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Masonry construction with drones

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Abstract

This paper presents new research in the area of construction of building-scale structures using unmanned aerial vehicles, commonly called drones. The work follows up on a previous paper presented at the 2015 IASS Symposium by Latteur et al. [1], which focused on the feasibility of drone-based construction systems with an emphasis on localization systems and building system units. Since then, the project has continued with a focus on masonry block structures, with new developments in block design, computational modelling and design tools for drone-built structures, and tests with a custom-built 40-kg payload quadracopter drone.

Keywords: droxel, drick, drone, masonry, digital fabrication, robotic fabrication, additive manufacturing, unmanned aerial vehicles.

1. Introduction

A few revolutions have marked the way human beings have built large-scale structures since the 16th century [2]:

- Scientific Revolutions, catalyzed in the 16th century by Galileo who was the first to develop the strength of materials;
- Social revolutions that have allowed workers to enjoy decent working conditions, even if it is still not the case in many areas of the globe;
- Industrial revolutions, including the advent of steel in the 19th century, the systematic use of reinforced concrete or the impressive developments in technology of construction machinery in the 20th century;
- Certificative revolutions (Eurocodes, iso certification, eurocodes, ...) guaranteeing a good quality of the construction materials, of the design processes and of the execution;
- Computer revolutions, that have completely changed the way architects and engineers work;
- The development of parametric design tools and Building Information Management/Modelling (BIM), probably the last revolution underway today.

Despite all these revolutions, the profitability of construction projects remains uncertain due to many factors: cost of security, human factors, bad weather conditions, lack of communication between stakeholders, lack of skilled labor, accidents etc ... all these factors being responsible for an additional cost that can reach up to 10% of the global cost of the building. However, the introduction of robots on construction sites should address this.

The industry has known for some years a revolution linked to the development of 3D printers that can produce complex and precise mechanical parts. This technology is currently implemented in the field of construction, where experimental 3D printers are attempting to construct buildings in full size. This way of building is nevertheless limited by the size, since the printer itself becomes a larger building than what it builds, which is a disadvantage.

This observation leads us to consider a coming revolution: the "robonumerization" of the construction. It should significantly increase the speed and profitability of construction project, linking BIM models to a swarm of perfectly coordinated robots that would build structures on a fully automated process.

This research project aims at developing new construction processes using flying robots (more commonly called drones, UAVs (Unmanned Aerial Vehicle) UAS (Unmanned Aerial System)).

2. First tests with a custom built big drone

This chapter is a summary of a more detailed and very recent paper [3].

2.1. Characteristics of the drone used for the tests

The drone is a quadracopter X8 equipped with eight 2-kW motors each powered by two batteries 6s Lipo 22V/22Ah, with propellers of thirty inches. It weighs about 12 kg empty for a maximum payload of 40 kg and has a battery life of about one hour unloaded (knowing that the autonomy of LiPo batteries depends strongly on temperature). Its overall dimensions are given in Figure 1.

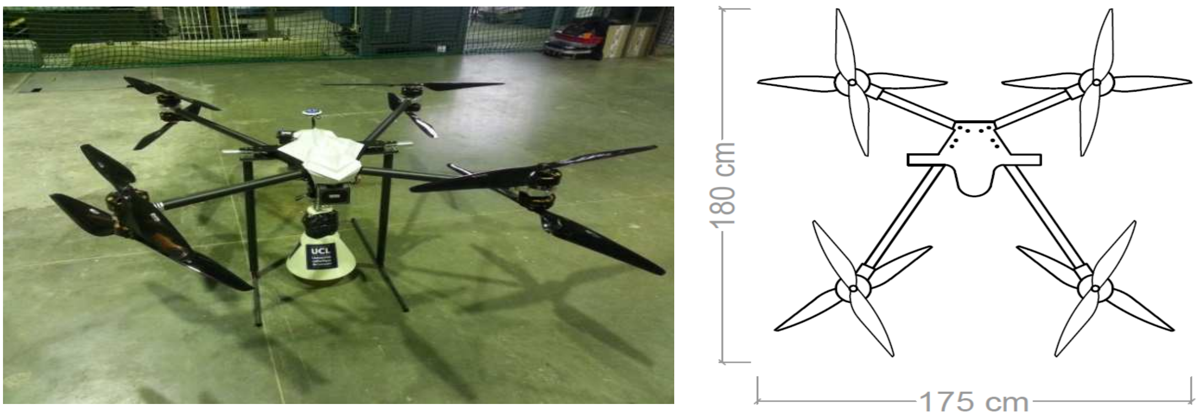

Figure 1: Photo and dimensions of the custom built drone used for the tests

2.2. First tests: the “Greek column”

Many factors impact the position accuracy and stability of a drone:

- The type of environment (indoor / outdoor);
- The neighborhood of elements that can disrupt UAV sensors (for instance, metal masses disturb the compass);
- The positioning system type;
- Weather conditions (wind gusts, temperature, etc.);
- The type of UAV used and the tools that equip it.

For the first experimental tests, stackable cylindrical concrete blocks of 15 kg to 20 kg were designed in order to build a column at real scale. The dimensions of the blocks are given in Figure 2 and they allow a dropping position inaccuracy of 6,5 cm around the vertical axis of symmetry of the block.

The drone is equipped with a 3D printed guide cone provided with an electromagnet, enabling it to grip and move blocks, thanks to a metallic plate situated at the top of the blocs (Figures 2 and 3). A device placed between the cone and the top of the bloc is able to evaluate the suspended load and to ensure an automatic dropping of the block.

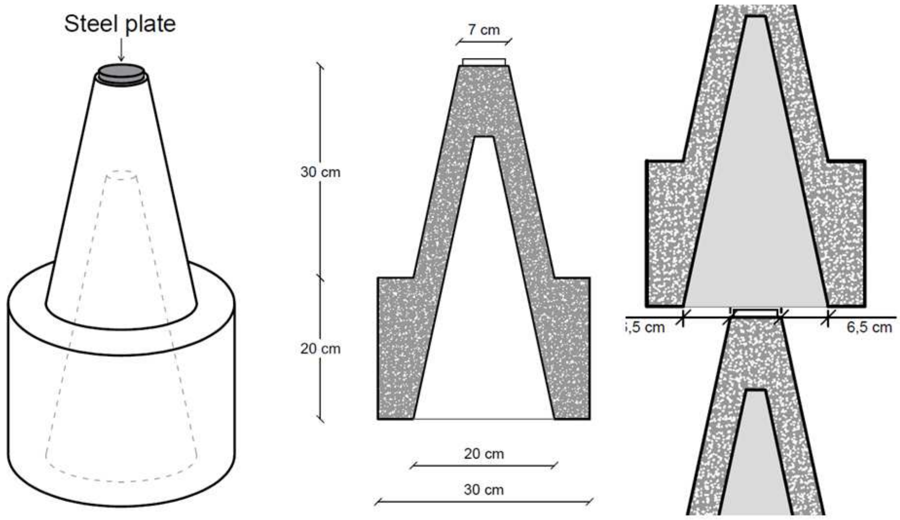

Figure 2: Drone compatible" circular concrete blocks used for the first tests

Figure 3: Construction of a column made out of concrete precast elements at the "Drone Zone" of the UCL

The tests of figure 3 were carried out at the "Drone Zone" of the UCL, with an operator who was piloting the drone. The pilot was able to easily take the blocks with the drone and to stack them on the top of each other (Figure 3). It can therefore be noted that the position inaccuracy of 6,5 cm allowed by the blocks (Figure 2) is sufficient for indoor building. For an automatic flight controlled by an electronic guiding system, being developed now by the authors and collaborators, one can expect a better accuracy, less than 5cm, although this needs to be confirmed in outdoor tests.

The tests confirmed that:

- The suspension and transporting of masses of tens of kg while maintaining a very stable drone is possible;
- The dropping and the quick stacking of the concrete blocks with a position inaccuracy of about 5 cm is possible, despite a manual piloting.

3. Other types of drone compatible masonry

3.1. The dricks

This section shows a few results from a master thesis on the subject of drone-compatible masonry units [4]. Drick is a portmanteau of “drone” and “brick”. The first indoor tests with the big drone piloted by an operator led to the conclusion that the dricks have to de shaped in such way that they allow a position inaccuracy of the drone limited to 5 cm. Moreover, their design must include consideration linked to the possibility of making walls with corners, as shown in figure 4. In particular, a first drick in place must not impede the arriving ones.

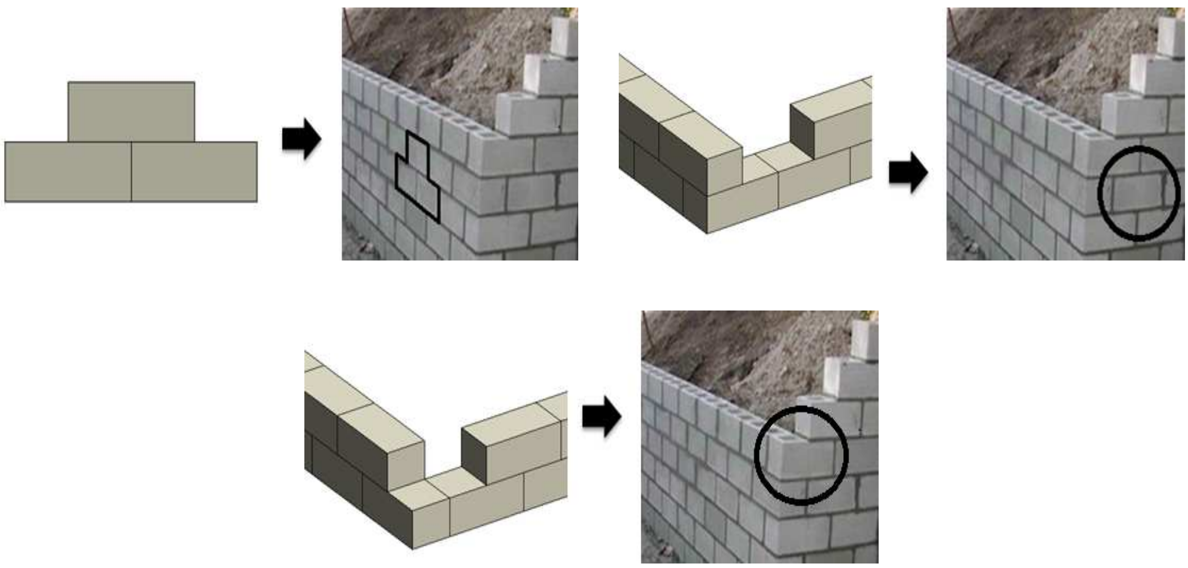

Figure 4: a few aspects of classical masonry

Furthermore, blocks should weigh less than 30kg (but more could be possible in the future, with the use of bigger drones) and should have some bearing capacity and stability properties similar to classical masonry blocks.

For this research, many geometries of dricks were tested, first with 2D models (Figure 5) and then with 3D models (figure 6).

The result of this study is the “Drick 60” showed in figure 7, which shows the best structural behavior and the best solution to the “drone compatible” requirements. The “Drick 60” was tested at real scale (figure 7) with a dropping system suspended to a crane, but tests with the big drone remain for future work.

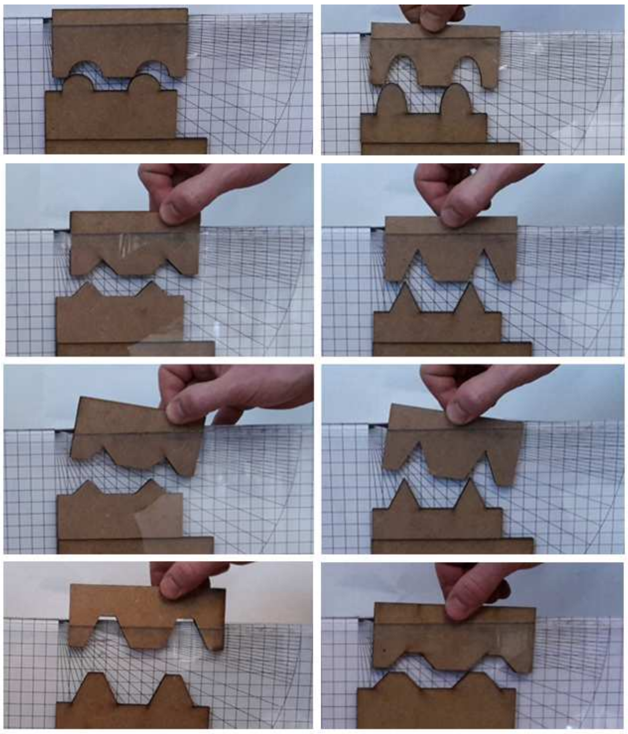

Figure 5: 2D models and search of the best drick geometry

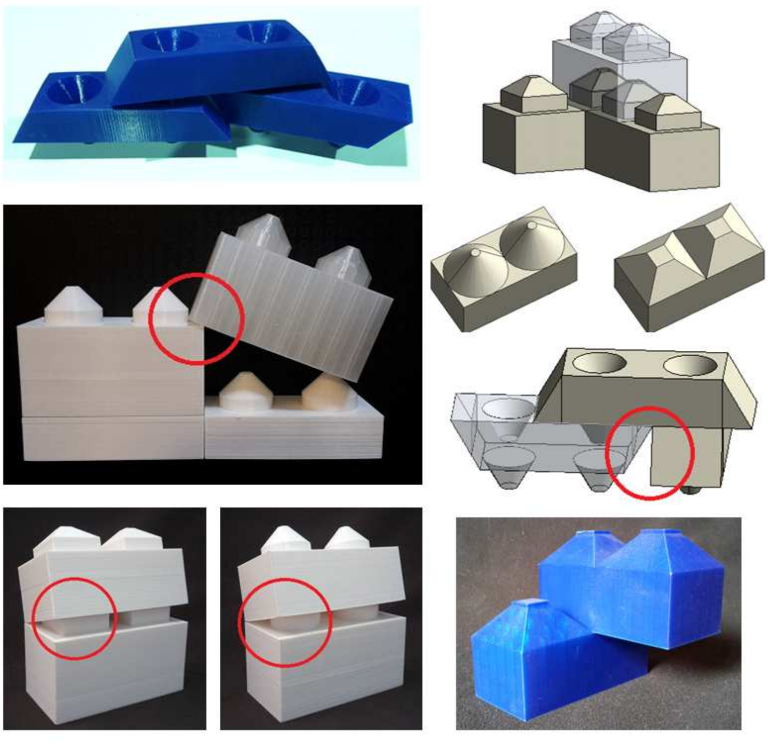

Figure 6: A few examples of the 3D printed samples for the research of the best drick geometry

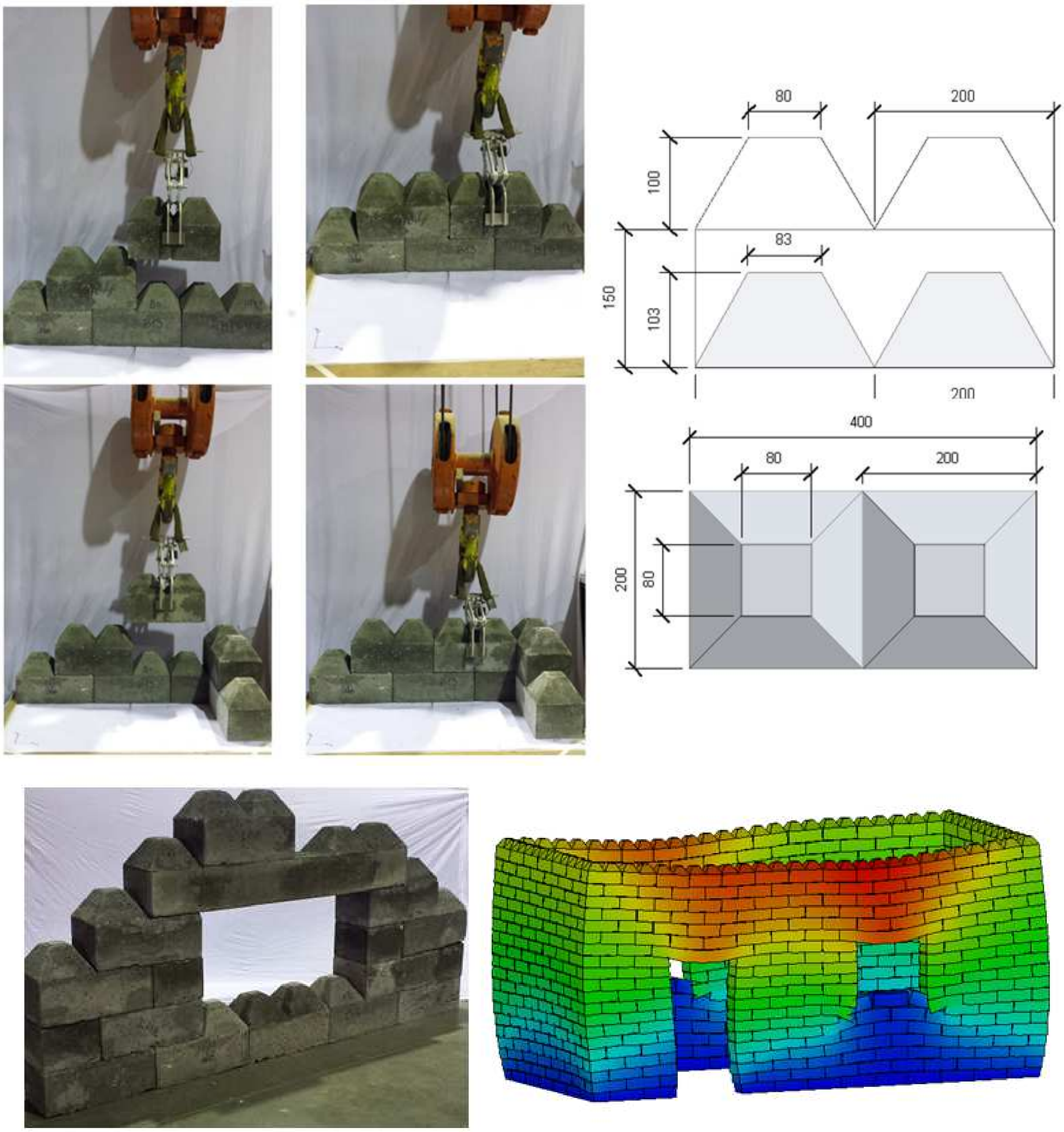

Figure 7: The “Drick60’, the best “drone compatible” masonry among the tested ones. Below left: a real scale wall. Below right: a Solidwork simulation on a small structure made out of Dricks60.

However, the weakness of the Drick60 remains in its thin sides that end up in edges at its bottom. Indeed, during compression tests it appeared that the bottom sides are easily ripped off. This is an issue for large scale production of dricks as we can’t produce them straight on their edges. Solutions exist (e.g. using a better concrete, placing reinforcement bars, etc.) but it complicates the process. Figure 8 shows another kind of drick which does not have this limitation, but this adjustment requires five types of dricks: two types for the walls and three additional types for the corners. The tops of the cones allow the placement of a metallic plate for the use of an electromagnetic handler (Figure 8).

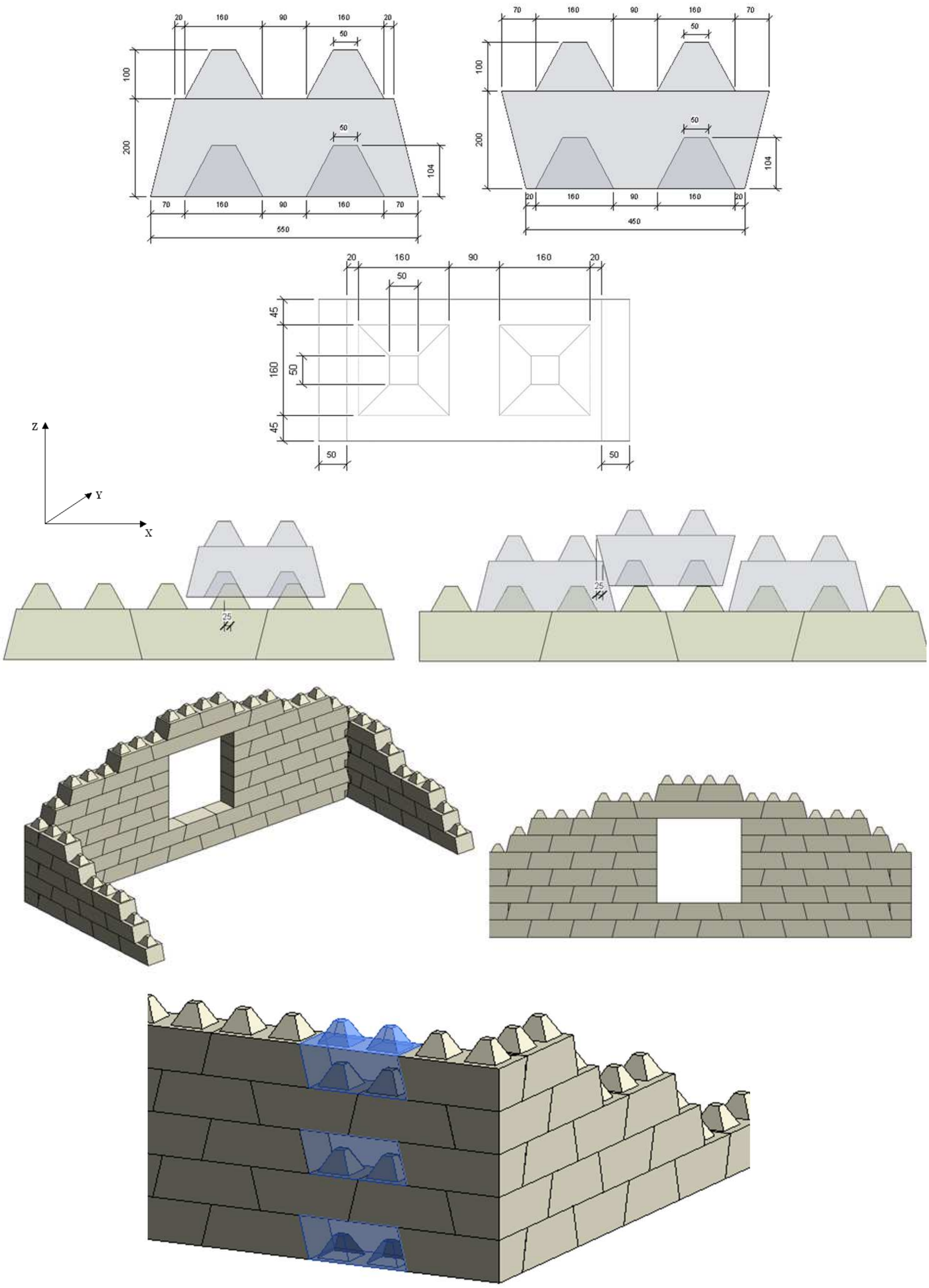

Figure 8: The “drick 60i’, which does not have the limitation of the drick60 (ending up with fragile edges at the bottom), but nevertheless necessitating a more complex formwork. The M-shaped dricks are guided both in x- and y-axis by the plots and the W-shaped dricks are guided in the x-axis by the plots and in the y-axis by the slopes.

3.2. The droxels

Droxel is a portmanteau of “drone” and “voxel”. The concept has already been presented in [1], and then experimentally confirmed at real scale with concrete samples (figure 9). Droxels is not made for walls for which dricks are more relevant, but they can however be very useful to create complex 3D structures, allowing cantilever (figure 10).

Figure 9: lab tests with real scale concrete droxels

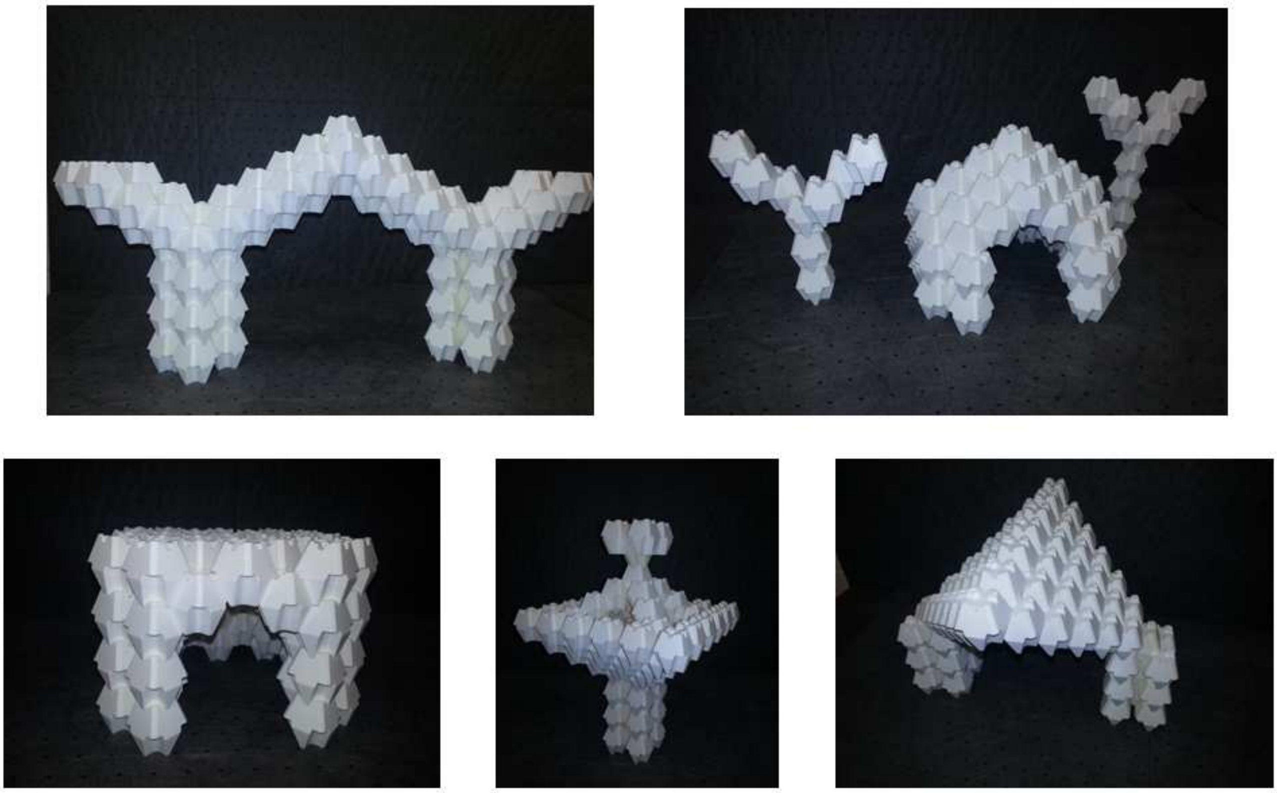

Figure 10: drone compatible droxels allow to build very complex architectural forms.

4. Software for the design of drone compatible masonry

This section is a very short summary of a master thesis on the subject [5]. Software *Dronicks* was developed (figures 11 and 12) to allow the fast and user friendly design of simple masonry buildings made out of dricks of type drick60, and to translate it into drone flight instructions for a fully automated construction.

The solution implemented uses WebGL for rendering 3D graphics. It integrates the estimated construction time (based on first tests described in section 2) and optimizes the assembly paths.

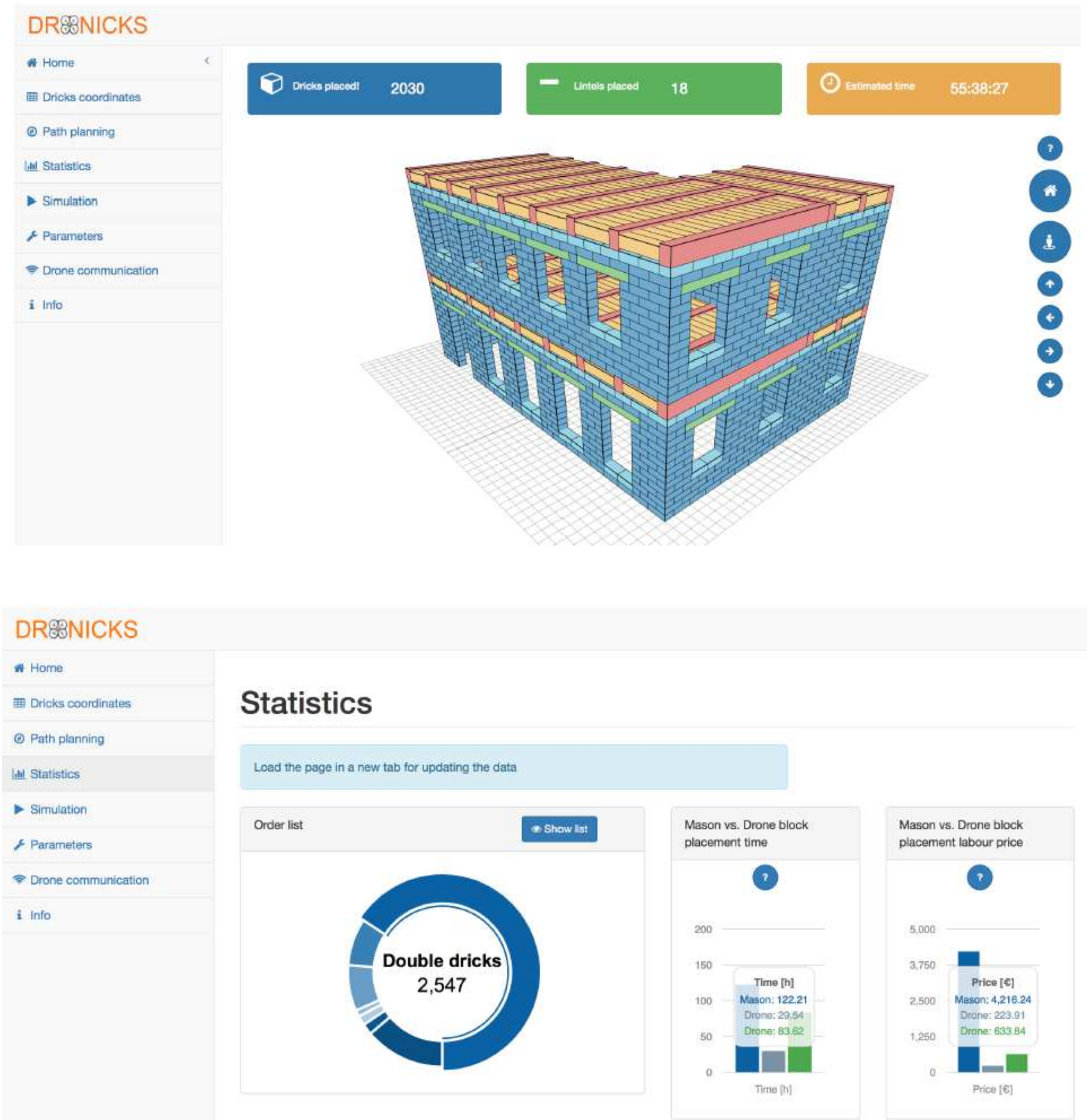

Figure 11: Software "Dronicks" for the user friendly design of masonry structures automated build buy drones. The software can give an output file which is the translation of the building into drone flight instructions.

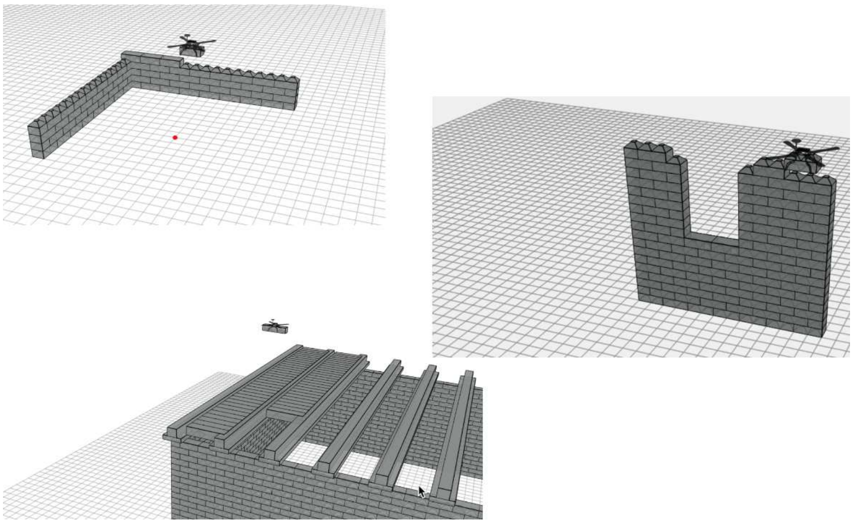

Figure 12: Simulations with software "Dronicks"

5. Conclusion

This paper shows the very first practical results of a recently initiated research collaboration between the UCL and MIT. Testing a big drone to carry masses of tens of kilograms to build a concrete column was an experience full of lessons that confirmed the feasibility of the concept. Further research directions and developments are now led in several directions: automatic guiding of the drone linked with BIM models, customization of the drone for more precise movements and development of the drone compatible timber building. All these researches will be presented in future papers.

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