Draft Reflection Paper

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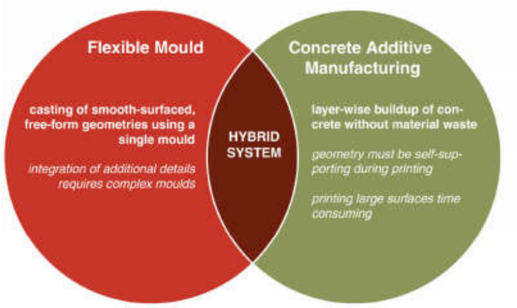
Introduction

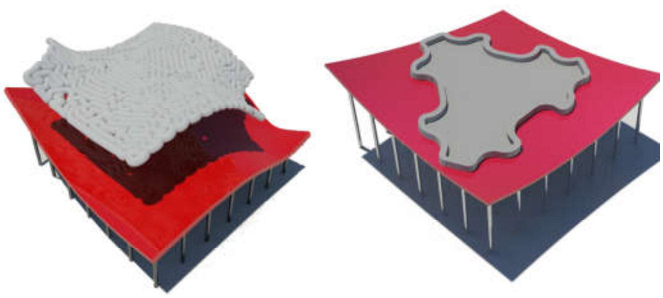
My graduation topic is the study of combining two relatively new, yet previously distinct manufacturing processes. The idea of combining concrete additive manufacturing with an adjustable moulding system was sparked off during the IASS 2015 future visions conference; where papers on concrete additive manufacturing, robotic fabrication and flexible moulding were presented (amongst others). It was at this time that the potential of combining the two techniques became apparent, as certain limitations of concrete additive manufacturing could be solved by an adjustable mould and vice-versa. My final aim is to setup an interface between a robotically-controlled concrete printer and flexible mould which will be used to produce a number of prototypes.



The thesis was always one which was speculative – one which had no definite answer whether the combination of the two manufacturing technique made sense and, if so, in which contexts. This meant that it was both an exciting and challenging process, but also one where it was quite easy to get lost in oneself.

Method and Process

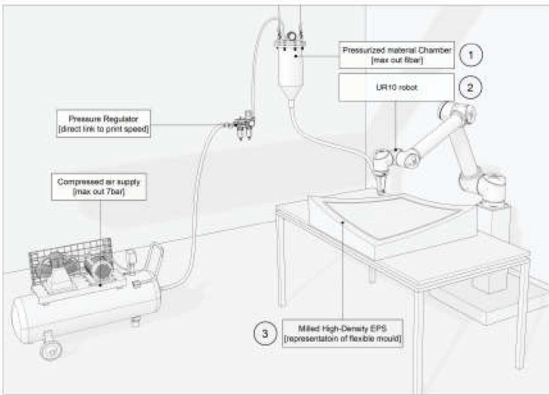
The first phase of my graduation studio was aimed at fully understanding the current systems of concrete additive manufacturing and the flexible moulding system. In parallel, other fabrication techniques which are also used in the context of free-form concrete fabrication were analysed and compared. This was done so as to judge whether the combination of the two fabrication techniques did in fact exhibit potential. From this initial study, I was able to identify a number of potential areas where this combination might be beneficial.



Part of this early study also included the manufacturing of rudimentary prototypes for what would eventually become attachments for a robotically-controlled 3d printer. This was primarily done in order to understand the desired and rather unique material properties which are needed for concrete additive manufacturing as well as the driving systems – as concrete additive manufacturing is a relatively new subject which is rapidly growing, technical literature on set-ups tends to be scarce. These early tests served as the basis for the later phase of my thesis, which involved setting up a full-scale robotically-driven printer.

The second phase of the thesis was the designing of a concrete end-effector which could be incorporated with a UR10 Robot arm, designing of the work-flow for the robot to detect a free-form surface representing a flexible mould and printing onto it. The greatest challenges were the calibrating of the robotic arm to be suitable for 3d printing. Such machinery was not designed with 3d printing in mind, but rather for point-to-point applications, such as spot welding or moving objects from one area to another. Additive manufacturing, however, requires a very smooth and accurate movement along a line, rather than between points.

This setup was assembled at the Digital Design Unit at TU Darmstadt, as this is where the required 6-axis robot arms were located. The setup, schematically shown below, was used to calibrate the robot to be capable of smoothly extruding cementitious material, a process which took around 4 weeks.



Once an interface was setup, where a digital model could be directly linked to the robotic arm and sent for printing, a number of physical prototypes were manufactured. In parallel to this thesis, a separate 3TU study was also undertaken on a large scale and using a gantry-robot rather than a articulated arm and was used to produce 1000x1000mm prototypes.

Relationship between research and design

Throughout this study, there was a strong relationship between research and design. Early design ideas were speculative, based on desk studies and brain-storming sessions. As research into the various topics increased (particularly, concrete printing and robotic control) new ideas for designs were formed whilst old ones were either improved upon or discarded. One such example of this relationship was the fact that, due to the *limitations* in movement of the robot arm, it is in fact extremely difficult to produce 90 Degree corners using the setup. While this meant that a whole class of geometry was no longer feasible to study, the same limitation allowed for the conceptualisation of far more free-form shapes.

While throughout the thesis a number of potential applications were envisaged, the study remained focused on the printing two types of geometries.

The first geometry type is a fully-printed panel. Traditionally, additive manufacturing is a layer-wise approach, however, using an adaptable mould as a temporary support a new method for printing was developed based off differential growth.

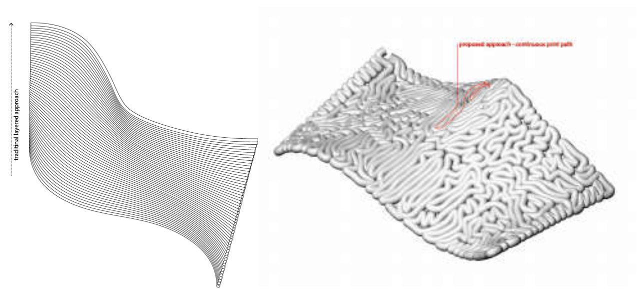
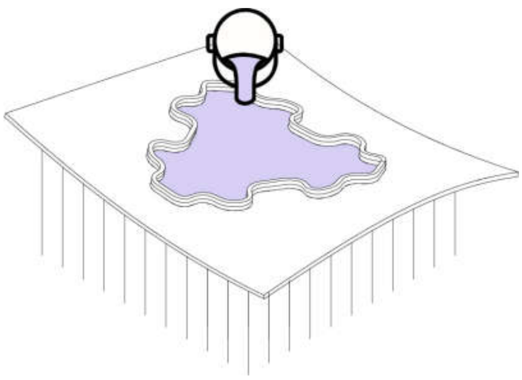


Figure 1[left] traditional layerwise printing approach. [right] printing pattern based off a differential growth algorithm

The second geometry set was one where a complex pattern is printed ontop of the temporary surface. This printed material then served as formwork where material is cast to allow for the fabrication of complex, free-form concrete panels.



The thesis was then concluded by providing a roadmap of the recommended areas of further development for future research.

Graduation in the wider social context.

I feel that the graduation project is, primarily, about a wider context: it as known from an early phase of the study that it will not serve as an open-closed research, rather as the first step to setting up a new manufacturing technique. My ambition was to propose a workflow for relating an adaptable mould system with robotically-controlled concrete additive manufacturing. While a number of potential areas of development have already been identified throughout the thesis, such as using printed concrete as a temporary formwork to casting, printing on features such as structural ribs onto already-cast panels or as an alternative method to the traditional layer-wise approach to additive manufacturing, I feel that there are much more areas which can be developed in the future.

Moreover, in parallel to this thesis, the same topic is currently being researched as a 3TU Lighthouse project in collaboration with TU Eindhoven.

Conclusions

One of the factors I hoped would have been different was the access to machinery. As the setup was arranged at TU Darmstadt in Germany, this meant that there was relatively limited time to actually calibrate, setup and learn how to control a robotic arm, test the end effector and print physical prototypes

Nonetheless, this was not the critical part of the thesis as other areas, such as digital design, developing of end-effector prototypes and material testing that was done in delft also formed part of the main research.

I feel that there is indeed potential for combining the two fabrication technologies, perhaps not for all the applications explored during this thesis. What I found personally interesting is the use of differential growth algorithms to produce fully-printed panels. The prototypes produced for combined printing and casting also show potential, though I feel much research still has to be done on improving the interface between cast concrete and printed concrete.

Other recommended areas for future research is to use sprayed concrete as opposed to cast concrete; this will also fall in line with research currently being carried out at ETH Zurich. The study for the incorporation of reinforcements strands and post-tensioning voids within printed filaments is also recommended.

Overall, I feel that the study was successful in providing a proof-of-concept and wider scope of potential research through the combination of these two previously distinct technologies.