Building Traditions with Digital Research

Reviewing the Brick Architecture of Raúl Hestnes Ferreira through Robotic Fabrication

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Brick construction has a strong tectonic tradition in architecture, being used both as a structural and as an expressive material. Despite several technological innovations at the composition and production level, its application still relies on talented craftsmanship, which has some natural human limitations and has becoming harder to find in the present days. To overcome this problem, robotic assembly technologies have been introduced in the field, opening new design and construction possibilities. In this context, this paper intends to examine their application but from a different perspective, by examining how they can be used to connect with the traditions in brick construction. To do so, it presents and analyses the work of Portuguese architect Raúl Hestnes Ferreira, and develops a computational design and robotic fabrication research on the topics of corner, column and dome bricks. The production of a column design at the 1:1 scale using an automated process serves to reflect on the relevance of new technologies to innovate in accordance to tradition.

Keywords: *Brick Construction, Hestnes Ferreira, Robotic Assembly, Computational Design, Digital Fabrication*

INTRODUCTION

Bricks are a man-made material, which has been used in architecture since the ancient times of the building construction history. Over time, the evolution of its composition and production possibilities, from crafts to industrial ages, never ceased to stimulate designers to explore not only their structural quality but also, their aesthetic potential. On his recent book, William Hall (2015) collects a series of notable buildings where architects creatively employed such small and regular components to achieve unique tectonic effects. More than simply *constructing* with bricks, architects can *design* with bricks, as Louis Kahn continuously referred to on his lectures and texts (Kahn and Twombly 2003).

The integration of robotic technologies

Aside with this creative intention, architects had also to devise ways to communicate and instruct workers on how to lay down the bricks. Until recently, this has always been a manual process requiring talented and dedicated craftsmanship. But in 2005, Gramazio and

Kohler (2007) started to implement robotic technologies to perform the assembly of brick structures. By recognizing the human limitations in understanding and executing intricate brick arrangements that can be easily conceived with computers, they showed how robots could be used to expand the design interests into a larger domain of geometric complexity. However, aside with this creativity-oriented approach, another technology innovation path has also been followed. The repetitive brick laying procedures when building regular structures are also an evident scenario for potential automation. That is the example of the Semi-Automated Mason (SAM) robot developed by the company Construction Robotics (Petters and Belden 2014), which claims to achieve a high level of productivity. What is interesting to observe is the fact that robots are being explored as a solution for both standard (i.e. repetitive) and non-standard (i.e. variable) design scenarios.

Rethinking traditions

When new technologies can open new design and construction opportunities, it becomes also important to examine the way they can contribute to rethink, or update, architectural traditions. In this discipline, technology is not an end but a mean, and only by working in both research directions it is possible to understand the whole spectrum of its disciplinary impact. The work on the Palladian Grammar by Stiny and Mitchell (1978), the Malagueira houses by Duarte (2001), or the recent one on the Alberti's treatise by Kruger (2015), are just a few examples of such interest in using digital technologies to revise traditions. But perhaps the most brilliant applied work at this level has been the one conducted by Mark Burry in the extension works at the Sagrada Familia in Barcelona, where both digital design and fabrication tools have been orchestrated to understand and continue the legacy of Antoni Gaudí in the present days.

The paper

Following this last trend, this paper summarizes and extends a Master Thesis (Oliveira 2015), which was developed in the scope of a larger research project on robotic technologies (Sousa 2015), and introduces the work of Raúl Hestnes Ferreira, who is a renowned Portuguese architect who mastered the use of bricks in his buildings. By studying his work, it describes a research on using computational design and robotic technologies to review and extend his design interest on brickwork. By preparing and discussing the experience with the architect himself, it was possible to reflect and validate better the relevance of using such advanced technologies in the current days. Aside with this goal, this paper also presents a fully automated system for robotic brick assembly, which is also another contribution to the field.

THE BRICK ARCHITECTURE OF RAÚL HESTNES FERREIRA

Raúl Hestnes Ferreira (b. 1931) is a preeminent figure of Portuguese contemporary architecture, especially in the second half of the 20th century. His very unique style was marked by a strong concern with the building details (Neves 2002). This interest derivates from the influence of a life experience in the United States in the 60's, where he post-graduated at the University of Pennsylvania and worked for Louis Khan, and the personal search for incorporating European values. His built work exhibits elementary composition methods, based on symmetry, axiality, proportion, basic shapes and historical values, as an architectural alternative to Modernism (Tavares 2003). By carefully realizing the physical properties and limitations of the materials, Raul Hestnes Ferreira looks for taking the most out of their design potential. This tectonic approach is noticeable on his brick buildings where, aside with the influence from Kahn, he invokes and reinvents the traditional Portuguese architecture (Tavares 2003).

Two reference brick buildings

Among the brick buildings designed by Raúl Hestnes Ferreira, the Municipal Library in Moita (1986-1997) and the House of Culture in Beja (1975-1985) were selected as case studies for this research work (Figure 1). In both buildings, the structural and expressive potential of bricks were carefully intertwined. In the Municipal Library, Hestnes Ferreira employed the material in several interior and exterior applications. In specific wall corners and columns the architect carefully designed the brickwork to deploy original material effects. In the House of Culture, Hestnes Ferreira employed bricks in the construction of domes as a reference to the traditional brick vault structures that can be found in the region. Due the necessity of defining a thicker base in the domes to support their own weight, the architect conceived specific brickwork with some elements placed perpendicular to their surface. The structural imposition was thus managed in favor of the tectonic expression that can be visible in the interior.

Motivations for digital research

The work of Hestnes Ferreira provides a rich demonstration of a tectonic approach to brick construction. Thinking in regular patterns and using hand drawing, he found the way to translate his design intentions and prescribe the corresponding rules for laying the

Figure 1
Brickwork details of a column and a corner in the Municipal Library building in Moita (top). One of the domes in the House of Culture in Beja and the detail of its brickwork, which was specifically designed for structural purposes (bottom).

bricks. By then, it would be very difficult to explore more intricate arrangements with the existing representational tools. Furthermore, on the construction side, he started to become concerned with finding talented craftsmanship to assure the production of more complex brickwork structures, like the domes in the House of Culture (Ferreira 2002). Thus, with the digital technologies available today, it seemed opportune to investigate how:

- Computational design tools can support architects in the tectonic exploration of brick structures, by expanding the design space of geometric possibilities;
- Robotic assembly processes can provide an efficient mean to assure complex traditional or novel brick constructions in a moment of scarce skilled labor.

THE DIGITAL RESEARCH

The digital research process unfolded in two sequential steps: a computational design exploration followed by a robotic fabrication experiment.

Computational design research

This work started by looking for the main brickwork themes found in the reference buildings described before: the *corner*, the *column* and the *dome*. By capturing the design intention presented on the existing constructions, the authors developed a computational design exploration using the software Rhinoceros and the Grasshopper plugin (Figure 2).

Supported by conversations with the architect (Oliveira 2015), the methodology followed the initial codification of the geometric rules, the parametric generation of alternative solutions, and finally, their formal verification through the production of 3D printed models using FDM technology. This digital-to-material continuity was essential to examine the

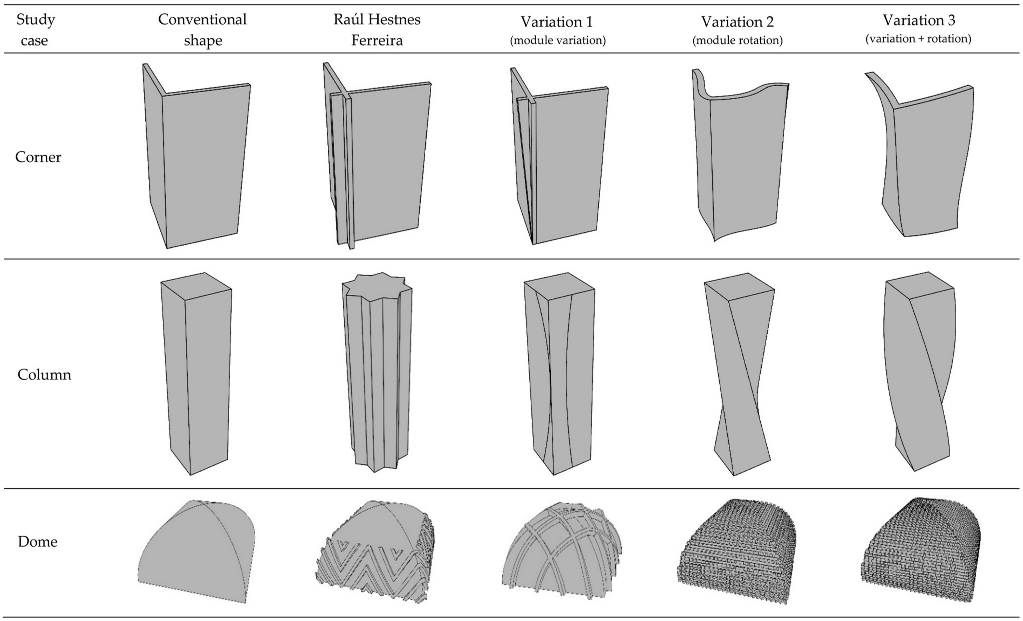

Figure 2
Summary of the computational design exploration developed on brick corners, columns and domes.

tectonic quality of the many different generated solutions to study the corner, column and dome situations (Figure 3).

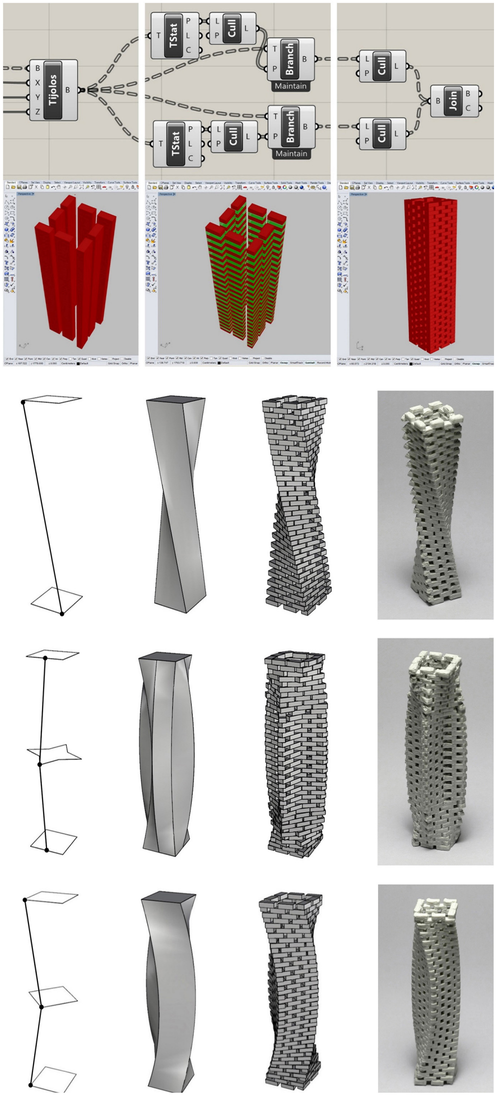

Figure 3
The parametric exploration of column designs using 3D printed models to evaluate each solution. The same procedures were followed to explore corner and dome designs.

Robotic fabrication research

The results of the computational design research were presented to Raúl Hestnes Ferreira who acknowledged the relevance of using such methods to operate with rule-based design interests. Furthermore the 3D printed models proved to be an efficient way to communicate and evaluate non-regular brick structures. Facing such information, the architect was invited to select one of the digitally generated solutions to be robotically fabricated at 1:1 scale. Attracted by the rhythm of its torsion and subtle variable openings, his selection fell on a twisted column design (i.e., the column in the bottom of Figure 3). On his words, "*it has a certain complexity in which what one sees from one side is not exactly the same of what is seen from another side. This piece is very beautiful and variable (...) I find it simple and complex. It's a good work.*" (Oliveira 2015). For this reason, this structure was named as the "Hestnes" column. A quick initial experiment trying to manually assemble ceramic bricks, made clear the difficulty in materializing its variable geometry conventional means (Figure 4).

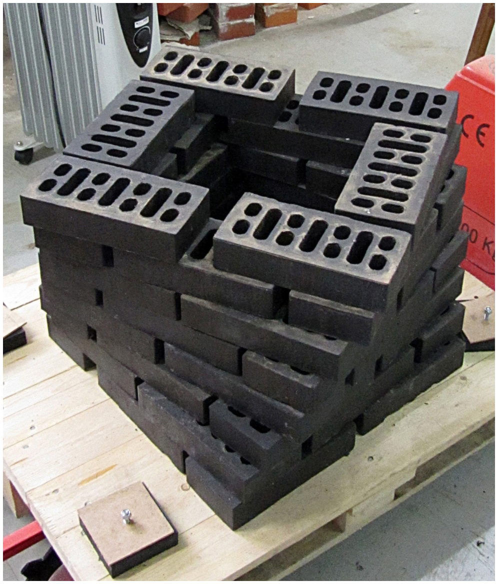

Figure 4
Manual assembly experiment of part of the Hestnes Column to realize the degree of complexity of its geometry.

Thus, the development of a robotic assembly research became relevant to test the physical production of the Hestnes column. This research part was run in the Digital Fabrication Laboratory (DFL) at the Faculty of Architecture of the University of Porto (FAUP), using a large size KUKA robot equipped with a vacuum gripper mounted on it. Due to the lack of equipment in the laboratory to carry heavy weights, the ceramic bricks were replaced by the use of EPS ones, cut in the real size (i.e. 200x120x50mm). The rest of the fabrication setup included a long tray to feed the bricks for the picking operations and a wooden base in the ground for placing them. To allow for a complete automated assembly process, an original system for spraying glue was devised and installed between the feeding tray and the assembly base. All fabrication instructions were defined using the KUKA|prc plugin for Grasshopper, which converted the movement trajectories and speeds, and the on/off activation of the tools (i.e. gripper and glue spray) in the KRL language of the robot (Figure 5).

The robotic fabrication of the column unfolded in two experiments. The first one explored a semi-automated process. After laying one level of bricks, the robot was paused to allow the manual deposition of glue on the top of the bricks, before running the pick and place operation of the next upper level. This was done in a first moment when the glue spray system was not yet available. The second experiment took advantage of the fully automated system, which consisted in the recursively doing the following steps, until finish the desired construction (Figure 6):

- pick the brick in the tray by turning the vacuum on;
- move it inside of the box and wait for 1 second to be sprayed with glue from below;
- move outside of the box and place the brick in the specific position over the base by turning the vacuum off.

With its 246 bricks and 2.10 meters height, the Hestnes column took 52 minutes to be assembled in the semi-automated process, and 57 minutes in the fully automated process, running at 75% of the maximum speed (Figure 7). Despite this minimal time difference, the second test avoided the pause for man-

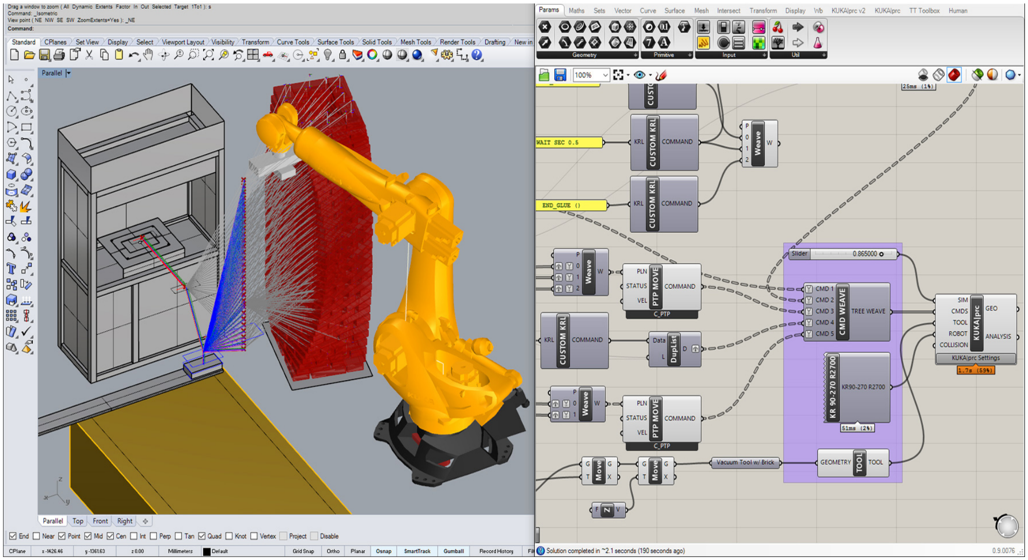

Figure 5
The digital parametric design environment that supported the design and robotic fabrication of the Hestnes column. It is possible to see the preview of all pick and place trajectories with a stopping moment inside the glue spraying machine.

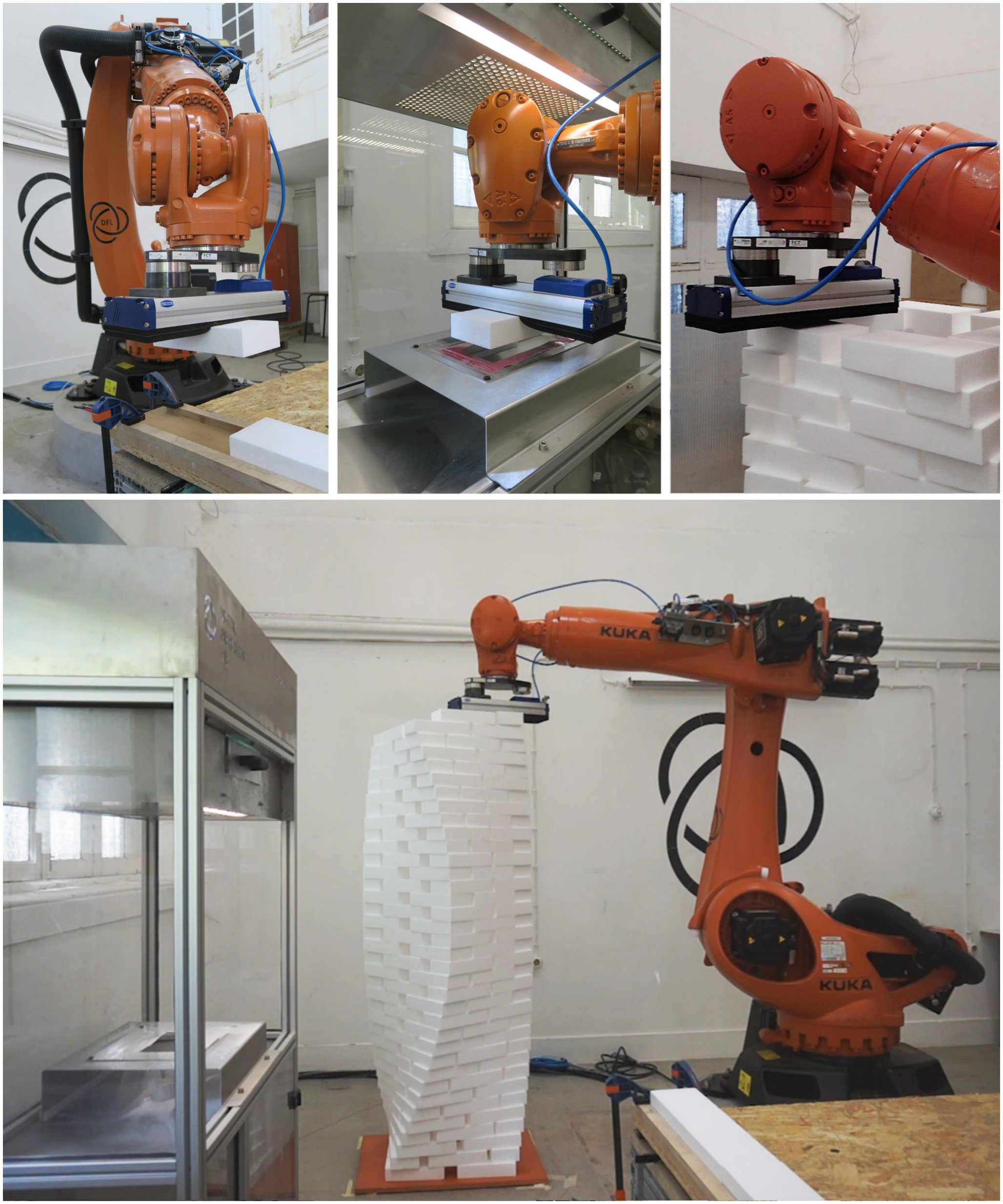

Figure 6
The key moments of each robotic assembly movement: picking the brick from the feeding tray, gluing its bottom surface in the spraying machine, and placing the brick on its specific position in the assembly (top row). The column near completion in the setup at the DFL, with the glue spraying machine on the left.

ual intervention, which made it a safer and human fatigue-free process. Although this was the only solution that was materialized, it was possible to realize that any other design variation would require a similar time to be built by the robot, since it has the same amount of bricks.

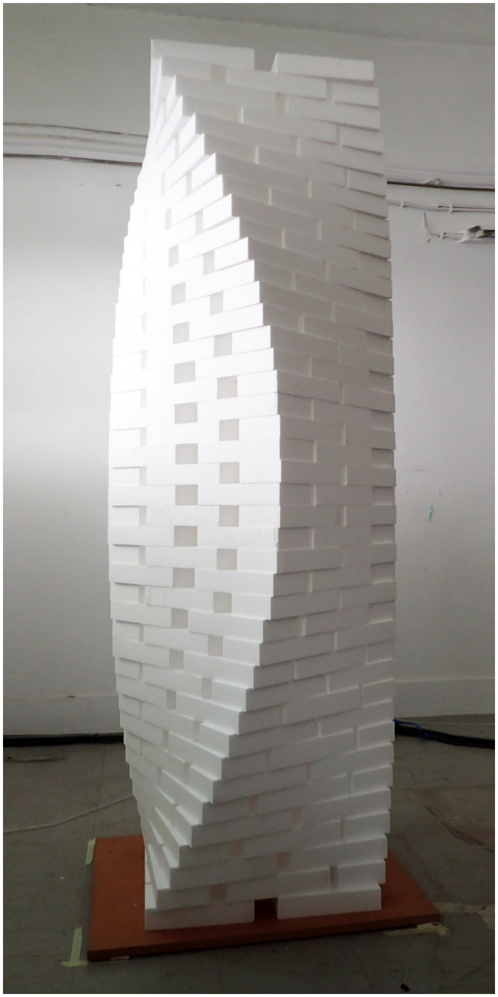

Figure 7
Photo of the robotically fabricated Hestnes Column.

CONCLUSION

The research work presented in this paper explored the possibility to employ robotic fabrication processes to revise the traditions of brick architecture. To do so, the authors studied the built work of Portuguese architect Hestnes Ferreira, and discussed with him the tectonic interests that guided his brickwork designs.

By using computational design tools, it was possible to encode the rules of the existing solutions and generate new alternatives with a higher degree of geometric complexity. Without the use such digital processes, architects would have limited representation means to think, evaluate and describe certain tectonic solutions. In continuity with building traditions, the computational design research revealed the potential of such technologies in expanding the creative space of design exploration in the present times. Facing the design possibilities allowed by computational design, the lack of talented craftsmanship opens the door for using robotic technologies for brick assembly purposes. In the past, Hestnes Ferreira described and told the workers the simple rules they had to follow to build the expressive effects of his brick details. In a similar fashion, the architect can now assure their design intention by dictating the assembly rules to the robot with the help of digital programming. Like in the domes of Casa da Cultura, brickwork design is not only essential for serving aesthetic purposes but also for achieving structural efficiency. Thus, brick construction nowadays can benefit from the use of computational design processes to define customised brickwork arrangements for more complex structural challenges.

Moving to a more generic level, the research work demonstrates how the articulation of digital design and fabrication technologies can support an exceptional design freedom without loss the control of its materialization. Recalling the 50 minutes that took to fabricate the Hestnes Column, one can imagine the significant number of columns that could be robotically built in a single day, independently of their geometric complexity or variation. The use of robotic assembly technology seems thus very appropriate to suit prefabrication production logics. In the construction site, and despite some advancements like the SAM robot mentioned before, it still seems difficult to be able to explore the flexibility of operations that can take occur within the controlled and safe environment of the factory.

Drawing from the experience described in this paper, future research would look to adjust the laboratory conditions to use real ceramic bricks. Although this objective does not imply any substantial change in the actual process, different glue will have to be incorporated in the system. At the same time, a sensor for measuring the structure during its assembly should be also considered to allow real-time adjustment of the robotic operations. This research avenue is a very important one, especially when dealing with larger structures where the accumulation of small deviations that are not anticipated in the computer (e.g. brick size variations, structural deflection, glue thickness) can become critical in the building process.

ACKNOWLEDGMENTS

The work presented was co-financed by the European Regional Development Fund (ERDF) through the COMPETE 2020 - Operational Programme Competitiveness and Internationalization (POCI) and national funds by the FCT under the POCI-01-0145-FEDER-007744 project, and the previous PTDC/ATP-AQI/5124/2012 research project. The authors are also greatful to industrial partner Cerâmica Vle da Gândara and to architect Raúl Hestnes Ferreira.

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