JURIJ LICEN, TADEJA ZUPANČIČ AND TOMAŽ SLAK

FACULTY OF ARCHITECTURE,
UNIVERSITY OF LJUBLJANA

EARLY STAGE RESEARCH

COMPUTATIONAL DESIGN FOR 3D PRINTING CONCRETE

EXTENDED ABSTRACT

3D PRINTING CONCRETE, COMPUTATIONAL DESIGN, LEARNING LAB

DDR STATEMENT

DDr methodology and thinking were used in learning labs, to investigate possibilities for a 3d printed object. This involved design experimentation as defined by Del Vecchio and Zupančič to arrive at a form without a clear pre-definition of what this form needs to be. Knowledge was created during the design process for different experimental objects, within a scope and context of DFC.

This kind of method is especially well suited for research in architecture and the pedagogical process in design oriented education. Students learned how to make a feasible bridge structure out of digitally fabricated concrete. At the same time, they developed evaluation skills to critically asses their design output. Using this process, students could enter the investigation with no prior knowledge and they were able to develop new skills and competences through design experimentation.

ABSTRACT

With the use of additive manufacturing technologies, the construction industry faces a new reality where complex geometry, which was once difficult and expensive to manufacture, is becoming easily available. Some of the benefits include material saving, structure optimization and new design aesthetics. On the other hand, architects and designers need to develop new knowledge and intuition about designing shapes and geometries which could benefit from the opportunities of complex geometry. The paper showcases the use of design directed research (DDr) methodologies in the context of learning labs carried out at the Faculty of architecture, University of Ljubljana. The aim of the labs was to develop novel geometries and designs for fabrication in the context of additive manufacturing using 3D printed concrete.

INTRO

The aim of the paper is to showcase the use of design directed research (DDr) methodologies in the context of learning labs (1) which were carried out at the Faculty of architecture, University of Ljubljana. Learning labs are part of an early stage PhD research titled "Computational design and fabrication of complex self-supporting structures out of 3D printed concrete". DDr was applied to develop novel geometries and designs for fabrication in the context of 3D printing concrete.

PART 1 - CONTEXT

The first part will discuss 3D printing in concrete which was the framework used for design research applied in the learning labs. More appropriately, 3D printing concrete is classified as digitally fabricated concrete (DFC), that is part of a larger field of additive manufacturing (2). Since the 1990s, additive manufacturing (AM) has been making its way into automotive and aerospace industries (3), where it is being utilized to optimize use of material in cars, redistribute weight in airplanes and manufacture more efficient rocket engines. AM represents a radical shift in fabrication compared to traditional manufacturing (4). Instead of subtracting material, and creating a substantial amount of waste in the process, AM adds material only where it is required. This is achieved by the use of 3d printing technology.

Traditionally building with concrete requires extensive use of formwork to cast material and hold it in place during its curing process. This requires preliminary construction of moulds, typically out of wood or steel, which are afterwards discarded. With the use of AM and DFC there is no need for any additional formwork (5). This means that geometries which were once expensive and complicated to produce become available without being constrained to the shape of the mould. There are many different versions of DFC being researched: "Contour Crafting" developed by prof. Behrokh Khoshnevis (6), "Concrete Printing" developed at Loughborough University (7) and "Particle-bed binding" pioneered by d-Shape (8). The aim of the learning labs was to apply the available fabrication techniques to design novel geometries.

PART 2 – LEARNING LABS

In the second part we will describe a workflow employing DDr methodology and thinking, used in the scope of learning labs with students, carried out at the Faculty of architecture at the University of Ljubljana. The aim of the labs was to investigate design for novel, structurally stable geometries within the context of DFC.

Two learning labs were carried out in the winter semester of academic year 2019/2020 and in September of 2020. The aim of the first learning lab was to design a structurally stable bridge that is well suited for fabrication using DFC and would be difficult to manufacture using traditional construction technologies. 33 participating students

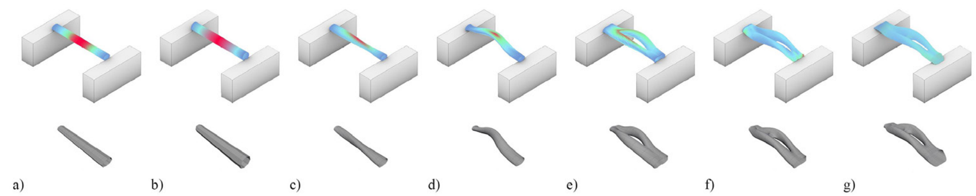

Figure 1. (a-g) Design sequence and structural evaluation of a series of options for a 3d printed pedestrian bridge. Bottom row shows the designed geometry; top row shows structural evaluation diagram of each of the options. Red colors signify larger deflections in geometry while green and blue identify a more stable shape.

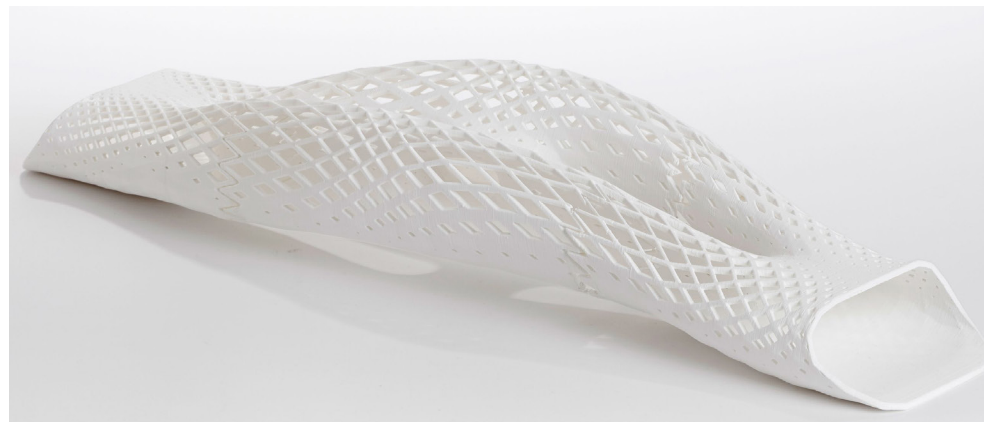

Figure 2. Photo of a scale model for a 3d printed pedestrian bridge. The perforation patterns are applied to reduce material in the middle where it is not required. At the same time, they lighten the self-weight of the bridge and open up views.

were working in groups of 2 or 3 people, to experiment with different shapes for a small pedestrian bridge. They had to cyclically create and evaluate their designs for printability, structural stability and usability by pedestrians.
The diagrams in Figure 1 show a cyclical design process used for shaping and evaluating structural stability. The bridge is designed, evaluated and redesigned according to the findings in each evaluation cycle. Figure 2 shows a 3d printed scale model for a pedestrian bridge made with DFC.

The second learning lab, which was carried out in September of 2020, focused its research on a small shelter dwelling. Computational tools were used to design complex shell geometries with a focus on minimal surface geometry. The limited time frame of the workshop did not permit an extensive cycle of design and evaluation as illustrated in the case of a 3d printed pedestrian bridge. Instead, a tool was developed in advance for students to experiment with. The process involved digital 3d modelling of simple rectangular geometries which subsequently got transformed into minimal surface shells via a pre-prepared algorithm.

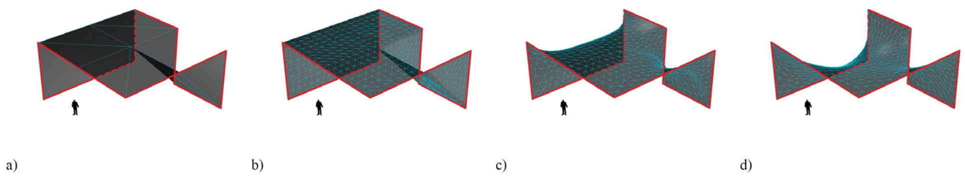

Figure 3. (a) Simplified rectangular shape designed by the students. (b-d) relaxation algorithm employed to determine optimal minimal surface given the boundary conditions highlighted in red.

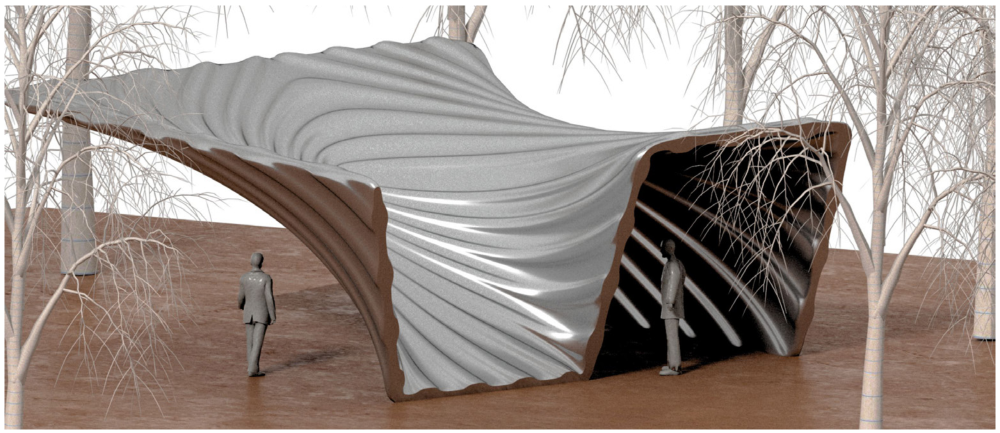

Figure 4. Rendering of an optimized structure shown in Figure 3. Additional ribbing was added to stiffen the shell surface and to express the topological flow as ornamentation and detail.

IMPORTANCE AND ROLE OF DDr EMPLOYED IN RESEARCH

DDr methodology and thinking were used in both learning labs, to investigate possibilities for a 3d printed object. This involved design experimentation as defined by Del Vecchio and Zupančič (9) to arrive at a form without a clear pre-definition of what this form needs to be. Knowledge was created during the design process for different experimental objects, within a scope and context of DFC.

This kind of method is especially well suited for research in architecture (10) and the pedagogical process in design oriented education. Students learned how to make a feasible bridge structure out of digitally fabricated concrete. At the same time, they developed evaluation skills to critically asses their design output. Using this process, students could enter the investigation with no prior knowledge and they were able to develop new skills and competences through design experimentation.

ENDNOTES

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