Double curved concrete printing

Printing on non-planar surfaces

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Innovative and Collaborative research projects from the 4 Dutch Technical Universities

Lighthouse Projects 2017

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3D Concrete Printing for Structural Applications
Combining the technologies of 3D concrete printing and fiber reinforced concrete, elements made by 3D concrete printing can become suitable for structural applications. A structurally safe full scale pavilion will be printed to finalize the project.

Theo Salet – t.a.m.salet@tue.nl

Eindhoven University of Technology
Delft University of Technology

65+ Best Neighbourhood Concepts: Happy Senior Living
Research into location and housing type preference will be used to design living concepts for the elderly. The feasibility of the concepts will be tested in a pilot.

Ioulia Ossokina – i.v.ossokina@tue.nl

Eindhoven University of Technology
Delft University of Technology

Adaptive Joints with Variable Stiffness
Structural joints with adaptive stiffness capabilities, will allow control over the shape and stiffness of the structures. This can lead to morphing and deployable structures, with foldable structures, active façade systems or origami inspired structures.

Qinyu Wang – Q.Wang2@tue.nl

Eindhoven University of Technology
Delft University of Technology

ExcaSafeZone
The developement of an automated system that generates excavation safety maps to enable urban planners, contractors and excavator operators to make more informed decisions about where and how to conduct excavation activities.

Léon olde Scholtenhuis – l.l.oldescholtenhuis@utwente.nl

University of Twente
Delft University of Technology
Eindhoven University of Technology

Geopolymer Concrete Bridge
As the first step towards cement free construction, structural elements will be designed, manufactured and tested. This proof of concept will be used to construct the first prefabricated geopolymer concrete bridge.

dr. G. Ye – g.ye@tudelft.nl
Delft University of Technology
Eindhoven University of Technology

Re3 Glass – A Reduce/Reuse/Recycle Strategy
The design and manufacturing of compressive building elements made from glass. Material use is reduced though the design, elements can be reused through dry-assembly and elements are made from recycled glass.

Telesilla Bristogianni – t.bristogianni@tudelft.nl

Delft University of Technology
University of Twente

Re-Printing Architectural Heritage
Exploring the posibilities of using 3D scanning and 3D printing in the restoration and/or renovation of architectural heritage. As feasibility study a fragment of the Hyppolytuskerk Middelsum will be recreated.

Carola Hein – c.m.hein@tudelft.nl

Delft University of Technology
Eindhoven University of Technology

TERRA-ink: Additive Earth Manufacturing for Emergency Architecture
Using local and recycled materials with 3d printing technology, a solution will be created for the housing emergencies in post-disaster and migration crisis events. The aim is a low cost dwelling unit made of earth-based materials.

Michela Turrin – m.turrin@tudelft.nl

Delft University of Technology
Eindhoven University of Technology

4TU.Bouw represents the collaboration between the four Technical Universities in the Netherlands on the large topic of 'The Built Environment'. The cooperation consists of the Department of the Built Environment at TU Eindhoven, the faculty of Engineering Technology at Twente University, the faculties of Architecture and Civil Engineering and Geosciences at TU Delft and Wageningen University. The goal of the 4TU.Bouw initiative is to promote collaboration between the member faculties, industrial partners and government, in order to meet the grand challenges ahead.

Built Environment is the biotope of the modern citizen, providing infrastructure for transport, defence against flooding, shelter, space for working, meeting and leisure activities, etc. The demands upon reliability, safety and comfort of these structures is continuously increasing. Meanwhile the Built Environment sector is confronted with enormous challenges like scarcity of resources, climate change, accelerated population growth and demographic changes. These challenges require joint strategies and collaboration between end-user, academia, the industry and governmental agencies, the so-called golden triangle. Therefore, in the context of the Dutch 'Nationale Wetenschapsagenda', 4TU.Bouw, with its partners, has identified the important, societal and scientifically relevant research themes: 'De Toekomst Wordt Gebouwd', as well as the 'Built Society Smart Reality' urgency and ambition 'map'.

Relevant themes have been utilized as context for the 4TU.Bouw Lighthouse programmes 2016 and 2017. In 2016 fifteen dedicated, fast track innovation projects have been completed, all addressing aspects of the agenda and map. These projects provide a proof of concept – or failure – of new technologies that will contribute to solid approaches and solutions to the challenges ahead, for all stakeholders. In 2017 eight more Lighthouse Projects will start. Also, a dedicated PDEng-training programme contributes to the future availability of well-trained specialists, meanwhile bridging the gap between academia and the market. 4TU. Bouw strives to respond rapidly to the ever faster changes, often emerging bottom-up, that new technologies bring about, by organizing workshops, brainstorms and training sessions with relevant stakeholders, and by forming dedicated consortia that act jointly. Only by such joint actions with respect to the urgent themes are positive changes expected to happen.

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DOUBLE CURVED CONCRETE PRINTING

LHP2016

It is no secret that there have been some great advances in the realm of concrete additive manufacturing. However, one of the major drawbacks of this fabrication technique is that the elements must be self-supporting during printing. While most other additive manufacturing materials can overcome this by using a secondary printed support structure, alternative strategies have to be developed for materials such as concrete.
This 4TU project explores the possibilities of combining concrete additive manufacturing with a temporary support surface. By printing on a free-form surface, more intricate geometries can be realized. A number of potential applications have been outlined, however the principle focus is combining concrete additive manufacturing and casting. The end result is a partially-printed pavilion using a completely digital design-to-fabrication workflow.

Although additive manufacturing (AM) is a fabrication technique which has been around for the past 20 years or so, it is only now that we are starting to see its applications emerge into the built environment. Whilst metals, plastics and

Concrete that shows great potential for large-scale additive manufacturing.

other composite materials are also being explored for their use in the Built environment, it is concrete that shows great potential for large-scale additive manufacturing. Concrete Printing techniques already allow for the rapid fabrication of large-scale structures with minimal material waste, as already exhibited by Winsun and the fabrication of 1,100 Sqm Apartments in Jiangsu, China.

Whilst this does indeed allow for the rapid fabrication of concrete structures, most elements printed remain as 2.5D rather than 3D. This is due to the fact that extruded material must be self-supporting during printing in order to avoid collapse, imposing somewhat of a geometrical restriction. Most other printing materials can overcome this by printing a temporary support structure, however this is not the case with fluid materials such as concrete. Instead, a temporary surface is proposed as a means of support to printed concrete.

The adaptable mould developed at TU Delft served as a means to provide such a surface. Consisting of a silicone surface connected to a bed of adjustable pins, double-curved surfaces can be produced in a similar fashion to milled surfaces. The main difference being that no material waste is generated since new surfaces are defined by adjusting the pin-bed. Prior to the 4TU Project, this system was used for casting free-form concrete panels. The combination 3D concrete printing and an adaptable mould resulted in a hybrid manufacturing technique consisting of two complimentary fabrication techniques.

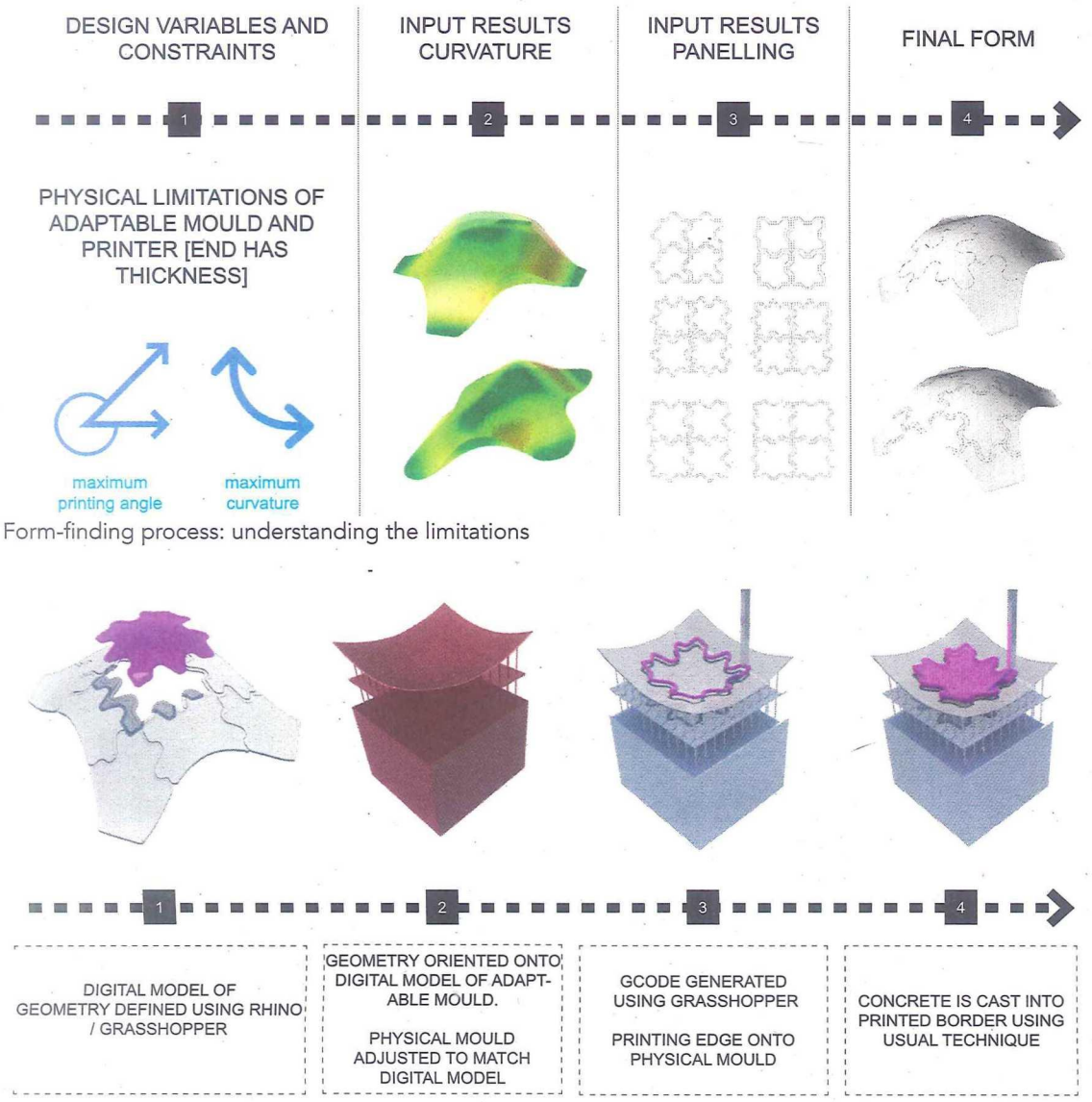
Three Potential areas of research were identified through this combination. Firstly, the potential for fully-printed concrete panels. For this, It is proposed to use differential growth algorithms to generate print paths over any given surface. The second potential identified was the printing of structural ribs following stress-lines to provide reinforcement to panels. However, the chosen theme was a combination of 3D Printing and casting concrete. In this, complex geometries are defined by printing a boundary into which concrete is cast. The advantage to this approach is that complex, free-form concrete panels can be realized without the need for complicated moulding systems.

Complex geometries are defined by printing a boundary into which concrete is cast.

Design Overview

In order to study the proposed manufacturing concept, a shell structure consisting of complex interlocking geometry was designed and printed. The basic principle of realizing the design consists of first creating a digital model of the structure using parametric design tools. Each individual panel is then digitally oriented onto an adaptable mould and G-code is generated by dividing splines that define the perimeter of the object. Once the physical mould is adjusted to match the digital mould, the Gcode is sent to the printer and the geometry is printed. Finally, concrete is cast into the printed shape and left to cure for 24 hours after which it is demoulded.

printing on non-planar surfaces



Form-finding process: understanding the limitations

Product concept

Fabrication Process

Both the 3D Printer and adaptable mould have their own set of physical limitations. Thus, a number of variables and constraints were set by studying the two technologies. Firstly, the maximum slope angle on which concrete can be printed was found to be 40 Degrees, after which material had a tendency to curl up and distort. This value was used to limit the maximum curvature of the form-found shell structure. Due to the printer's incapability to print right angles, a minimum turning radius was also determined and was used to generate the tessellations for printed geometry. The end result is a 2.5 m x 2.5 m shell with a maximum slope of 35 degrees and minimum turning radius of 150 mm, consisting of a total of 9 Print-And-Cast panels.

The end result is a 2.5m x 2.5m shell consisting of a total of 9 Print-And-Cast panels.

In order to have a design process which consists of a single file from design to fabrication, a custom g-code generator was created using Grasshopper 3D. This was also necessary because slicing techniques used in traditional additive manufacturing could not be used since a later-wise approach was not used. Instead, the geometry is defined as a spline and is divided into a number of points depending on curvature of the curve. These points are then expressed in terms of their relative co-ordinates and communicated with the Printer. An additional bespoke script was generated to take into account collisions of the Printer Nozzle with the Surface. This was required because printing was not done perpendicular to the surface meaning that the physical nozzle had a tendency to collide with steep surfaces. The way this was corrected was by determining the intersection between the nozzle and surface at every co-ordinate and raising the point such that no intersections occurred. The corrected print path is then defined by interpolating the raised points which is then converted into G-Code.

Final Structure

The final structure is printed in a single print pass taking approximately 20 minutes to complete as shown in the image below. After the individual panels are printed, plasticizer is mixed in with printed concrete and cast inside the panels. These are left to cure for 24 hours and demoulded as an inverted shell structure. This is later temporarily propped up and held together through mortar joints.

Challenges and conclusions

The project was limited to a relatively small 2.5 m x 2.5 m shell structure and the geometries printed were kept relatively simple so as to focus on refining the design process. However, given that the physical constraints of the printing process have been established it is easily imaginable that scalability and increase of geometrical complexity can be achieved if boundary conditions are maintained. Moreover, the project focused on combining printing and casting, however other directions such as generating print paths which follow stress-lines could serve as future areas of research using the same basic design process.

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