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INTEGRATION OF AN ALGORITHMIC BIM APPROACH IN A TRADITIONAL ARCHITECTURE STUDIO

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Abstract. Algorithmic BIM combines BIM and Generative Design (GD), merging the potentialities of both approaches. In this paper we describe the design process of a set of parametric facades developed using Algorithmic-BIM, and how this approach was integrated into the design workflow of two architectural studios. We demonstrate how the integration of GD together with BIM influenced the whole design process and also the selection of the final solution. Some of the limitations found during the entire process are also addressed in the paper, such as tight deadlines and financial constraints. Finally, we explain the pros and cons of using this design method compared to a traditional BIM approach, and we discuss the implementation of this paradigm in a traditional design practice. This work was developed using Rosetta, an IDE for Generative Design that supports scripts using different programming languages and allows the generation and edition of 3D models in a variety of CAD and BIM applications. The result of this work is an information model of three parametric facades for a residential building, from which we can extract material quantities and construction performance tests.

Keywords. Generative design; collaborative design; CAD-BIM portability; parametric facade design.

1. Introduction

Architectural practice is being redefined by the increasing use of BIM technologies, which have been replacing CAD tools at certain design levels. BIM allows architects to represent buildings' components in their 3D models, containing not only the geometrical information, but also the corresponding constructive information. As a result, the obtained models include all the building's information, which is important for the different specialities, and also for analysis and optimization processes during the design stage (Asl et al. 2014).

On the other hand, Generative Design (GD), a design approach that creates shapes through algorithms (Terzidis 2003), has been empowering architects' creativity by allowing the generation of several solutions in a short period of time and the fabrication of highly complex projects that would be very difficult and time-consuming to produce manually (Kolarevic 2003). Initially, most GD tools were developed for CAD environments but there are already some extensions that allow the exploration of GD inside BIM tools, thus merging the potentialities of both approaches (Humppi & Österlund 2016) and allowing the emergence of a new design approach called Algorithmic BIM (A-BIM) (Feist et al. 2016).

This paper focuses on the integration of A-BIM into the design process of a traditional, BIM-based, architecture studio. To this end, we present a methodology for facade design using A-BIM and its evaluation in a real case where we collaborated with two portuguese studios (*Atelier dos Remédios* and *FOR-A architects*) that had no previous experience with GD and A-BIM.

2. Algorithmic BIM

Due to the changeable nature of architectural design (Bukhari 2011), architects require a design process that supports change. Unfortunately, traditional CAD tools require too much time and effort to modify designs and models, thus limiting the exploration of more intricate solutions. Nevertheless, recent technologies have already allowed the development and proliferation of more complex solutions, new patterns, and advanced fabrication methods (Kolarevic 2003). This includes GD, which is an approach to design that creates shapes through algorithms (Terzidis 2003). This approach requires the designer to develop an intermediate step between the idea and the design. In that step, the designer produces the algorithmic description of the intended design (Leitão 2013). It is this algorithm that, upon execution by a computer, creates the actual design.

When we combine GD with BIM-based approaches to design, a new paradigm emerges. This paradigm is named Algorithmic-Aided BIM (Humppi and Österlund 2016) or Algorithmic-Based BIM (Feist et al. 2016), and there are already some tools that support it: *Dynamo* (Autodesk 2015), *GenerativeComponents* (BentleySystems 2007), *RosettaBIM* (Feist et al. 2016; Ferreira & Leitão 2015; Lopes & Leitão 2011), *RhinoBIM* (VirtualBuildTechnologiesLLC 2015), and *Lyrebird* (LMNArchitects 2014) are examples that allow the exploration of algorithmic approaches inside BIM tools.

3. Case Study

The work developed in this paper is part of an architectural project authored by two portuguese design studios: *Atelier dos Remédios* and *FOR-A Architects*. The proposed challenge was to create a parametric facade for a residential building in Lisbon that ensured different degrees of permeability, with one important limitation: the solution had to be developed in six days. As both design studios required the final model in *Revit*, we decided to develop the design using an A-BIM approach.

The project consisted in a residential building for the urban area of Belém, in Lisbon. The intervention lot had a pre-existence that had to be maintained during the development of the new project (figure 1.A), which was then incorporated into the building's main facade, the one facing the main street.

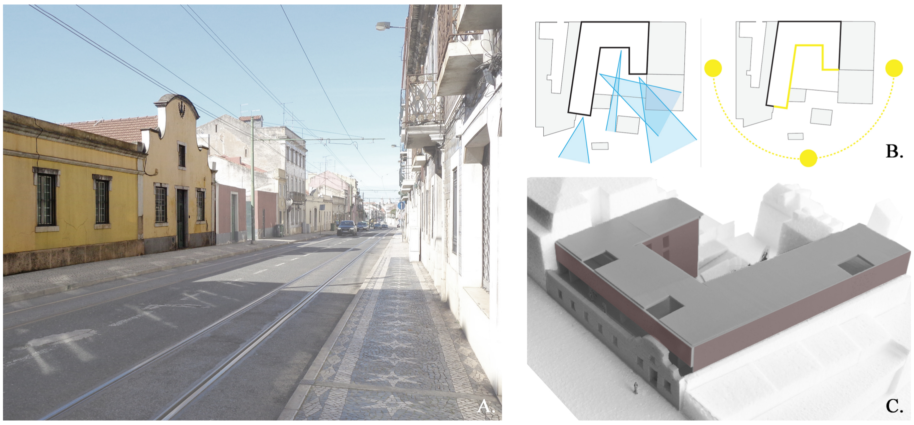

Figure 1. A - View of the intervention lot; B - Dwellings' views and natural light analysis; C - The building's physical model with the developed facades in colour.

The building had a *U* shape in plan to create a central courtyard that provided natural light and pleasant views to all the dwellings (figure 1.B).

The proposed challenge was the development of three parametric facades for the residential building (figure 1.C). The idea was to create an architectural envelope that would be more or less perforated depending on the type of function of the space associated. When the facade coincided with the dwellings' terraces it should be more permeable. When the facade corresponded to more private areas, i.e. bedrooms and kitchens, it should be less permeable or totally opaque. Initially, this concept *permeability-opacity* was left open, allowing us to explore a range of different solutions. The architects could then evaluate the proposed solutions and suggest improvements. This resulted in a dynamic design process with the direct participation and feedback of both parties.

4. Methodology

We started by implementing an algorithm that addressed the architects' idea and the information related to the project. Then, new parameters and relations between parameters were added to the algorithm in order to produce different facade patterns. Since there was no decision regarding the material to be used at this design stage, the developed solutions took advantage of different materials, such as brick, tiles, etc, creating different strategies of permeability. After analysing the range of proposed solutions, the architects decided to combine features of two designs (figure 2.A-B), using bricks of different sizes placed in order to create random protrusions and also casual voids, i.e. brick absences (figure 2.C). It is important to note that this is the type of solution that few people are willing to produce manually, especially with the existing time constraint.

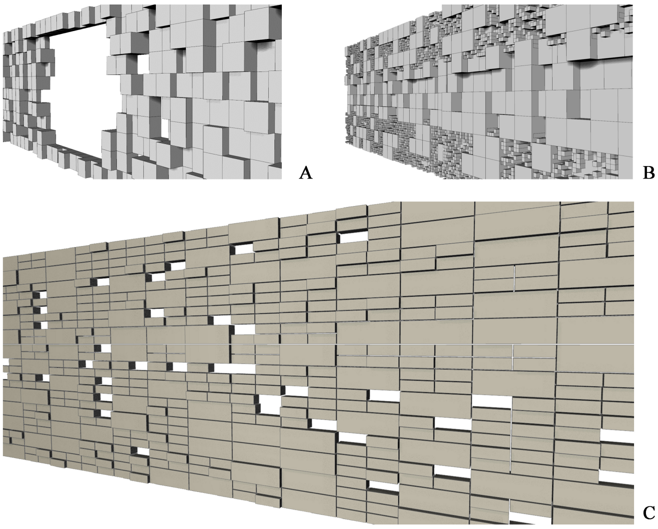

Figure 2. Some of the ideas developed at an initial design stage (A and B); C shows the obtained facade pattern at a final stage.

With the aim of achieving a higher control over the feasibility and cost of the final solution, the architects suggested a rationalization of the design, reducing the degree of variation of the final pattern. As a result, although the initial designs, exemplified in figure 2.A-B, were composed by elements with different protrusions, this variation was reduced to only two possible protrusions. Similarly, the bricks sizes were reduced to only two, wherein the bigger bricks (60x5x20cm) had four times the size of the smaller ones (30x5x10cm). Lastly, the architects decided that facade voids should only be created by the absence of small bricks. The choice between placing one large brick or four small bricks was randomly controlled, as was the creation of a void and the placement of a protruded brick.

To sum up, the architects' idea was to maintain the initial concept of randomness and irregularity, but with more restricted design variables. Figure 2.C is a conceptual representation of the pattern that was achieved after implementing all suggestions. The following stage was the generation of a more detailed model adapted to the building's dimension and to the areas with different permeability degrees.

Compared to a traditional modelling approach, one of the advantages of using an algorithmic approach is the ability to implement changes more rapidly during the design process, allowing us to obtain improved results with much less effort and time. In this case, the architects could instantaneously visualize the resulting models right after the implementation of their feedback. Similarly, it also allowed the application of increasingly small design changes in more advanced design stages, thus enabling a step-by-step improvement of the models until the architects' goals were completely reached. Figure 3 represents some of the variations that were applied to the pattern, which included (1) the balance between the placement of a large brick or a set of four small bricks, (2) the percentage of protruded bricks, and (3) the degree of the facade's permeability in certain areas, i.e. the percentage of absent bricks.

Finally, as the set of parametric facades was directly generated in *Revit*, these were easily incorporated and correctly placed in the final model. As a result, the BIM model was thus completed with the correct BIM elements/families and construction information.

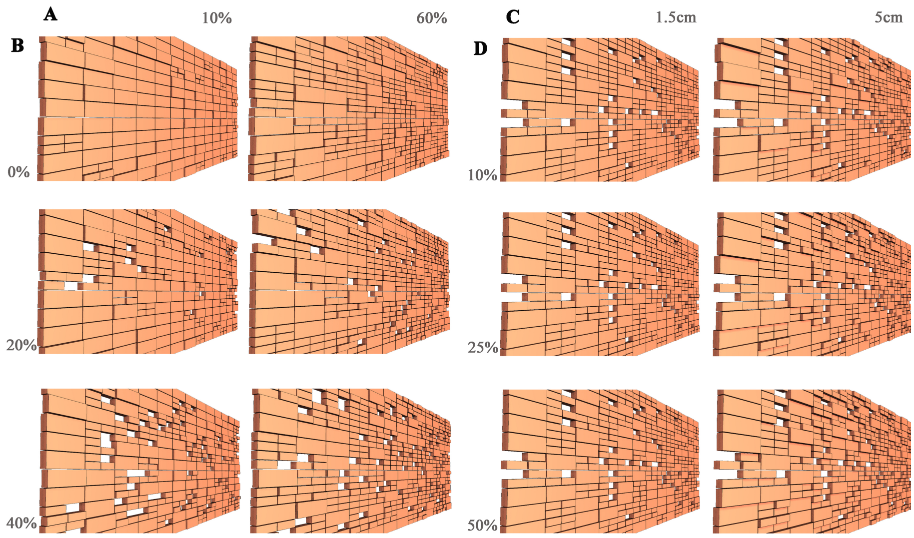

Figure 3. Design Variations: A - Percentage of four small bricks; B - Percentage of absent bricks; C - Protrusions' depth size; D - Percentage of protruded bricks.

5. CAD / BIM Portability

The work presented here was developed using *Rosetta* (Lopes & Leitão 2011). One of the advantages of this tool comes from its emphasis on portability between CAD and BIM tools. As we had only six days for the development of the facades, each of the stages described previously had to be very short. Therefore, it was important to quickly generate different design solutions. Given that CAD tools are typically more efficient than BIM tools, we took advantage of *Rosetta*'s portability to test our algorithms using *AutoCAD* or *Rhino*. When we had a design ready for evaluation by the design studios, we used the same algorithms to generate the model in the BIM tool without any extra effort (figure 4), thereby avoiding spending time redoing the model from the scratch. The resulting BIM model had the corresponding BIM families, construction information and correct dimensions to be directly incorporated in the 3D model of the whole building developed by the design studios. The only required step was to place it in its correct location (figure 5).

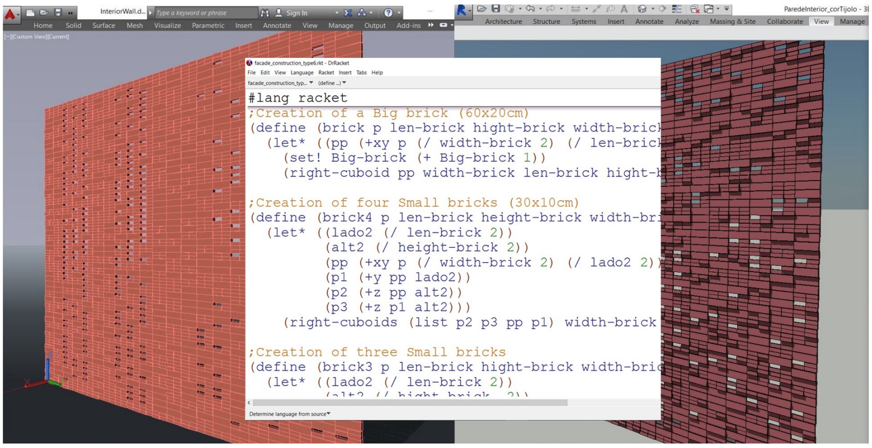

Figure 4. The visualization of two models generated in different tools with the same algorithmic program: AutoCAD on the left, Revit on the right, and Rosetta IDE at the center.

6. Manufacturing Stage

The next stage was dealing with the construction rationalization. As the budget for this project was relatively low and the availability of advanced manufacturing processes was limited, it was important to find a balance between the different manufacturing strategies in order to solve the existing constructional issues. The bricks used in this facade had a non-conventional size and so they had to be prefabricated. In order to reduce the production cost of these customized bricks, the architects had already limited the number of different brick sizes to only two. Nevertheless, one of the greatest challenges found during this stage was the placement of the bricks since several characteristics of the produced pattern were controlled by random factors: (1) The decision between placing a large brick or four small bricks; (2) The selection between two different positions for the placement of each brick; (3) The location of the facade voids.

Figure 5. Rendered views of the building's final model. On the left: view from the main street where two of the developed facades are visible; On the right: view of the building's inside courtyard with the third facade.

6.1. CONSTRUCTION RATIONALIZATION

At this stage, the first limitation found was the depth of the bricks, which was too narrow to obtain the necessary stability when stacked. In order to overcome this situation, the architects decided to double this dimension.

Another limitation was the existence of small bricks immediately above a facade void, which meant these bricks would have no support. One possible solution was regenerating the facade models with an additional constraint to only place large bricks on top of facade voids. However, this would decrease the degree of variation of the pattern. Another possible strategy was to fabricate the sets of three or four small bricks as single units. This created another challenge, which was how to fabricate the smallest number of different molds while maintaining the facade pattern complexity and randomness. Fortunately, as the back face of each unit of bricks had the front pattern inverted, we could horizontally and vertically rotate them to obtain different patterns. Figure 6 shows some of the typologies created for each unit of small bricks and their corresponding variations.

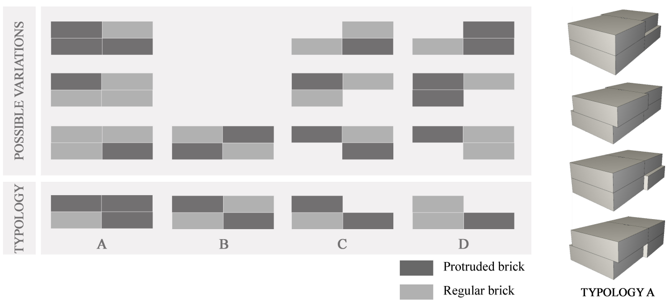

Figure 6. On the left: Four typologies developed (A-D) with the respective variations that each one produces when rotated; On the right: typology A in 3D model.

6.2. THE PLACEMENT OF THE BRICKS

For the placement of the bricks on site, we merged two approaches: the use of metal profiles to maintain the verticality of the stacked bricks and the application of angle brackets to fix the bricks to the building's wall. These elements were also algorithmically developed, which allowed us to adjust some details in order to minimize material waste and improve the facade stability and ventilation.

Our solution required the creation of four small grooves on each brick to then place the metal profiles. These would be centred and distanced according to the protrusions dimension so as to allow the placement of the bricks in two different positions: when placing a protruded brick, the below and above metal profiles fit the first grooves. Otherwise, they fit the second (figure 7.A). This process is repeated at each level of bricks and, simultaneously, some mortar is added to glue the bricks together. Additionally, in order to give stability and fix the bricks structure to the facade wall, we decided to use angle brackets to hold alternating rows of bricks (figure 7.B). The obtained solution also had the advantage of creating a thermal isolation zone between the bricks structure and the facade wall, which is visible in figure 7.C.

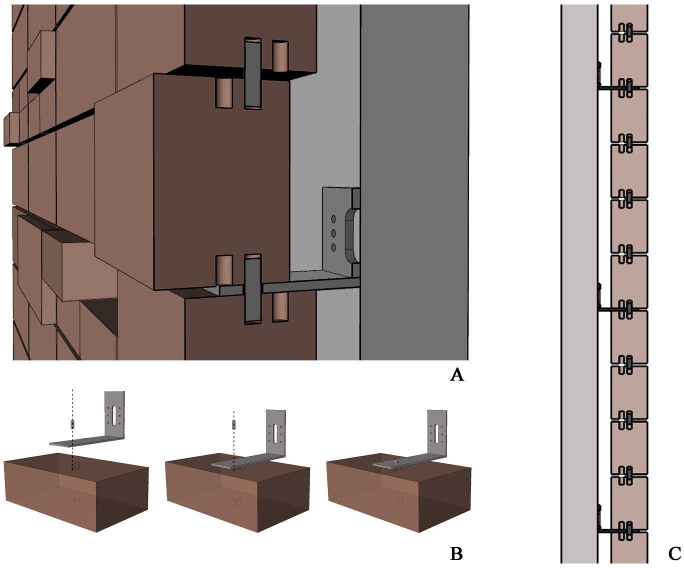

Figure 7. A - A facade section showing how the brick grooves create different brick placements; B - The fitting process of the angled brackets and metal profiles; C - A section of the facade model showing the thermal isolation zone.

For both cost estimation and the following manufacturing stage, it is important to have the list of quantities of all the facade elements. However, due to the complexity of the design, tallying is not trivial and it is difficult to get this information from tools such as *Revit*. To overcome this problem, we extended our algorithm to include the tallying process. As an example, figure 8 shows the exact quantities of each brick typology that was used.

Finally, having the 3D model of each set of moulds, metal profiles and angle brackets, and the constructive information about each element's position, material, and dimensions, the design studios can proceed with the fabrication of the required elements and with the construction of the facade.

7. Evaluation

The case study presented in this paper demonstrated how the application of the A-BIM approach in a traditional architectural studio supported the architects with a more flexible design process. Moreover, the example also showed how this approach allowed the architects to develop the desired facade solution in a very short amount of time. It is important to note that, due to the tight deadlines (six days) of this project, the use of a traditional approach might not have enabled the development of the obtained final solution. Firstly, because it would be tiresome and would take much more time due to the complex nature of the design. Secondly, the obtained model would not be flexible enough so as to allow the incorporation of design changes. The A-BIM approach allowed the incremental improvement of the obtained designs by including the architects' feedback almost immediately, thus enabling the quick visualization of new results.

Additionally, the A-BIM approach enabled the generation of the algorithmic facade model directly in *Revit*, the BIM tool used by the architects. The resulting model included the corresponding BIM information and it facilitated the exploration of the manufacturing stage. In the end, the final model was further developed in order to include several construction elements. This allowed the architects to have a model with the elements' information (i.e., dimensions, material quantities, prices, etc.) necessary for the construction stage.

Figure 8. The bricks typologies and the number of times each one appears.

8. Conclusion

Only recently were both the BIM and GD paradigms combined in the development of architectural models, allowing architects to take advantage of both approaches during the design process. In this paper, we described the design process of a set of parametric facades which were developed using A-BIM, an algorithmic-based process for BIM, and how this approach was integrated into the design workflow of traditional studios. We also demonstrated how the integration of GD together with BIM influenced the whole design process, the selection of the final facade design, and the rationalization of the design for the construction. Additionally, we addressed how we dealt with some of the limitations found during the entire process, including tight deadlines and financial constraints. Finally, we explained the pros and cons of using this design approach compared with a traditional BIM approach, and we discussed the integration of this paradigm in the traditional design practice.

This work was developed using *Rosetta*, a programming environment for Generative Design, which supports scripts written in different programming languages that can generate identical models in different CAD and BIM applications. In the paper, we also demonstrated how this capability was fundamental for speeding up the entire process, as it allowed us to experiment with designs using efficient CAD tools and, when satisfied with the results, to quickly switch to the BIM tool used by the studios.

Acknowledgements

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