity;
- Due to the low performance of the oil used as a release agent, some edges got damaged during the removal of the blocks from their formworks. These edges were rebuilt afterwards;
- Some bricks presented internal walls with a slightly larger thickness than it was previously defined due to the fact that the chosen plywood boards were not sufficiently resistant when compared to traditional formworks (as it had to have a limited thickness to be cut in a Laser Cutter). When filling the formworks with the concrete mix, they have moved slightly.

During the development of this work, some obstacles have emerged. As mentioned before, the main reason for choosing a 6-mm plywood board was due to the requirements to use a Laser Cutter, an equipment that would ensure a high level of accuracy during the cutting process, making it faster as well. Another point to be highlighted was the need of going to a different institution to be able to use this kind of equipment, since the Laser Cutter at UFMG School of Architecture was out of order at that time.

It is also important to mention the number of reuses that the formworks allowed. Produced in a unitary scale (one formwork for each type of block), they could only be used once due to the ineffectiveness of the oil used as a release agent, as mentioned previously. The formworks got stuck to the concrete blocks, making it difficult to remove the elements without damaging them somehow. In the first stages of this work, it was proved that steel formworks were way more efficient than their wooden counterparts, not only for their higher rate of reuses but also for their higher resistance against moisture. However, for financial matters and for a easier handling, the solution held was to choose wood as a main material for the formworks. Since only one set of blocks was produced, the resistance and thermal tests are going to be run in future works.

5 Conclusions

The blocks developed during this work had as their main goals the improvement aspects with crucial importance in the construction sites: excess of material loss due to brick breaking, cleaning of the construction site and construction productivity. Focusing on the drawing of the blocks and how they would interact with each other and with other building installations, it was possible to develop solutions for the problems mentioned previously.

Some observations, however, are worth to be mentioned. Steel formworks would achieve high standard results when compared to wooden formworks. Plus, the importance of choosing a proper release agent is undeniable. The infrastructure issue has also created an impact on this work. Although the UFMG School of Architecture has indeed a Laser Cutter, its maintenance status was not allowing it to be used at the time it was requested. That brought up the need of going to a different educational institution to use this type of equipment. Besides, the lack of laboratories to produce the prototypes at the School of Architecture caused the process to be done in the laboratory at UFMG Sustainable Production Center.

Finally, it is important to emphasize the reason for this work to be done by an architect. In addition to having knowledge to understand the construction process from a technical standpoint and the requirements of the human habitat, having a three-dimensional view of the space and being able to represent that through drawings, the architect is able to deal with aspects related to building technology and sustainability. This professional is also prepared to produce knowledge in order to help the construction chain and its development. It is relevant to have in mind the several ways that an architect can (and should) be acting within the industry, contributing to its growth.

Further Observations

The blocks produced in this work are in process of patentability analysis. The focus of this patent is to protect the designs of the blocks, not the mixture used in it. The subsequent testing phase is currently in progress.

Acknowledgments

We would like to thank professor Abdias Magalhães and technical staff, Mr. Cléber and Ms. Daniela, for allowing the use of the facilities at CPS UFMG and for monitoring the works during its development. We would also want to thank the contribution of the FabLab at *Centro Universitário Newton Paiva* and their technical staff, Mr. Dário Nascimento and Mr. Brício Salles, for allowing the use of their facilities as well.

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