Automating the rationalized masonry project

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ABSTRACT

The present research aims to develop a diagram that serves as the basis for the automation of rationalized masonry project at any Building Information Modeling (BIM), with the goal to develop greater computational efficiency processes. The Building Object Behavior method (BOB) was used in the research. This method was developed from 2001 to 2004 by the research group composed by Chang Lee, Rafael Sacks and Charles Eastman at universities in the United States and Israel in a partnership with North American companies of reinforced concrete and it fits as design science research. The research was conducted in four stages: clarification, design, validation and implementation. During the development of the study it was found that there are two possible diagrams: the first one proposed by us and the other proposed by Monteiro in 2011. With both possibilities analyzed, our diagram demonstrated better computational efficiency. At the end of the research we were able to generate the expected diagrams and propose a diagram showing better computational efficiency compared to previous works in the area.

KEYWORDS
parametrization, BIM, masonry design, automation design.

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1. INTRODUCTION

This study is the result of a Master research carried out at the Federal University of Ceará (UFC). The thesis is also included in the research project "Development of an Integrator System (software) for Design and Execution of Building Systems in Masonry Coordinated Modularly"[1]. The project is developed in partnership with Brazilian universities, including the Federal University of Alagoas (UFAL) and the Federal University of Santa Catarina (UFSC) and it is funded by the Brazilian Innovation Agency (Finep).

The Brazilian construction industry has serious problems in the method and form of production mainly because of its still low tech constructive process, and also by having issues on the information flow (Addor et al., 2010). Among the ways to improve the construction process we have industrialization and rationalization. The Method of Masonry Walls Designing for Production (MWDP) (known by the acronym PPVV in Portuguese) has some potential tools for these purposes (Greven, 2007; Monteiro, 2011). On the other hand, the failure on the information flow can be solved by the use of the Building Information Modelling (BIM) (Müller, 2010).

The first steps to rationalize the civil construction in Brazil occurred in the 1970s with the production of various standards related to modular coordination mostly applied to masonry (Silva, 2003). The rationalization of masonry is really important since masonry is the most widespread construction process in Brazil and it also interacts with various subsystems such as structural, hydraulic and electrical (Peña and Franco, 2006). The MWDP was introduced in the Brazilian market in 1980 and aims to optimize the compatibility of masonry with the various subsystems that interact with it, such as facilities and structures (Ferreira and Santos, 2008). Despite these efforts, Sabatini (1989), in the late 1980s, indicated that the performance of construction still has very poor results regarding productivity and material waste. In the early 2000s can be seen a greater investment by the construction companies in masonry projects of rationalized sealing aiming to reducing costs of construction.

The concept of BIM has existed since the 1960s; however, it only became commercially available in the mid-1990s due to the absence of efficient computers (Ayres, 2009). The BIM platform is based on the parametrization of technologies which enables data management and planning through parametric objects, which means objects with rich semantics, applied to the phases of the lifecycle of a building (Succar, 2010). These tools allow the system to easily identify projects incompatibilities; extract automatics quantitatives and generate instantiations of 2D and 3D Models (Arayci et al., 2011). It should be noticed that the BIM software generally does not meet the specific needs of each designer, so most platforms allows its customization (Sacks et al., 2004). Thus, at international and national levels, the production of customized work of BIM platforms for design automation can be verified.

Internationally, a large production of research was accomplished from the partnership between North American companies of reinforced concrete and the universities: Georgia Institute (USA) and the Israel Institute of Technology (Israel). The partnership "Design and Engineering Software Platform", developed in the period of 2001-2004, produced design automation methods like Building Object Behavior (BOB); Description notation and method and Georgia Tech Process to Product Modeling (GTPPM) (Lee et al., 2005).

The BOB method consists in a kind of abbreviatted writing to describe the behavior of parametric objects and their relationship towards other objects; and the GTPPM a method to translate one computer language to the behavior of these objects. Rafael Sacks, Charles Eastman and Chang Lee can be highlighted by their work in the project. Sacks and Eastman were responsible for developing the book BIM Hand Book, published in 2005, a document that presents itself as a guide for the implementation of BIM (Eastman et al., 2008). It can also be

[1] The Project original name is : Desenvolvimento de um Sistema Integrador (software) para Projeto e Execução de Sistemas Construtivos em Alvenaria Coordenada Modularmente" (SISMOD). It has not been published in English yet, but the translation was made to the understanding of the reader.

cited researches of Cavieres et al (2009), a researcher at the Georgia Institute, who applied the BOB method in the automation of masonry projects.

In Brazil, we have an emphasis on customization work of BIM software, but few studies stand out in design automation. Ayres (2009) and Miller (2011) (Checucci et al., 2011), and Romcy (2012) are among the studies developed independently and in different universities on the topic of automation modular construction systems, based on the parametric modeling, but without use or refer to the BOB method.

By analyzing studies already developed in Brazil, we can see some automation features of masonry design that can be optimized by the BOB method. Thus, this research aims to develop a diagram which serves as the basis for the automation of the rationalized masonry project at any BIM platform, aiming for greater computational efficiency processes. The focus of the automation is to generate automatic paging walls with window frames.

2. LITERATURE REVIEW

The automation of the implemented design to BIM platforms can be developed by various methods based on parametric modeling. In researches of Lee (2005) and Cavieres (2009) they studied the automation of parts of a concrete system using the BOB method and parametric modeling. Romcy (2012) and Monteiro (2011) generated rationalized automation masonry from shape grammar and parametric modeling.

Shape grammar has emerged as form generation system for painting and sculpture by rules composition and it belongs to design computing knowledge area. The term computing does not necessarily mean direct application in computer applications, but any type of information processing. However, many researchers are studying the applications development for the shape grammar automation and it is being used in generating system of architectural forms (Celani et al., 2007). Some important elements which produce shape grammar are: vocabulary of shapes, spatial relationships, rules and the initial form (Monteiro, 2011).

Current technologies of parametric modeling allow better linking between design and geometry of shape grammar (Cavieres, 2009). Parametric modeling is a computational representation of a virtual object constructed from attributes. The attributes can be fixed if they did not suffer modifications or variables when they are represented by parameters and rules, which allow automatic adjustment of objects according to user control and the change of context (Andrade and Ruschel, 2009). Therefore, it is understood that the objects have to be shaped not only by the geometrical shape, but as units of information containing specific semantic relationships within its domain (Sacks et al., 2003).

Parametric modeling is an ambiguous and complex method because the parametric object can be developed by many ways; the best one is that which generates the lowest processing data for the computer system. Its complexity is therefore the number and the scope of the parameters and restrictions which grow exponentially as more building components are considered. Parametric modeling also still requires an algorithmic and mathematical thinking process (or programming), even though it does not actually require the use of a programming language (Lee et al., 2005).

According to Sacks et al (2003) there are three possible automation routines for a parametric object. The first routine is to design parts and connections, which can be understood as the automatic generation of individual parts and their connections from the power parameters. After that, an automatic adjustment of the object is done when a its parameter is changed, such as changes of charge or size. The last routine is to generate a layout based on knowledge, when a building system may be generated automatically after being fed parameters.

The BOB method was developed within a partnership of researchers and North American companies of reinforced concrete. It started due to the need of uptade and feeding a library of

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parametric objects of reinforced concrete pieces collaboratively. The BOB can be understood as shorthand writing and a protocol for description of the settings and behavior of parametric objects in a reusable and sharable format (Lee et al., 2005). The forms of BOB method representation are technical drawings and two dimensional or three dimensional orthogonal perspectives, but their representations do not require precision in the early stages. Only relationships and behavior between system components are important to be captured and communicated clearly. The geometric precision is determined during the final modeling of the object. The considered behaviors are four primitive types: fix, rotate, transfer and remodel. Special relations with other components can be: aligned, equal spacing, horizontal and normal restriction (Cavieres, 2009).

3. METHOD

The current research uses the notation method and description BOB developed by Lee et al (2005), related to design science research. This methodology differs from conventional science; it does not figure out anything new, but it produces something new. It is a tool to solve problems found in real world, in which its theoretical contribution happens from its application. Among artifacts that can be produced there are: models, diagrams, plans, organizational structures, commercial products and design of information systems (Lukka, 2003).

The original method is developed in four stages. However, due to the absence of a programmer to support the work, we will make small changes in the final two stages. The first stage is clarification, which consists in defining the construction systems and automation purpose. The second stage is the design phase in which the parameters, restrictions and minimum system standards are identified. The third stage was supposed to be the implementation phase, where we should deploy the patterns within a plug-in, but we slightly changed it to be the validation phase. In this stage, we evaluate the behavior patterns of submitting them in different situations in script form within the platform ArchiCAD 18. The last step will be the implementation phase, where activity diagrams will be developed in UML. According to Booch et al (2000), activity diagrams do not need to be developed in programming language. Thus, the diagrams developed will serve as the basis for the generation of plug-in BIM applicable to any platform.

4. RESULTS AND DISCUSSION

4.1. Clarification phase

The parametric object chosen to be automated was the building system of rationalized masonry of ½ mooring, which has as main components bricks blocks (ceramic or concrete) and mortar joints. Additional components such as channels blocks "U" serves as lintels and sills, which means they will serve as structural components of the rough rough openings. The function chosen was the full pagination of an isolated masonry with spans (see Figure 01), which falls within the automation level: *generation layout based on knowledge*.

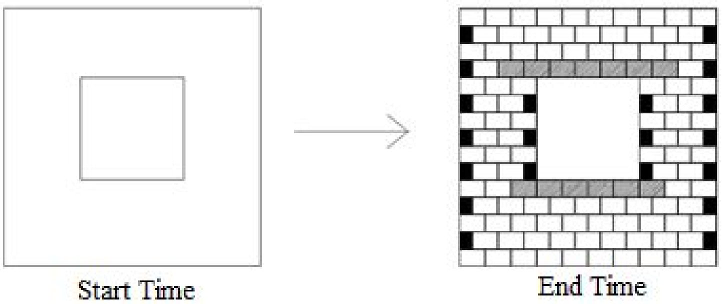

Figure 01: Parametric object behavior. Source: Levi Teixeira, 2015.

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4.2 Design phase

During this phase the constraints and parameters were analyzed and the behavior patterns identified. The method was introduced through the concept of "modeling top-down" Sacks (2003), which initially walls with no details were observed, assessing its geometric behavior and restrictions on other components such as lintels, sills and mooring between blocks.

4.2.1 Restrictions and parameters

The common parameter to all system components is the fact that every component should be multiples of the M module, which is common to all commercial components of ceramic or concrete. The M module which will be set 15 cm. In addition to this convergence of parameters there are some particularities: the spans can only be inserted into the walls and both objects can only suffer any dimensional remodeling in relation to height and length because the thickness is fixed (see Figure 02). Lintels and sills act as structural components of frames and spans and should be located above and below them respectively. The structural components have a fixed thickness and height and width should be left at least 30 cm longer than the span for each side (see Figure 03). It’s important to notice that there are different types of existing rough rough openings such as a door with only lintels and windows that have the two structural components.

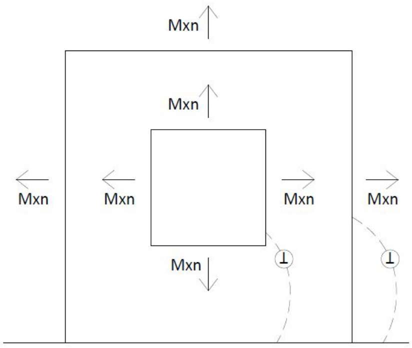

Figure 02: Rough openings: parameters and restrictions. Source: Levi Teixeira, 2015.

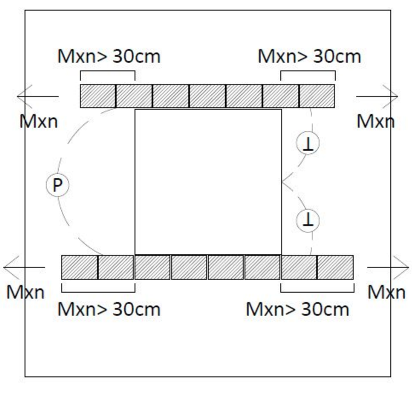

Figure 03: Lintels and sills: parameters and restrictions. Source: Levi Teixeira, 2015.

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In addition to rough openings, which are optional components, the walls are mainly formed of blocks and mortar joints. The length of the blocks must be positioned parallel to the floor and the adjacent blocks in the same row must be fitted by the thickness. The top course of blocks must be fitted on the lower half avoiding the simultaneous joints (see Figure 04). Between one block and another in the lateral and upper sides there are mortar joints of 1cm (see Figure 05).

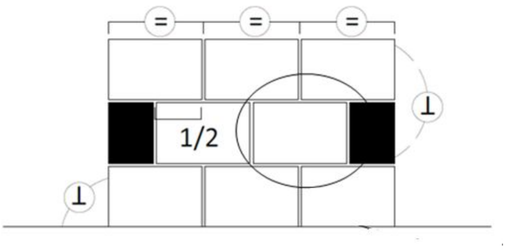

Figure 04: Blocks: parameters and restrictions. Source: Levi Teixeira, 2015.

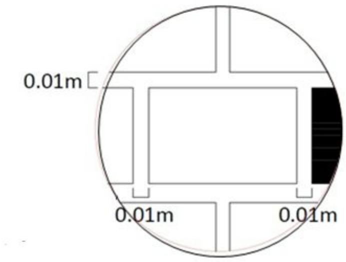

Figure 05: Details of the joints: parameters and restrictions. Source: Levi Teixeira, 2015.

The blocks that make up the walls have fixed dimensions which are multiples of the M module, equal thickness and heights and varying lengths. Therefore, there are three main types of blocks called 2M and mooring blocks 1M and 3M, which have the following modular dimensions in terms of length, thickness, height: 15x15x20cm, 30 x15x20cm and 45x15x20cm and actual sizes of: 14x14x19cm, 29x14x19cm and 44 x14x19cm due to the presence of horizontal and vertical joints. The channel type blocks have dimensions 1M and 2M and are used as lintels and sills (see Figure 06 and 07).

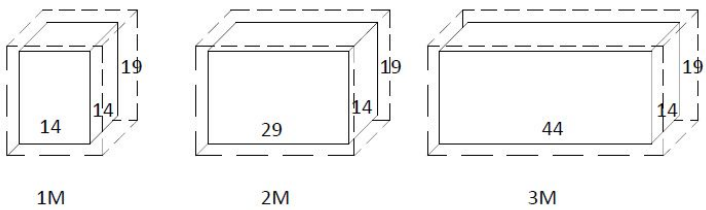

Figure 06: Main blocks: Parameters and restrictions. Source: Levi Teixeira, 2015.

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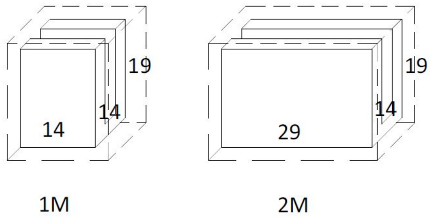

Figure 07. Channels blocks: parameters and restrictions. Source: Levi Teixeira, 2015.

4.2.2. Identification of minimum standards

The building system behavior patterns are identified by association of the restrictions presented with the modular dimensions of the components of the building system and the lease of it. After analyzing previous studies we observed that there are two sets of standards to generate automatic paging walls frames. The first possibility was proposed by Monteiro (2011) and another one is proposed by this research. Two different paths were chosen for automation, so we have some variation patterns according to each of the selected paths.

By observing the behavior of a wall from its dimensions, the R1 patterns can be extracted when the length of it obeys the following formula: C = M x N + 1 M (see Figure 08), and R2 can be extracted when the length obeys the following formula C = MxN (see Figure 09). Both patterns were already predicted by Romcy (2012).

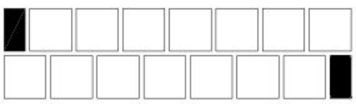

Figure 08: Wall R1. Source: Levi Teixeira, 2015.

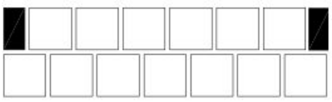

Figure 09: Wall R2. Source: Levi Teixeira, 2015.

By observing the interface variables with a frame rough opening we can work with them as Monteiro (2011) did: by separating them in filling areas. However, unlike the insulated wall standards presented above, where the walls begin only with R1 in this scenario and then open and close with R1 or R2, as the variation of the angled wall depends on the location and length of it. Thus, we have the following situations by determining areas (see Figure 10):

- If the area is A1, the laying can only start with R1 and end with R1 or R2;

- If the area is A2, A3, A4 or A5, the laying can begin or end with R1 or R2;

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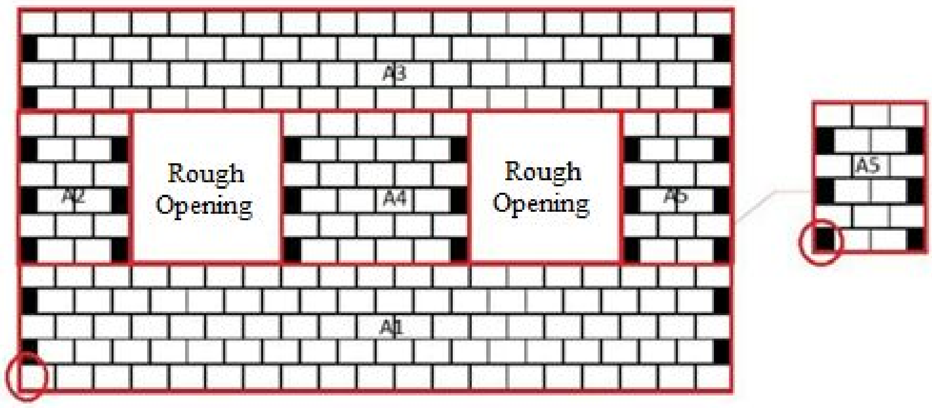

Figure 10: Experiment I. Source: Levi Teixeira, adapted form Monteiro (2011).

Another possible way to laying a wall is to fill the entire laying disregarding the presence of the frame as it was a single area of A1 type; and then remove or replace necessary blocks. From this premise we have new situations which are valid for any kind of rough opening:

• Standard AB1: If there are blocks entirely within the rough opening, all of them will be eliminated;

• Standard AB2: if there are 2M blocks partially within the rough opening, all of them will be replaced by 1M blocks;

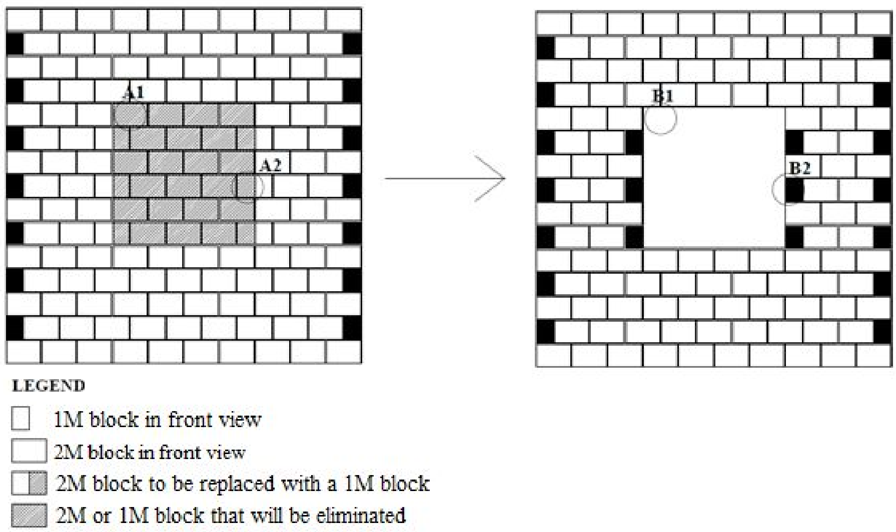

Figure 11: Experiment II. Source: Levi Teixeira, 2015.

The standard intended for the lintels and sills is the same to both experiments. These structural parts must be located respectively above and below the rough opening and in accordance that the laying opportunities may assume two different sizes (see Figure 12):

• Standard CD1

- The size of the lintel shall follow the formula: rough opening + 30 cm if the block located at the end of the rough opening is entirely above it.

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- The size of the sill shall follow the formula: rough opening + 30 cm if the block located at the end of the rough opening is entirely above it.

● Standard CD2

- The size of the lintel shall follow the formula: rough opening + 45 cm if the block located at the end of the rough opening is partially above it.

- The size of the sill shall follow formula: rough opening + 45 cm if the block located at the end of the rough opening is partially above it.

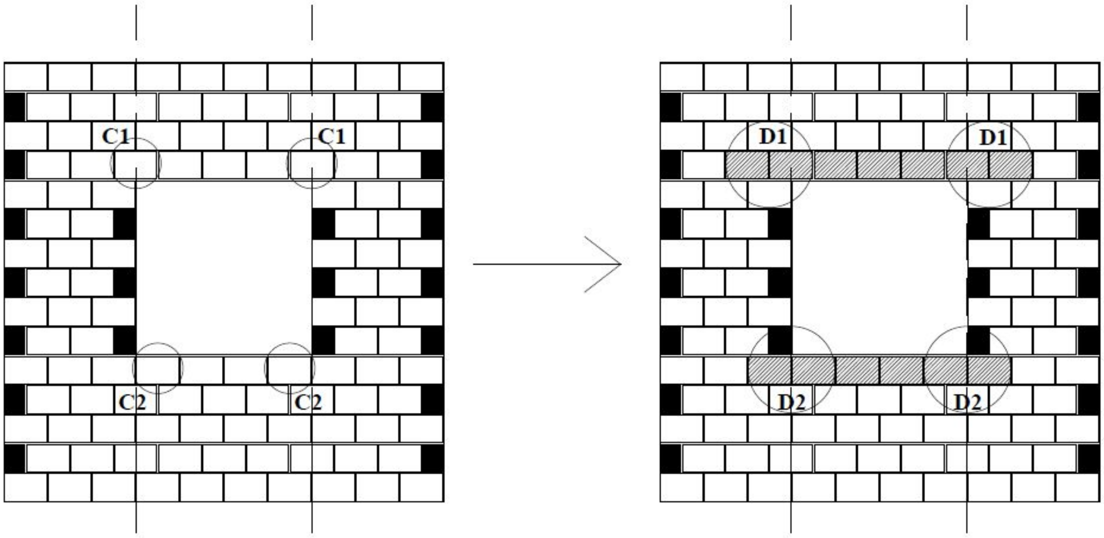

Figure 12: Lintels and sills.

4.3. Validation phase

The standards were modeled and tested within the ArchiCAD 18 software at the script level during this stage, where different situations were simulated. The developed models have three dimensional and two dimensional representations. We decided to use only two dimensional representations, since they allow a more o clear visualization of the patterns behavior. Two or more tests were conducted on each presented pattern. The first test was the recognition of behavior, where we consider that when the same behavior is repeated on the second test the tendency is that it will be repeated over the other tests.

We submitted two automation paths to similar tests. The first test consists on filling a laying wall with the dimensions of 3m x 3m with a rough opening of modular size 1.05m x 1.20m and real size of 1.06m x 1.21m. In the second test we used the same wall with an increased value of a module (M) of 15cm to each side of the window and 20cm upward. The block height value was the same with the modular size of 1.35cm x1.40cm and real size of 1.36cm x 1.41cm. The increase of a module corresponds to the minimum change that may arise. In the event of unforeseen appearance of new standards, new tests will be done expanding more 15cm and always adjusting the real size with modular size (see Figure 13).

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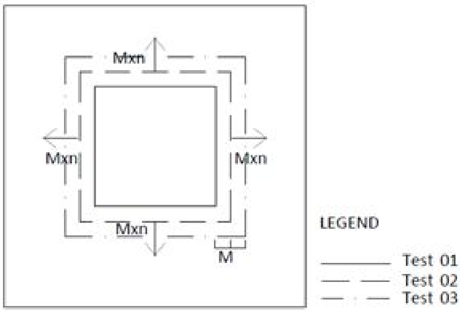

Figure 13: Tests 01, 02 and 03. Source: Levi Teixeira, 2015.

After the tests it was realized that the method I was fully contemplated. On the other hand, Method II partially met our expectations since we applied the replacement rule of blocks A2 for blocks B2 (replacement of a block 1M for a 2M) and the blocks located at the right of the rough opening were relocated in the wrong position (see Figure 14). This can be explained by the fact that all parametric objects in ArchiCAD platform have a reference point to be replaced or inserted. In order to solve the problem we would have to create two 1M blocks with distinct points of reference or move them after inserted. The first option was discarded because it was not possible to achieve it in ArchiCAD 18 software, so we opted for the algorithm that generates the shift even after inserted. At the end, it was suggested the subdivision standards in C2.1, C2.2 and we conducted new tests that proved the same.

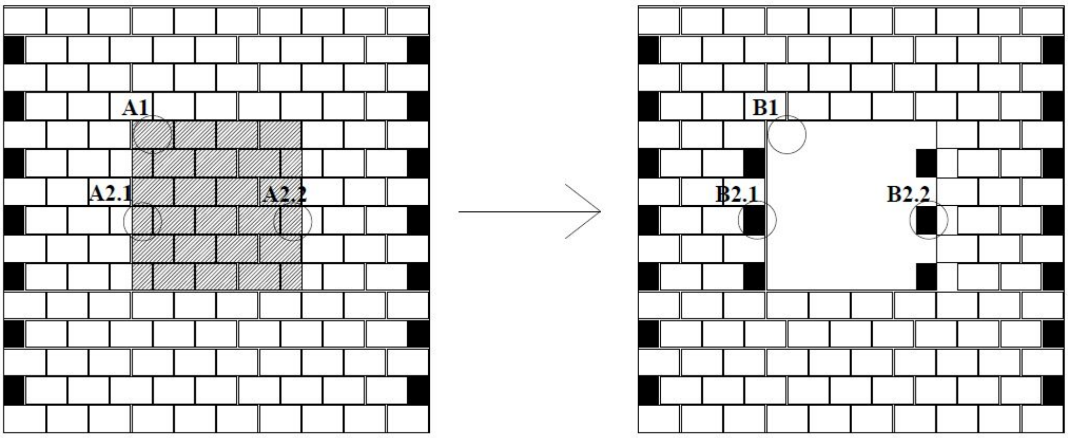

Figure 14: Method II: Test 01. Source: LEVI TEIXEIRA, 2015.

The algorithm related to lintels and sills is common to both experiments and showed unexpected behavior where two patterns (CD1 and CD2) generated a single set of actions (see Figure 15).

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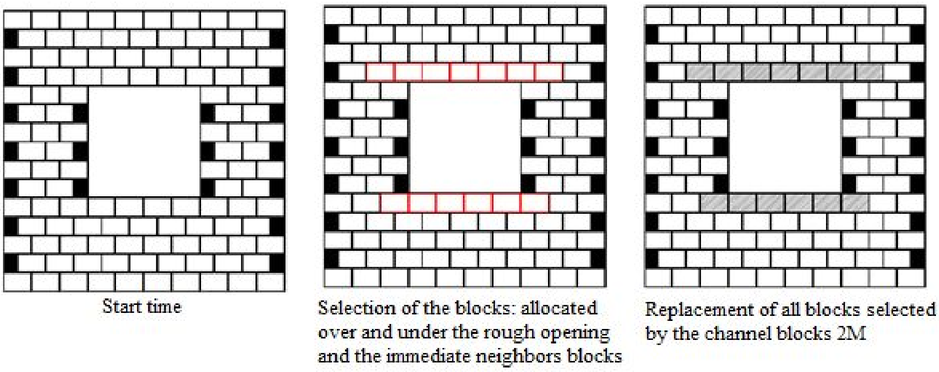

FIGURE 15: Lintels and sills simulation. Source: LEVI TEIXEIRA, 2015.

When the frames are placed in the corner of the wall, which is a more common situation to doors, we have the presence of blocks 1M and 2M, which have to be selected and replaced individually, thus generating a new standard.

4.4. Implementation

The activity diagrams were developed in three steps. First we searched for actions present in each method and their respective tests. Then the existing actions were compared in each test compared. Lastly, a single diagram was generated for each method at the end of the process. So, when we found similar actions we operate a continuous flow of actions and when action divergences were found we used a tool called *bifurcation*. In specific cases, where after the use of *bifurcation* it was necessary to unify the flow, we used a union bar (see Figure 16).

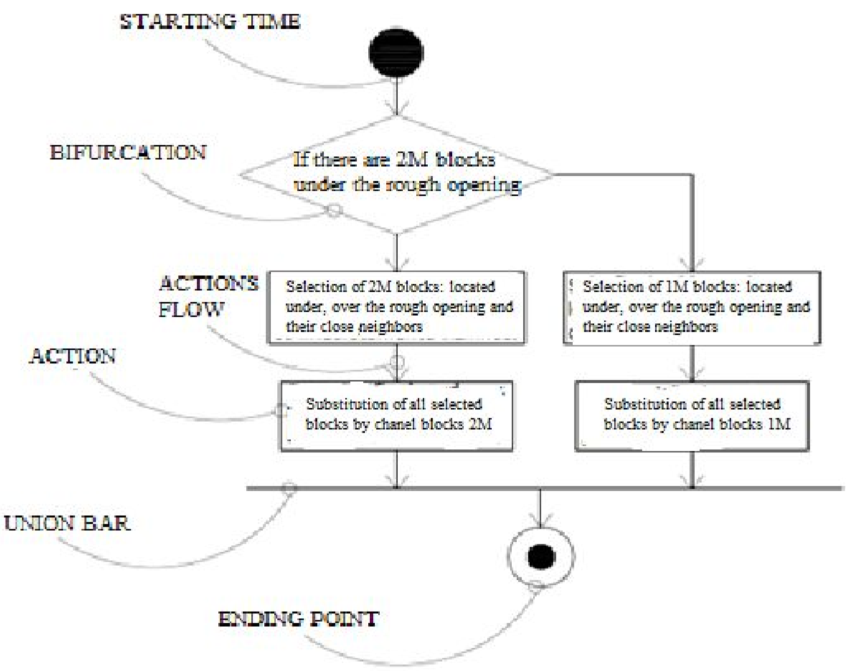

Figure 16: Diagram of lintels and sills.

After the development of both diagrams it can be seen that the path chosen by us generates a flow of much smaller actions compared to the one chosen by Monteiro (2011). However, Monteiro (2011) chosen path has the possibility of repeating the same algorithm, which depending on the number of frames on the wall may be repeated four to five times, which generates reducing flowchart actions, but it is always dependent on one an algorithms library and is still bigger than our flow (Annex 01 and Annex 02). Lintels and sills have only one action flow to two different visual patterns. However, we added more flow due to the possibility of 1M blocks substitutions, which has the same action set only by changing the type of block (see Figure 16). Another advantage offered by the new produced algorithm is that it can be applied in other situations, such as having a laying wall.

5. CONCLUSIONS

During the experiment some theories were proved true, such as the parametric modeling efficiency and its ambiguity and complexity. The scientific support design science showed itself necessary for adjustments to the BOB method used in the study.

Lee et al (2005) considers the parametric modeling as an ambiguous method because there are several possibilities to reach the same path and the best way is always the one with lowest data processing. The experiments showed the path developed by us as the best way because it has the lowest actions flow. The two visual patterns of lintels and sills, which were checked during design phase, have been translated into a single action flow at the implementation phase. This proves the ambiguity of this method and it also demonstrates that it not always generate different patterns generates different actions. The BOB method has proven far more effective in the sense of clarity and objectivity during the identification and validation of the behavior patterns of the masonry project components, especially when compared with other similar national studies using parametric modeling and shape grammar to develop their own methods.

The theory of design science helped us to solve all doubts regarding the BOB method, especially on how to validate the experiments without performing the programming and which artifacts we could generate. As the design science showed itself as a way of validating of the submission of the artifact in all possible contexts, we performed experiments with modular size variations. The artifact may be presented as a diagram. Regarding the scientific contributions, this study presents the development of a new path for laying walls that interface as rough opening and inserting the script in the simulation tool BOB method.

The insertion of the script simulation to the BOB method helped greatly to develop more accurate diagrams due to the absence of a programmer. We recommend that in future studies that have programmers on the team by still using the BOB method for key standards. It is also recommended the application of BIM diagrams developed on a platform by the use of a plug-in.

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