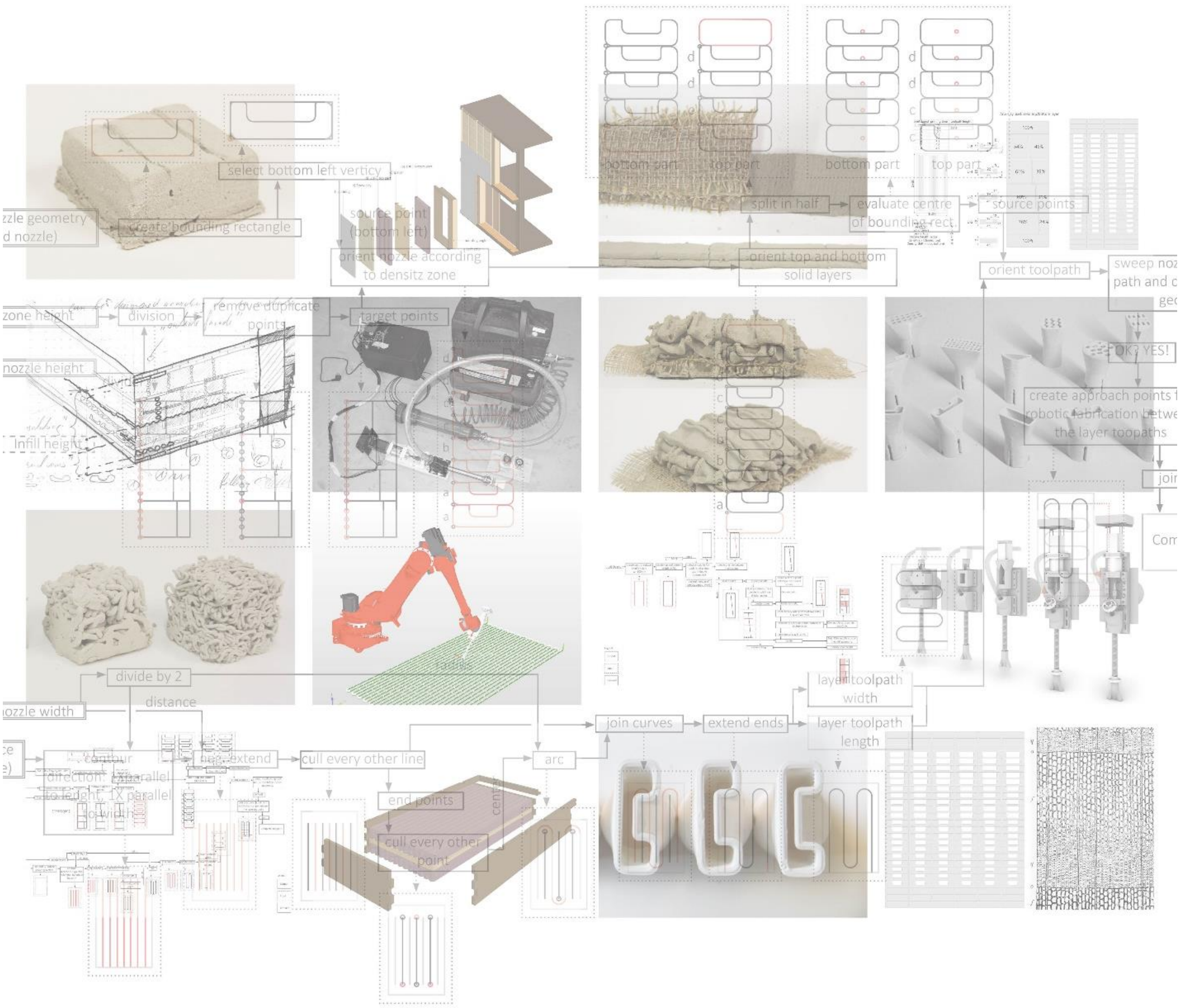
TU Delft
MSc Architecture, Urbanism & Building Sciences
Building Technology Track

Robotic 3DPrinting Earth

Earthen additive manufacturing with customized nozzles to create a gradient material for on-demand performance.



Master Thesis Reflection by Maximilian Mandat 2020

Reflection

Earthen additive manufacturing with customized nozzles to create a gradient material for on-demand performance.

Project: Robotic3DPrintingEarth

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The reflection is separated in three different branches: "Material", "Building Component and Prototype" and "Production and Tooling". Each of these groups required a different approach of research and execution. At the end is a general reflection.

Material:

Earth or soil is a varying material that is composed differently depending on the region. It is a very complex yet simple material as well. Depending on the different clay, sand, silt and water content the properties of the wet mixtures change largely. This material requires a "hands on" approach and experiments to gain a better understanding. Earth is a material that requires dirty hands and a certain "feeling" for the right viscosity and mixture. This is stated by most clay construction professionals and I fully agree with it after gaining my own experience with this intuitive material. Even very precise mixture recipes can differ from one day to another, because of air's change in humidity or due to temperature differences. To develop this "feeling" it can take years and professional, traditional guidance. Luckily, I previously had the chance to participate in multiple clay construction workshops where I developed a better understanding for this material and its properties. However, I am years of practice away from understanding this material fully. Using a "hands on" material with inconsistent properties for a digital fabrication process seems like a paradox at first thought. But digital fabrication offers many possibilities adapting to those varying material properties. Finding a way to combine the material and the fabrication is the key challenge in 3DPE. What fascinated me about this material, is the possibility of bridging the gap between millennia old construction techniques and state of the art robotic fabrication. An unusual friendship that hopefully leads to a new way of sustainable and circular construction. One possible implementation is the functionally gradient material infill that I designed. Trying the achieve a density shift within the cross section due to specific material deposition was a challenge but very interesting.

Building Component and Prototype:

The research should lead to a 1:1 prototype of a building component with a 3DPE gradient material infill. Sustainability and circularity are words that are used today very generically. Almost all products or materials are marketed as sustainable by their producer. However, this is not always the case. My definition of a Sustainable and Circular building component is: The used material is biodegradable without the need of any industrial process and/or easy to recycle/upcycle or reuse without the need of industrial processes. The material cannot harm the environment and user or be toxic. This was the reason why my choice felt on: Wood, Straw, Earth, Jute. Some Metal for screws and connectors is unavoidable, even when most of the parts a friction fitted with wooden dowels. The design of the building component is not the focus of this research, but it is necessary to implement the 3D printed part. In addition, the timber frame protects the clay infill from outside influences. A functioning building component creates a possible market implementation and allows future research in many different directions. Some directions might be façade design, circularity and sustainability, production methods and automatization, joining. But as well building physics, fire safety and structural design.

The fabrication of a 1:1 prototype with the robotic arm will unfortunately not be possible due to the closing of the workshop. A small 3d printed portion of the building component can be done with the handheld extruder. The design of the component will be shown in detailed drawings. The production will be shown through simulations instead of videos.

Production and Tools:

To allow large scale 3DPE with a 6-axis robotic arm, an extruder that can extrude a certain volume per minute is required. Especially when the focus of the research is the nozzle design and its extrusion geometry. The size of the extruder is especially important since the geometry of a nozzle cannot simply be upscaled. Something that works on a small scale might not work at a larger scale. For this reason, I tried to execute all experiments in a 1:1 scale from the beginning onwards. Starting with a handheld manual clay extruder, initial nozzle and material mixtures where tested in a very early state of this research. This permanent testing next to theoretical research and design to avoid deviating from a realistic path to a non-buildable design that only works on the computer screen.

Unfortunately, a large-scale motor driven extruder was not available to further develop experiments with the robotic arm. My colleague Athanasis Rodiftsis and I decided to build our own extruder after considering the extra amount of work and some discussions with mentors and colleagues. Without any previous experience in machining, we accepted this major side challenge next to our regular research. I am grateful for the dedication and support of my mentors, as well as the staff of the LAMA lab, for their contribution to the development of this tool. Developing and building our own motorized extruder for up to 22mm nozzle width led to a much better understanding of 3d printing clay. Since I was unfamiliar within the field of 3D printing, I gained a lot of experience during the development and production of the extruder. Like previously mentioned, the combination of material properties and fabrication possibilities is a key challenge. By designing our own extruder, we could allow for certain adjustments in the motor control, the inlet and outlet nozzles as well as possible adaptation for research that will happen in the future by other students. This is meant as a contribution to the community of teachers and students of the LAMA Lab.

The spread of the Covid19 Pandemic in Europe has led to the closing of the faculty shortly before we could realise the final version of our clay extruder. Due to the excellent support from the LAMA staff and my mentors, I was able to borrow some of the equipment such as a 3d-printer, buckets and miscellaneous tools. This allowed me to continue my research from home, almost as planned and print the customized nozzles, as well as the final parts of the extruder. The finished extruder was tested in the warehouse of the “Smits Design Centre Delft” that was so generous and opened its gates for us. The extruder is working and could be used now to precisely adjust material mixtures, print speeds and print patterns with the robotic arm. But since the robot is unavailable these tests cannot be done. Executing these tests manually by holding the heavy extruder and the clay cartridge would not help since the required precision cannot be achieved by hand and would falsify the results. To test the nozzles anyway, I was going back to the use of the manual, handheld clay extruder. This allows for a much more convenient handling. The scale of these test will remain 1:1 and therefore possible to reproduce with the motor driven extruder.

General

This research only covers a small part of what is necessary for a functional building component, that includes a 3DPE infill. Research topics such as Acoustics, Fire Resistance, Thermal mass, Humidity Control, safety and structural design would require years of development before a market-ready product could be launched. Within the field of robotic 3D printing there are many additional research options as well. For example: By optimizing the nozzle’s geometry, I was able to significantly simplify the robot’s toolpath. Exploring the toolpath generation and possible benefits would be a great opportunity to further optimize 3DPE. In addition, the integration of reinforcing fibres by robotic weaving would be very interesting as well but is currently out of scope. Developing the facade as a load-bearing exterior wall with non-structural 3DPE infill would as well be a promising option. Structurally optimizing this system would possibly lead to non-uniform infills. Robotic 3D printing is ideal to deal with non-uniform shapes.

One project is almost never enough to have a significant impact and it requires a large effort from many branches and researchers. The combination of clay and timber as construction materials offer many benefits and could be a part of a new environmentally friendly, nature-related and regional architecture and construction culture. Translating traditional vernacular construction techniques within the framework of the fourth industrial revolution allows us to move forward while acknowledging our historically developed building culture.