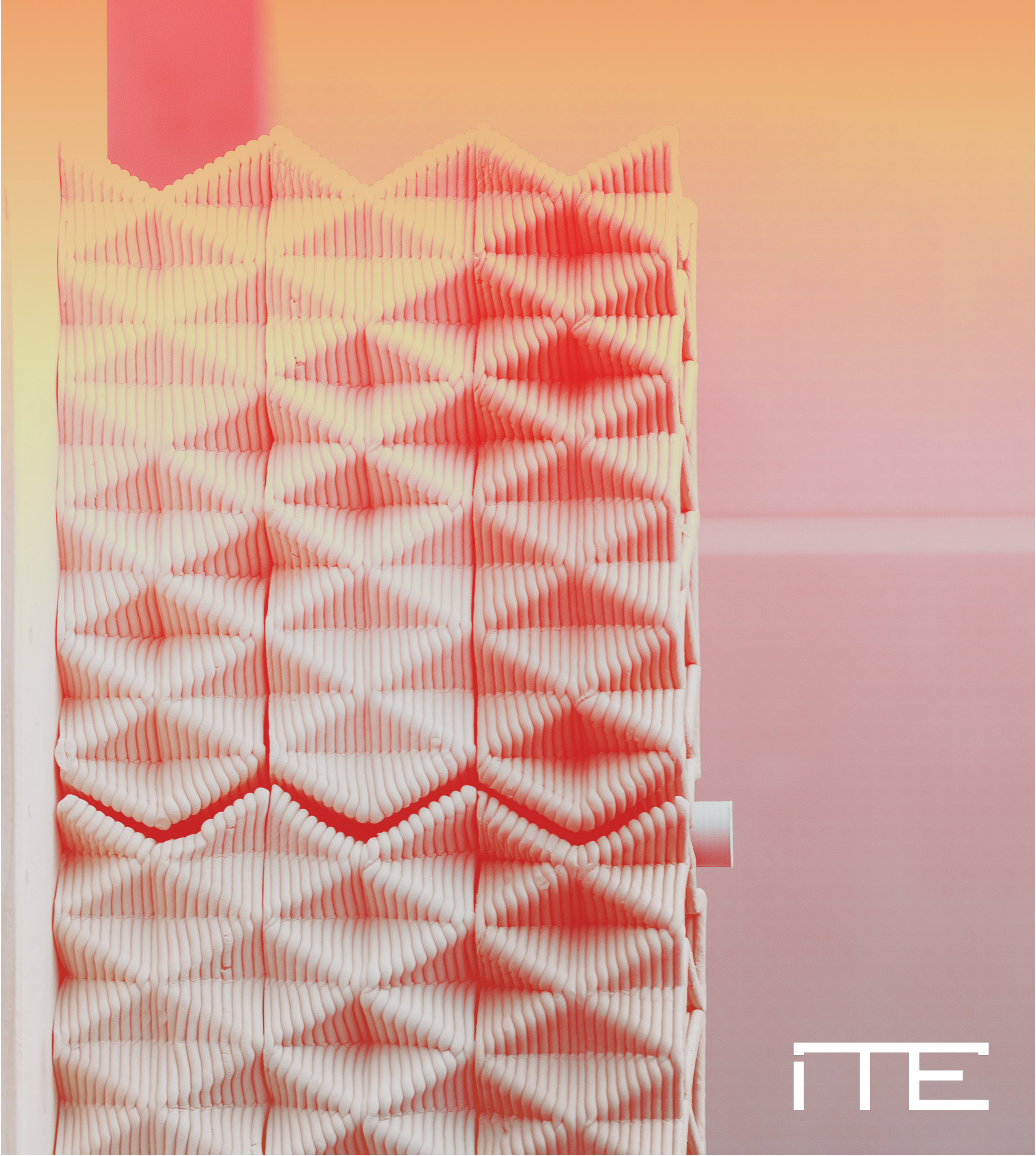
Earth Printing
Compact Design Studio

Institute of Structural Design
Summer 2023



ITE

The Earth Printing compact design course led by Prof. Norman Hack and Noor Khader from the Institute of structural design (ITE), explored the ways in which advanced technology, specifically 3D Ceramic Printing, has transformed the world of design and fabrication nowadays. The use of advanced technologies and parametric modeling has enabled designers and architects to develop intricate and complex designs informed by variable parameters. This has opened up new possibilities for a novel design expression, highly detailed patterns and textures, and visually striking objects that are both functional and beautiful.

The students developed in 6 weeks a section of a Façade Wall that is segmented into parts and informed by the investigated experimental process such as parametric design, assembly and disassembly, fabrication limitations, interface connection and functional integration. Through series of lectures, digital modeling workshops, and mainly hands-on 3D printing sessions, students have learned fundamental principles of 3D digital modeling, the technical aspects of 3D ceramic printing, and the creative possibilities and pronounced aesthetics enabled by this technology.

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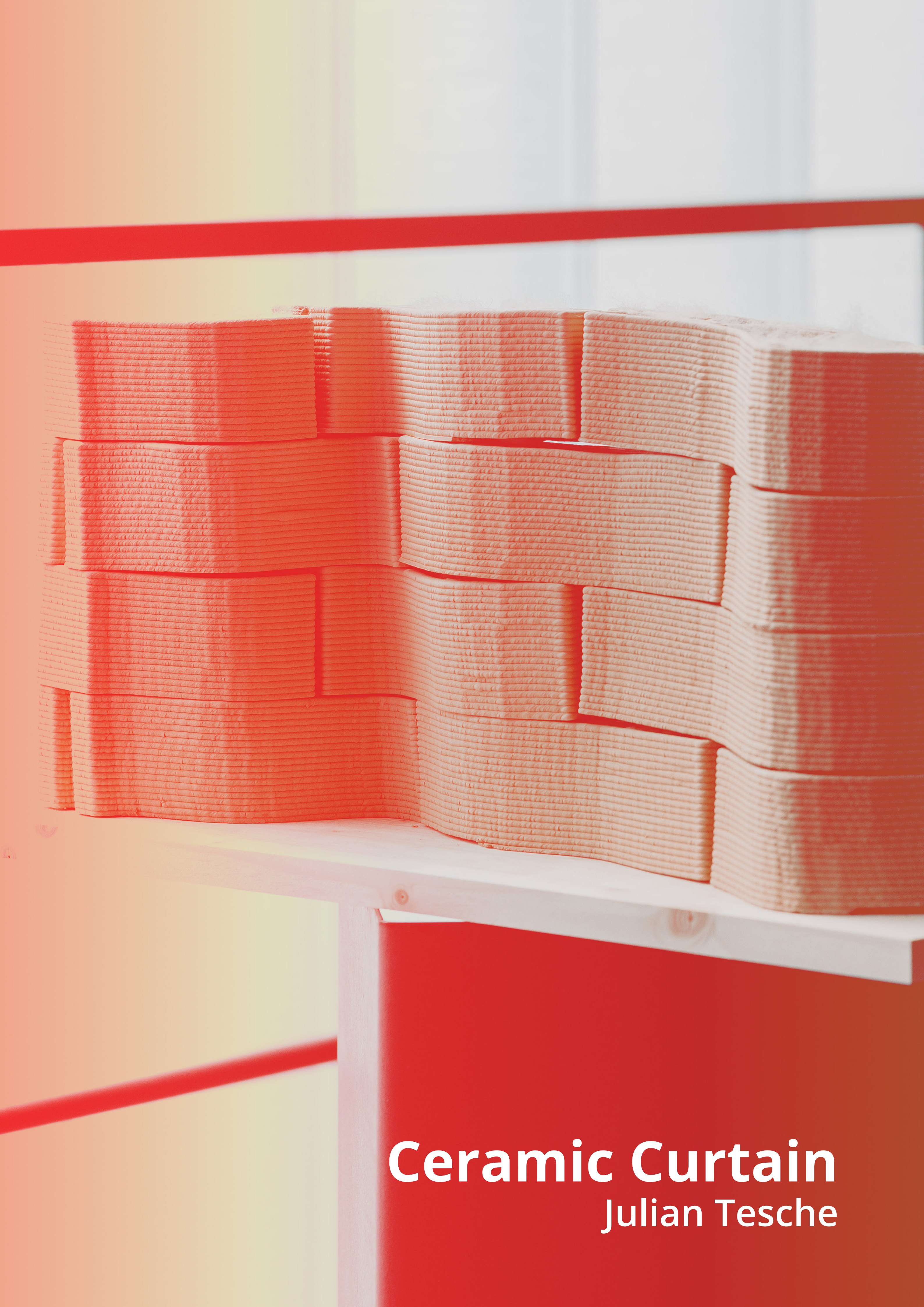
Printed Explorations

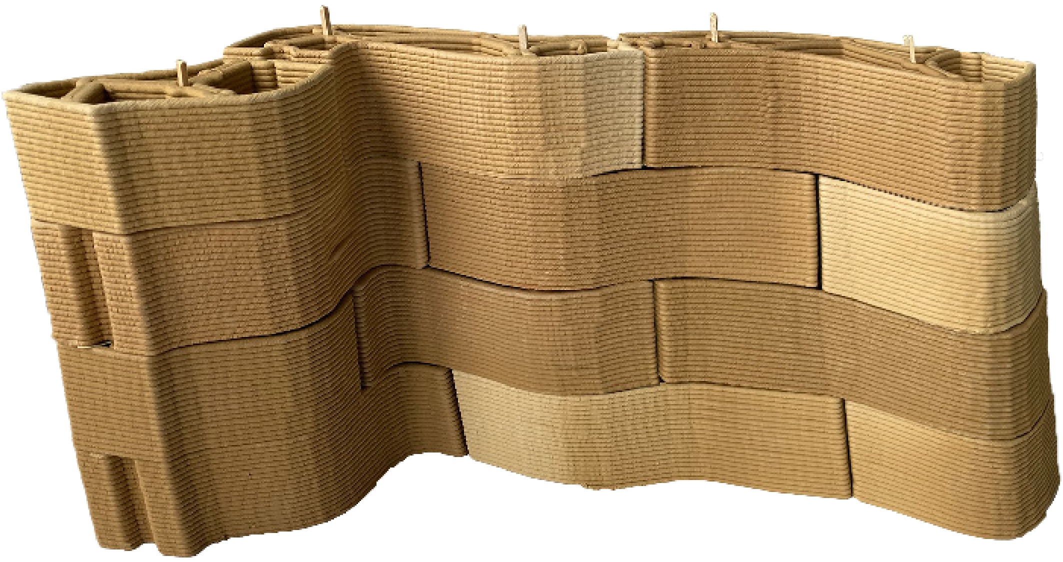


Ceramic Curtain

Julian Tesche

Ceramic Curtain

Making earth textile



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1 Printed section of the final wall design

Preface

The 'Ceramic Curtain' design was derived from the idea of using the possibilities of parametric design and additive manufacturing to create a wall that had a textile, dynamic feel, despite being made of earth. The basic idea for this design came from a fascination with drapery in sculpture. There it was used to show movement, dynamism, and the structure of the fabric. Mastering drapery in subtractive sculpture required a deep understanding of the properties of textiles. Many models and studies were necessary before the final sculpture could be created.

At that time, drapery could be created using computational textile simulations, with a much higher degree of realism thanks to physics engines. Furthermore, additive manufacturing made it possible to convert these simulations into a real model with high precision. This project was an attempt to transform the traditional, subtractive process of sculpting drapery into a parametric, additive process. The aim was to develop a tool that could be operated without much prior knowledge in the field of computational and parametric design.

Textile Simulations

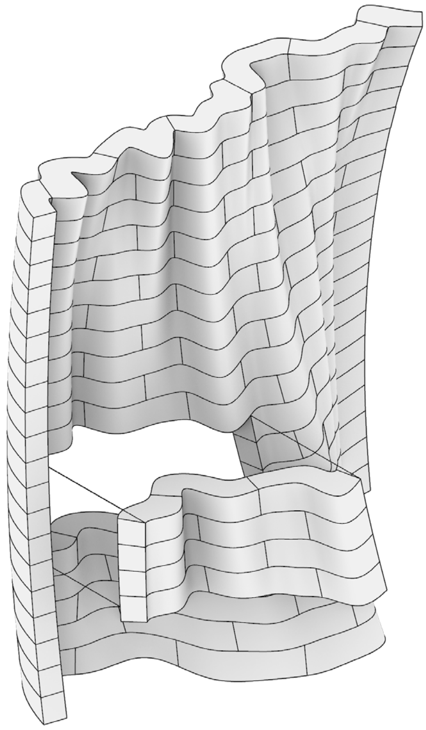
To provide a basis for the subsequent experiments, textile simulations were first developed in Rhino Grasshopper using the Kangaroo 2 physics engine. The focus was on defining the properties of the textile as accurately as possible, with parameters such as the elasticity and weight of the fabric. Factors such as wind and other colliding objects made the simulation more dynamic. This resulted in a selection of simulated textile surfaces.

What defines a brick?

The next logical step was to use Grasshopper to translate the simulated textile geometry into a printable structure that would become part of a larger wall. A first brick was designed to represent the surface of a hanging curtain, but at the same time fulfil the functions of a classic brick. Clearly, the textile surface needed to have depth, as well as connection points for further bricks and a certain strength. To achieve these goals, the first step was to create simple semicircular connections for other bricks, and an infill that touches the front, representative side of the brick twice at each level of the print. A script ensured that the robot's path planning (Figure 3) overlaps only slightly, so that the double-curved front of the piece does not warp, but there still is a stable connection between the two paths (Figure 5).

From Micro to Macro

Once the initial printing tests on the bricks had been successful, the next question was how to create a façade with a textile shape over its entire height. The conclusion was that the textile structure of the individual brick had to be transferred to the entire wall, so that the bricks were only part of the overall picture (Figure 2). The idea of developing a tool to parametrically control the whole process came to the fore at this stage. In the first part of the script, the basic shape of the wall (macrostructure) would be modelled and then translated into



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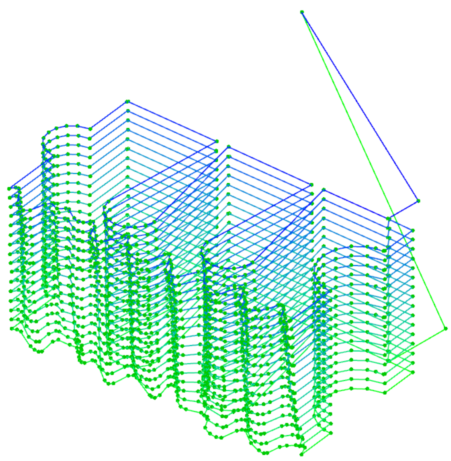

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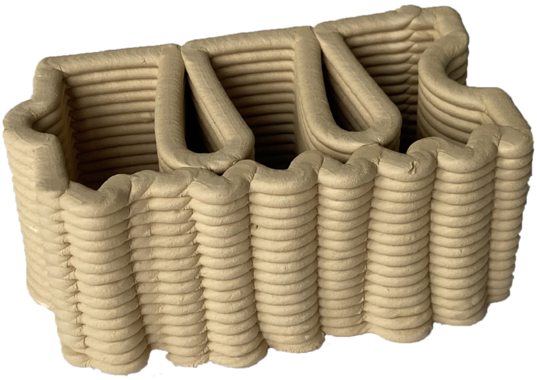
2 Final wall design with highlighted printed section

3 Path planning with targets for a previous brick design



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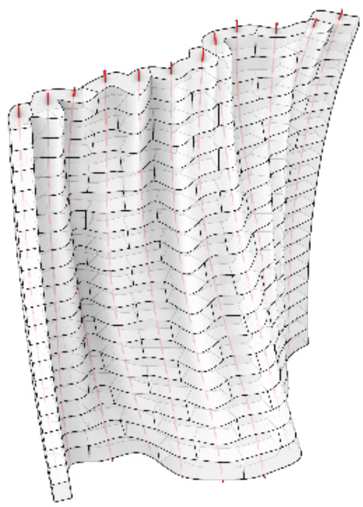
4 Printed demonstrator of previous brick design

5 Top view of previous brick design showing connection ideas and infill system

bricks (microstructure) in a second part. The first part defines the dimensions, curvature and resolution of the wall into bricks (Figure 7). There are two versions of this step, one that still uses a simulation as the basis for the wall, and a second that is easier to use. Once a macrostructure has been developed, the second step is to define the individual bricks (Figure 8). Here, an adaptive infill pattern is developed that can handle the strong curvature of the bricks and provide the necessary stability for the elongated bricks. In addition, cable channels are positioned so that cables can later run through and interlock the entire façade (Figure 6).

Print and Material

For the final print, this script was used to find the shape of an entire wall. A section of this wall was selected for the final demonstrator (see Figure 2). The section only hints at the overall curvature of the wall, but it shows the strong curvature of the individual bricks, as well as the connection of the bricks. The bricks were printed with different batches of earth, which proved to be a problem. The final assembled demonstrator (Figure 1) shows that many of the bricks have different colors. This is not due to the different composition of the clay, but rather to the water content. This water content causes the bricks to shrink differently, resulting in unwanted curvatures. It also affects the viscosity of the clay, resulting in different flow rates during printing (Figure 9).



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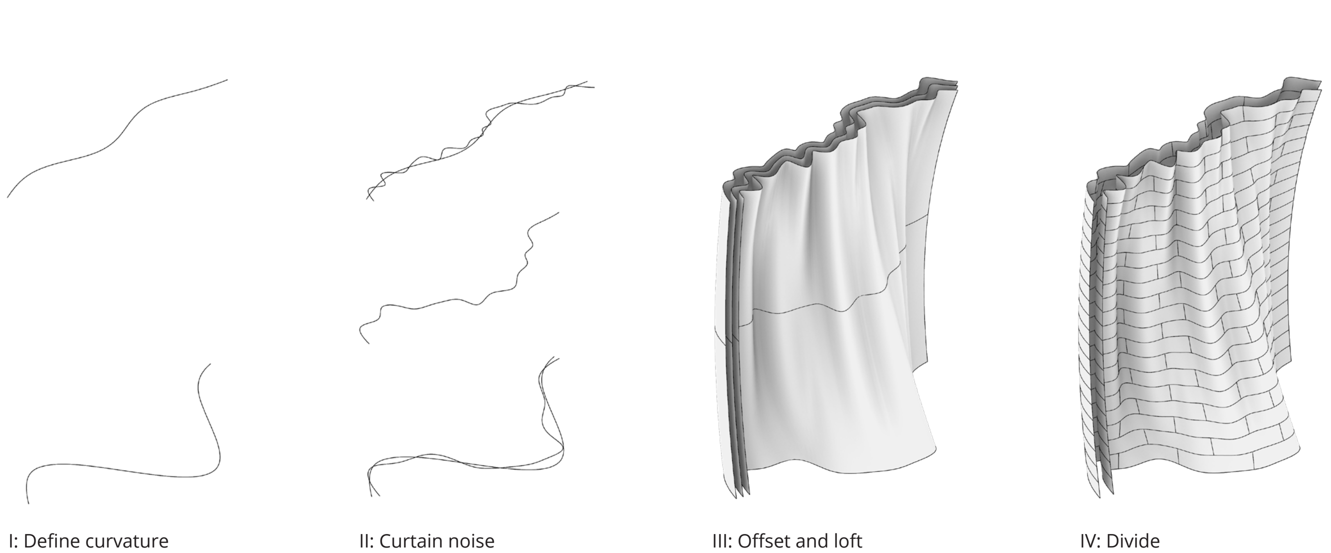
6 Locking of the facade by steel cables. Due to the offset of the bricks, a secure connection is created as soon as the cables are tensioned.



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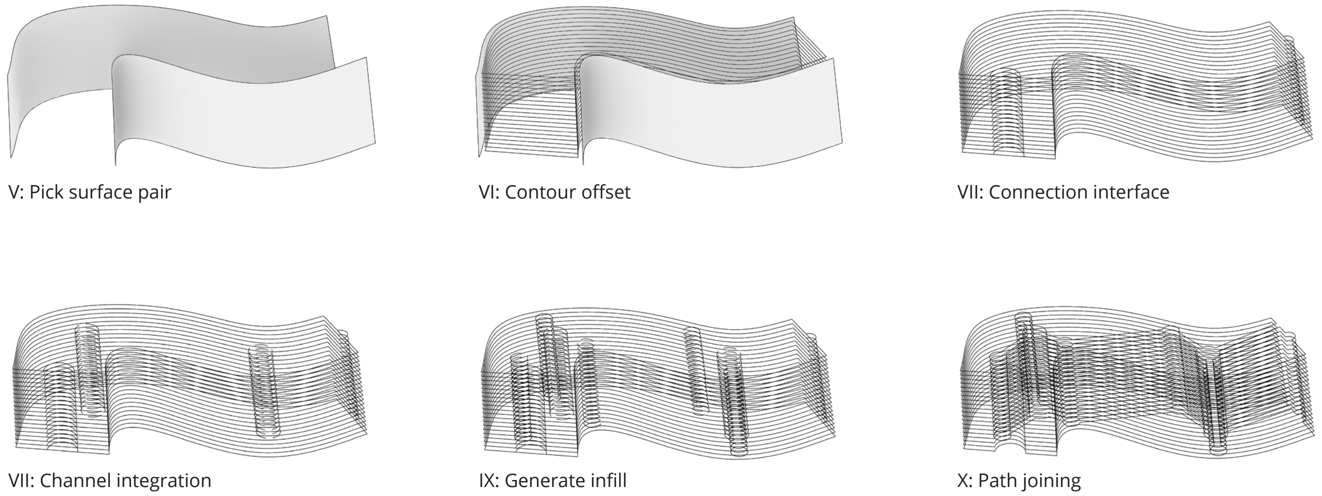

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7 Diagram showing the different steps of the final tool to design the wall. Without textile simulation.

8 Diagram showing the different steps of the final tool to modify each brick. Development of the infill, the connections and the cable channels.

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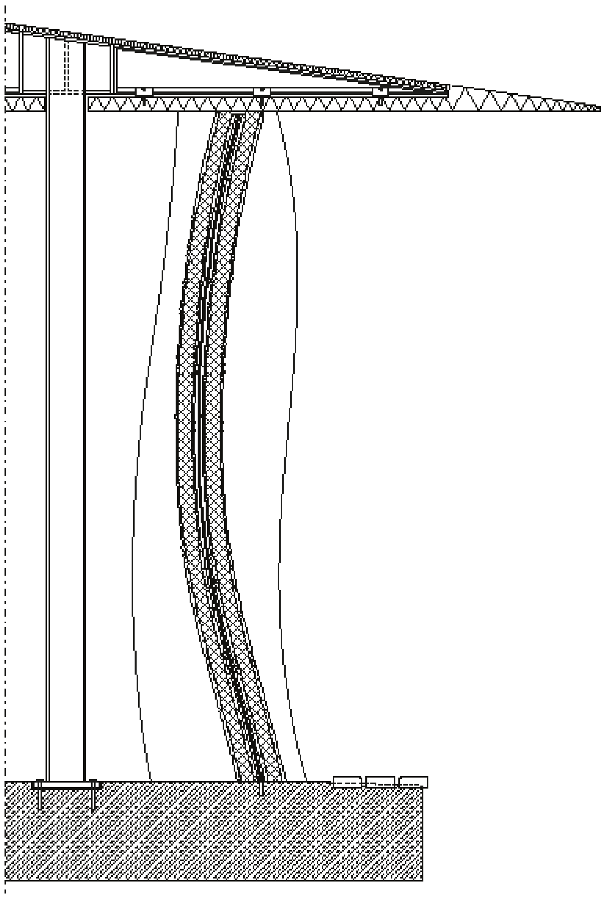
9 Two prints printed with the same nozzle, speed of the robot and feed rate. The different moisture content of the clay resulted in different outcomes.

Use Case

The developed tool allows to design self-supporting facades that have a large base area due to their curvatures and thus have more stability. In addition, the steel cables connecting the individual bricks can be fixed in the base slab and tensioned in the top layer. There is no need to use mortar to fix the layers of the wall resulting in increased deconstructability. In the exemplary section (Figure 10), you can see a wide roof overhang that protects the unfired earth bricks from the elements. However, the bricks could also be fired or glazed (Figure 11,12), but this limits recyclability. The section also shows that the individual bricks are additionally stuffed with insulation made of sheep's wool.



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10 Simplified sectional drawing of a facade made of printed bricks. Steel cables fix the individual bricks insulated with sheep's wool.

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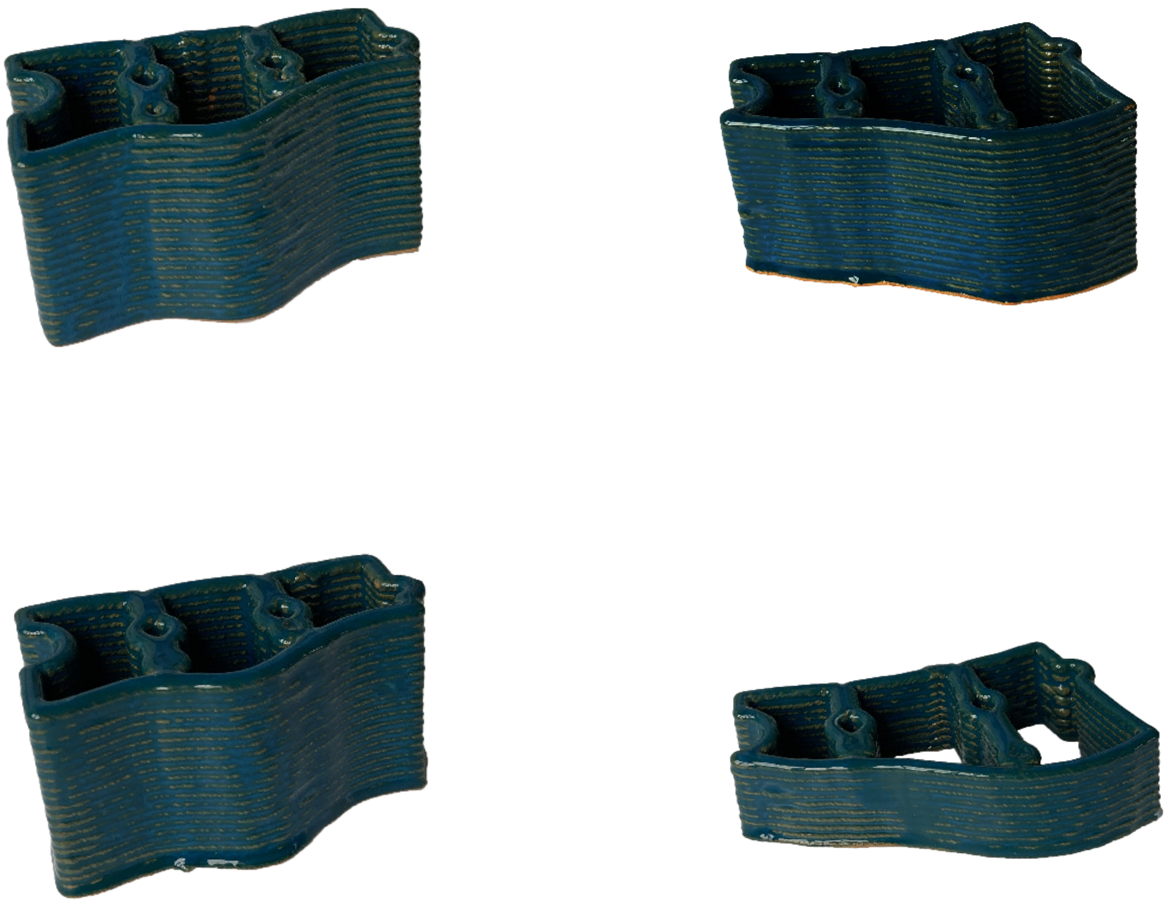

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11 Single glazed bricks of the final demonstrator. Due to the moist content of the earth immediately before firing, the glaze was applied with a brush.

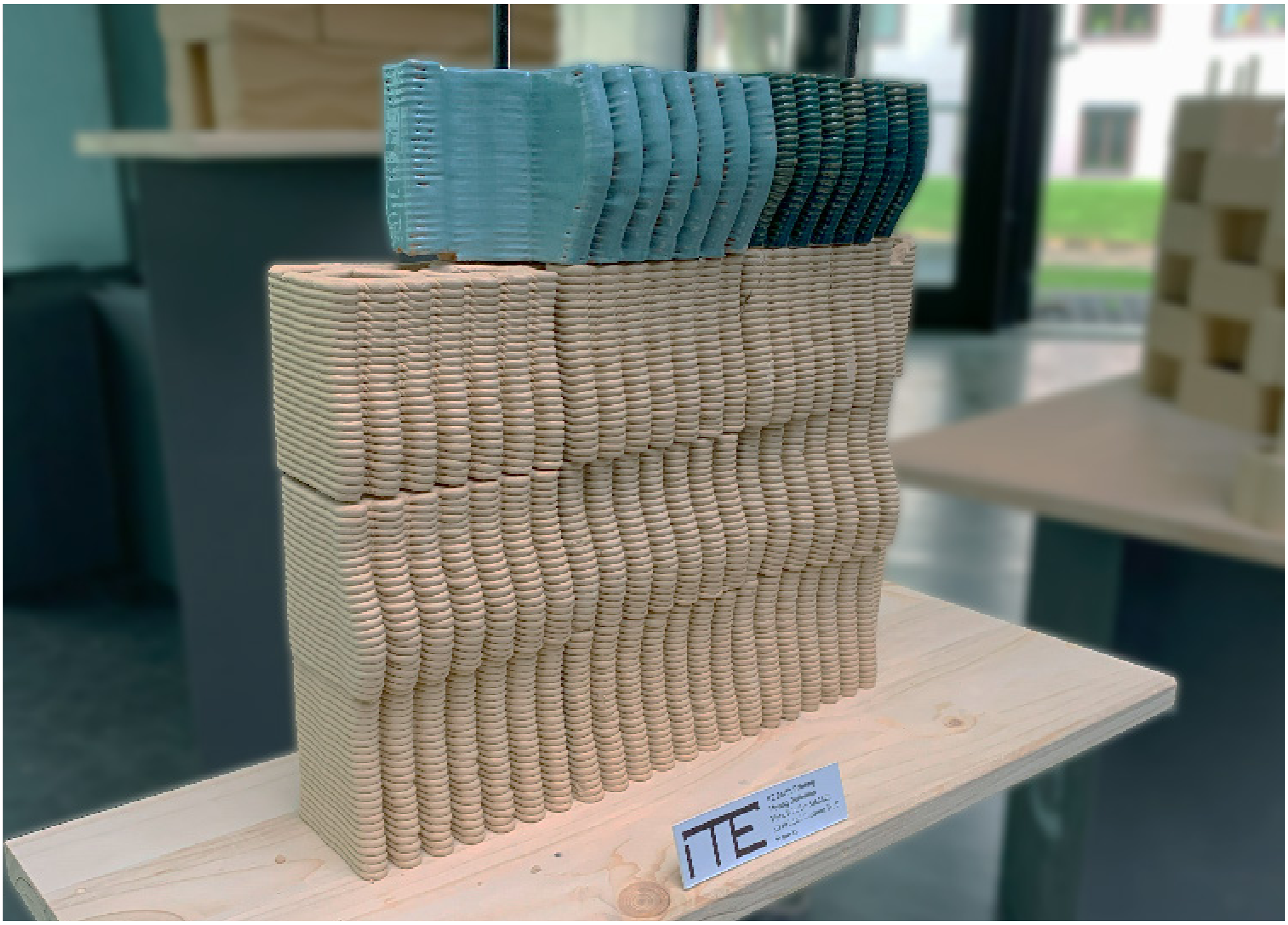
12 Glazed prototype brick. These were already dried in air before firing, so the glaze was poured over.

Moving Definition

Tjark Windler

Moving Definition

New arrangements of bricks with a new connection method



1 Entire model on presentation day

Preface

Clay as a building material dated back to 10,000 years ago. In addition to wood, clay was a popular material for the construction of buildings, which had survived to that day. Clay 3D printing was then taking this construction to a new level with many new possibilities.

In general, 3D printing had changed the way we thought, designed, and built. Drafts from the 3D program transformed directly into reality. In addition, new shapes became possible that had not even been imaginable 30 years earlier. The hidden interior structure had also changed as a result. We were no longer dependent on filling in molds and could save up to 90 percent of the material with intelligent fillings, which did well for the change in the construction sector towards sustainability. In addition, the material could be reused if it was not burned in the process. This manufacturing method also resulted in enormous accuracy with which one could manufacture. This was essential for the construction sector and facilitated many construction steps. These reasons showed that research on this topic was important for a sustainable construction transition. That was why I chose this course and wanted to explore the possibilities of clay 3D printing.

First Experiments

We used the first week to improve our knowledge of Grasshopper and work with the plug-in for Rhino7, with which we can operate the robot. In addition to this, we were given an introductory course on the robot itself. At the beginning, we tried it out with this basic knowledge. The first prints were initially limited to the parametric facade. Figure 2 shows the first attempt at a parametric facade.

But there is more to a brick than just the outer shell. So the next focus was on a material-saving yet stable filling. In addition, the new manufacturing method using the robotic arm made it possible to create new connection methods. The goal here was to integrate the filling and the connection into the brick. In the best case, the connection even forms directly from the filling. I tried that in my next printing experiment (Figure 3). Here you can see the same facade again, only with an infill and a connection formed from it. From the top view (Figure 4) you can see, I measured the gaps in the brick far too large, which is why the filling was not really connected to any side. To fix this I reprinted the infill and compound and dropped the robotic arm speed from 10 to 8 (Figure 5). The filling works much better here, yet not perfectly. The connection has been relatively normal so far. For that I have constructed a simple design of a positive and a negative so there is one joint that digs into the other brick. However, these have become significantly smaller than expected and probably only make a small contribution to stability.

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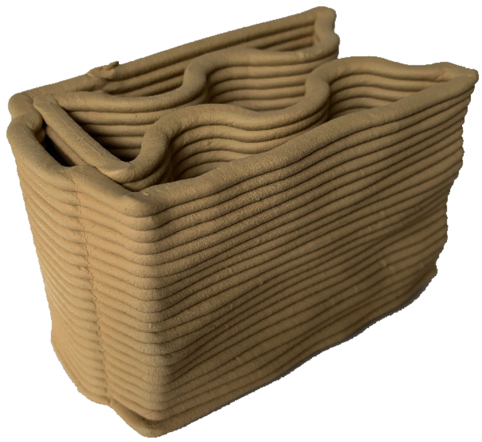

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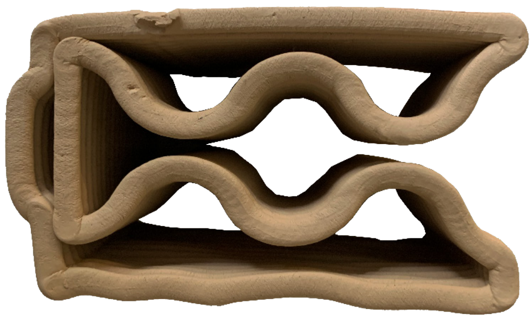

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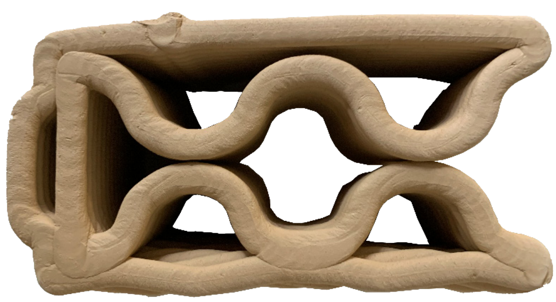

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2 First test print with a parametric facade.

Nozzle: 5mm; Layer height: 3.2mm; Speed: 10

3 Second test print with infill and connection

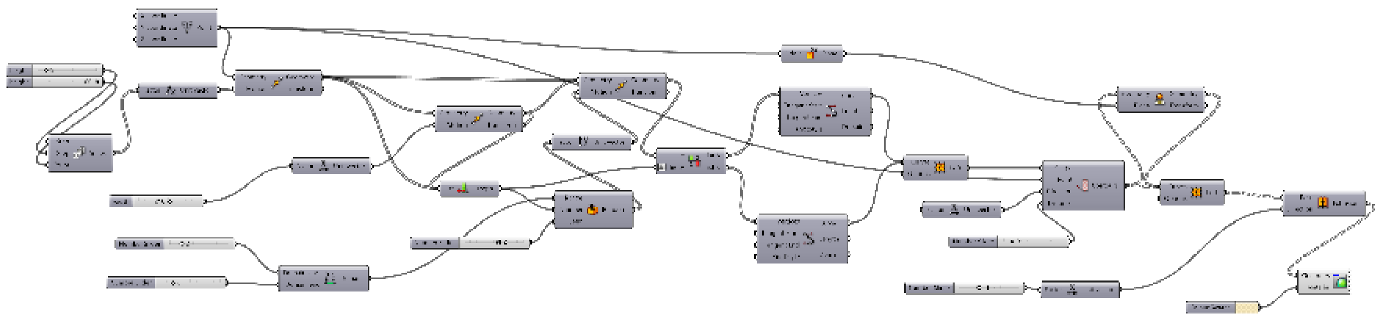
Nozzle: 5mm; Layer height: 3.2mm; Speed: 10

4 Top view of the second test print with infill and connection

Nozzle: 5mm; Layer height: 3.2mm; Speed: 10

5 Top view of the third test print with infill and connection and slower speed

Nozzle: 5mm; Layer height: 3.2mm; Speed: 8



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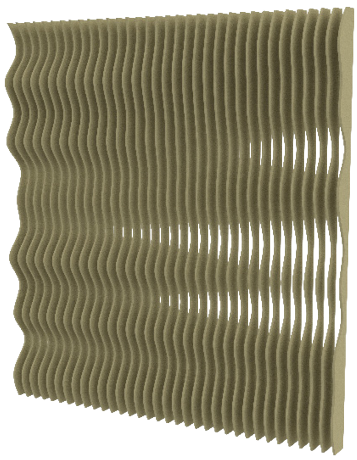

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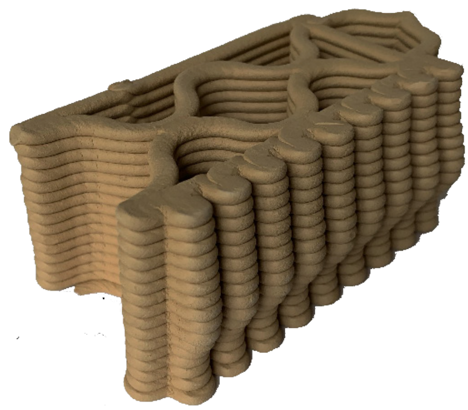

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Parametric Facade

So far, my facade had been limited to the scripts that we learned in the first week of introduction. But after the first experiments, I wanted to program and design something of my own. Here I remembered a parametric facade that I saw on vacation in Greece. Inspired by this, I created a script with which I could create and modify a parametric slat facade (Figure 6). You can see a preview below of what such a facade looks like in the script (Figure 7). I then inserted this into my existing brick for my old facade and printed it (Figure 8). I only slightly adjusted the filling and the connection. I was very satisfied with the print of the facade and adopted this design in my further experiments. I particularly liked the clearly recognizable layers that naturally occurred in a print of this type. They showed the manufacturing method and defined the facade horizontally as well as the vertical definition by the slats. It was at this point that my work was titled "Moving Definition."

In the top view, it could be seen that the filling was now touching each side (Figure 9). When I later tested the brick under pressure, it withstood significantly more than my previous experiments. To the connection, I only added a small corner so that it fit even more precisely into the next brick.

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6 Script of a parametric facade with vertical slats

7 Preview of the facade created by the script
8 Print of a parametric facade with vertical slats

9 Top view of the print with a parametric facade with vertical slats

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New Connection

However, the facade I designed also had a problem. Any seam between the bricks was relatively easy to spot and disrupted the actual picture of moving definition. The best result would have been if I could have stacked the bricks directly on top of each other so that the joints always met in a cross. In this way, the gaps would have fit seamlessly into the others. Normally, such an arrangement was not very desirable because it was very unstable. In order to still arrange them in this way, a new connection was required. For this, I moved the back part of the brick. This was how the bricks reached behind each other, hidden behind the facade. The first print with this connection also fitted very well (Figure 10). The filling was only clearly too full and should have been significantly reduced. The most important point from there on was to find the right distance for the connection because significantly more distance was needed than in other places.

Nevertheless, the connection with several bricks worked very well and was much more stable than just putting them next to each other (Figure 11).

To improve this connection, I added a joint that stuck into the next brick, so the bricks could not be pulled apart (Figure 12). However, I needed even greater accuracy for this, which unfortunately was not possible at the time because the robot kept having difficulties due to very heavy and regular use.

When I printed the next brick, the connection worked to some extent (Figure 13). However, it was clear to me that to get the connection just right, I would need more time than I had available and, more importantly, a reliable robot. This explained the smaller gaps that appeared in my final model (Figure 1).

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10 Print with the new connection

11 Top view of the print with the new connection

12 Print with the new connection and a joint

13 Top view of the print with the new connection and a joint

14 Final glazed brick (dark blue)

15 Final glazed brick (light blue)

4

16 Final printed bricks

Organic Shift

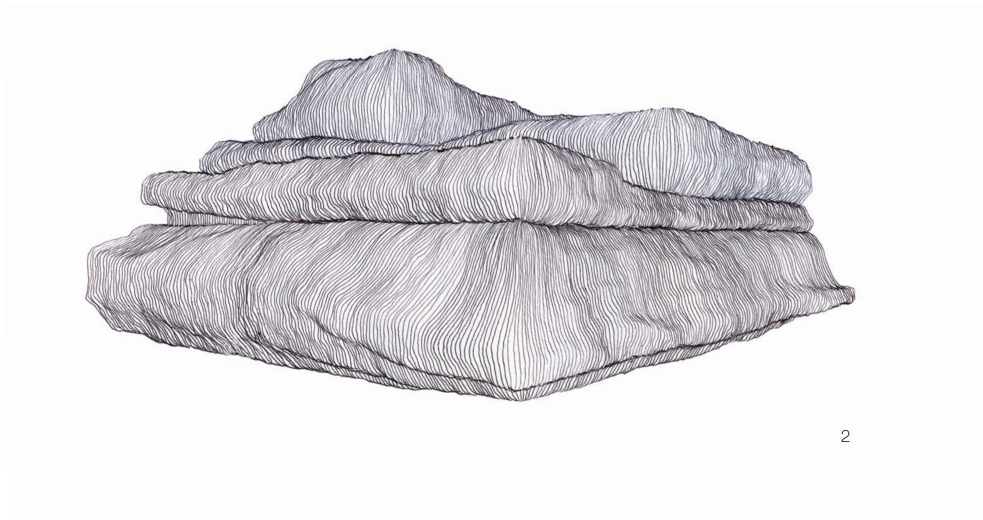
Rahel von Freier

Organic Shift

1

Organic Shift

Exploring the depiction of organic shapes and geometries thought hand drawings and sketches for some time, translating them into the design of a 3d earth-printed facade was a logical following step. Inspired by natural shapes like roots, I was curious to see a solid wall being molded by this kind of motion.



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1 Printed Wall Segment

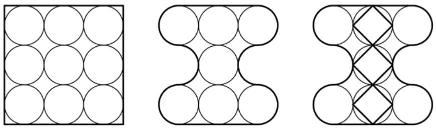
2 Hand drawing

Brick Design Evolution

The goal was to design a free-standing wall whose shape was determined by the geometry of its individual bricks. Based on a circular grid, the prototype of an H-shaped brick and a simple plug-in system were developed, which offered several advantages. Both sides of the wall could be provided with the intended structure in this way, and the type of joint could be hidden by the bricks being pushed into each other.

One side of the brick was deformed, while the opposite surface remained flat.
The result was a wall of individual bricks based on the same basic shape. Thus, by moving the outer walls of the prototype brick bit by bit, it was possible to find a proper connection between the individual bricks. The first test prints ensured that the structure of the manipulated surface could be reproduced well. Secondly, the correct offset was determined in order to generate a precisely fitting connection.

While the first test prints were made with the 3mm nozzle, in the course of the experiments it was decided to use a 5mm nozzle due to a rescaling of the bricks (from 5x5x5cm to 10x10x10cm in M1:2 scale). The moving surface of the design could also be reproduced in the required level of detail with the larger nozzle, as further test prints made clear.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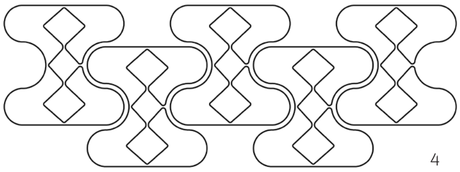
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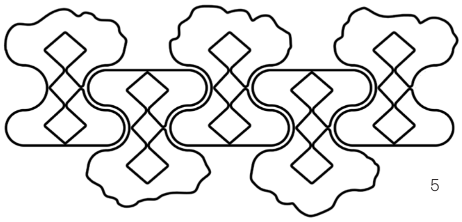
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3 Circle grid

4 Interlocking system, initial brick

5 Initial bricks shape with manipulated surfaces

6 Final testprint connection

7 Print of two bricks with 3mm nozzle

8 Print of rescaled brick with 5mm nozzle


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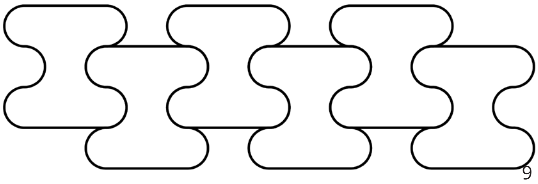
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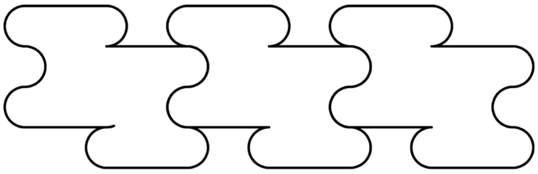
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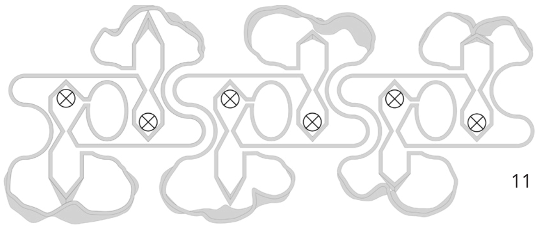
Evolved Assembly Method

Since the H-shaped bricks could not be joined in a composite, a change was needed at that point to improve the structural properties. By joining two bricks into one, this was achieved without changing the original design of the facade. The development of an infill, which generated an overlap when the bricks were layered, was a prerequisite for the installation of the wall. For the secure connection of infill and moving surface, Rhino Grasshopper Script was consulted.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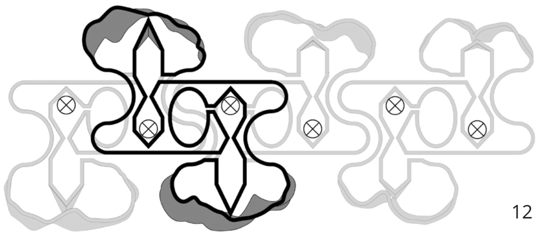
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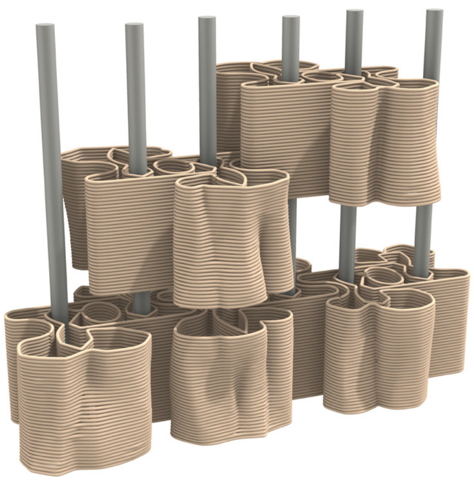
Printing Process

A complex, high-resolution surface in the design resulted in a high number of dots that the robot had to process during the print. However, the number of dots for one printing process was limited, so all bricks were printed in three sections each—with the maximum possible number of dots. Because of the high resolution of the surface and the size of the bricks, the clay cartridge had to be changed after 2/3 of a print. In this context, it was necessary to ensure that the clay for the second section had the same properties as in the previous section to ensure a good connection between the layers and as seamless a transition as possible. Even the smallest changes in the setup, such as screwing on a cartridge by hand, could lead to undesirable shifts in the printing path of the nozzle, which is why particular care had to be taken.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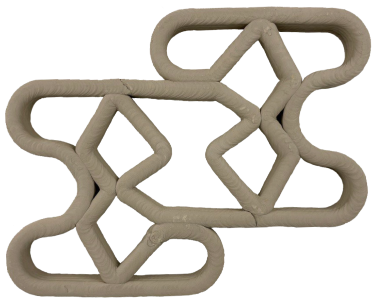
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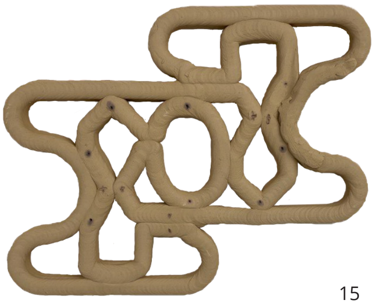

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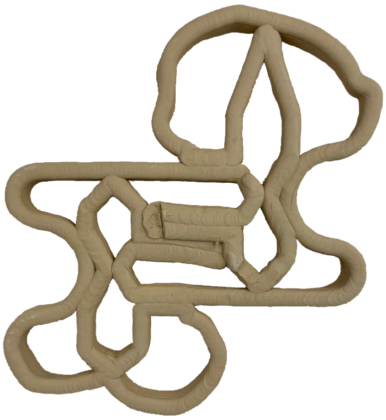

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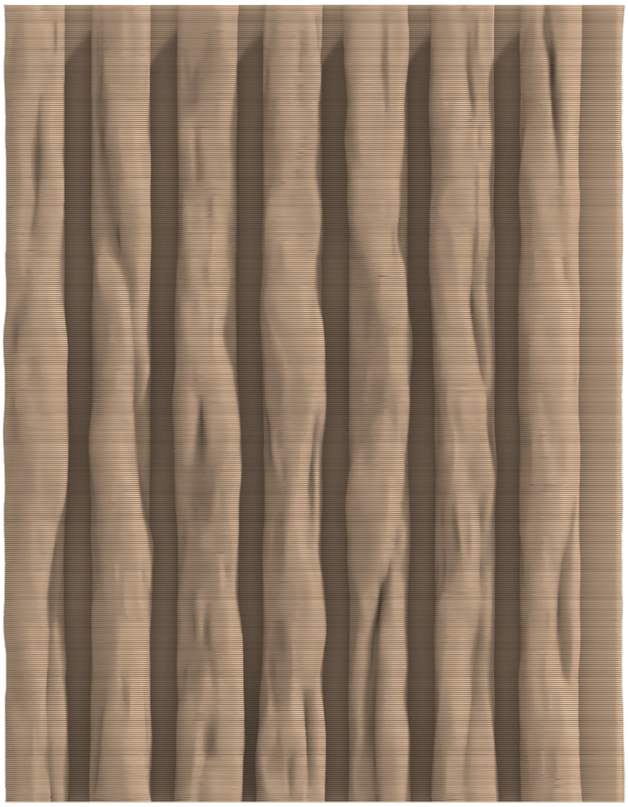

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Design

One problem that had to be solved during the design process of the façade was the relationship between randomness and decision—not only in the design of the individual, tree-like strands but also in their interplay. After all, they were meant to grow naturally over the façade while playfully reacting to each other. A readable movement had to be visible across the entire façade, with the growth of the individual strands responding to the movements of their neighbors.
While the design of the basic brick shape and many experiments in surface manipulation were done in Rhino Grasshopper, a combination of parametric and manual design components was chosen for the final design. When generated purely parametrically, the random components suggested too strong a pattern, as they were pseudo-randomized interventions. Thus, manual decisions had to be made, complemented by smaller randomized effects in the microstructure.

9 H-shaped bricks

10 Combined bricks

11 Topview first layer

12 Topview second layer, first brick

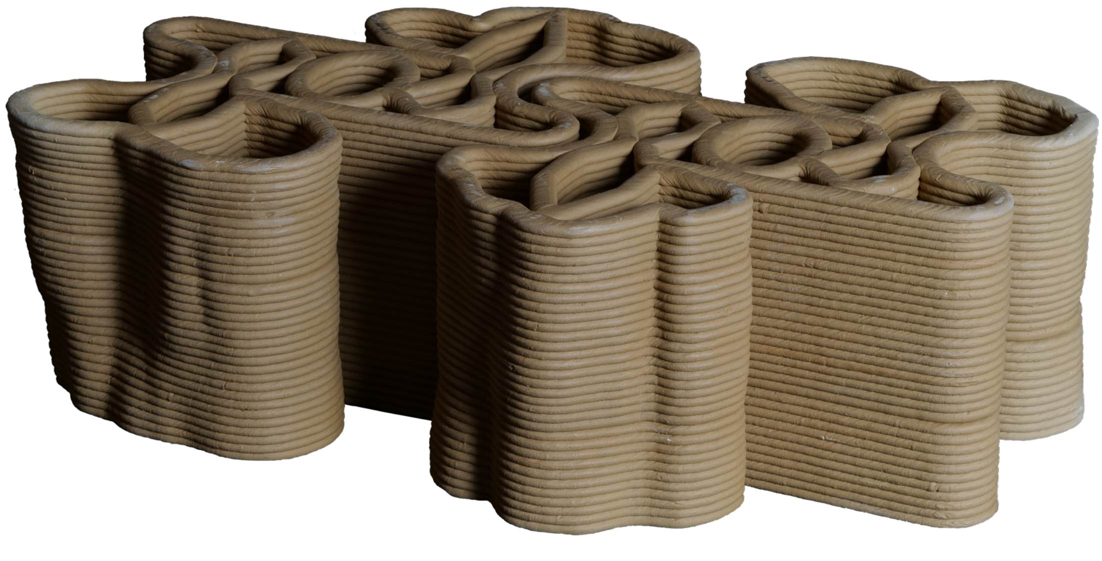
13 Isometry stacking system

14 Testprint base form double brick

15 Testprint base form double brick

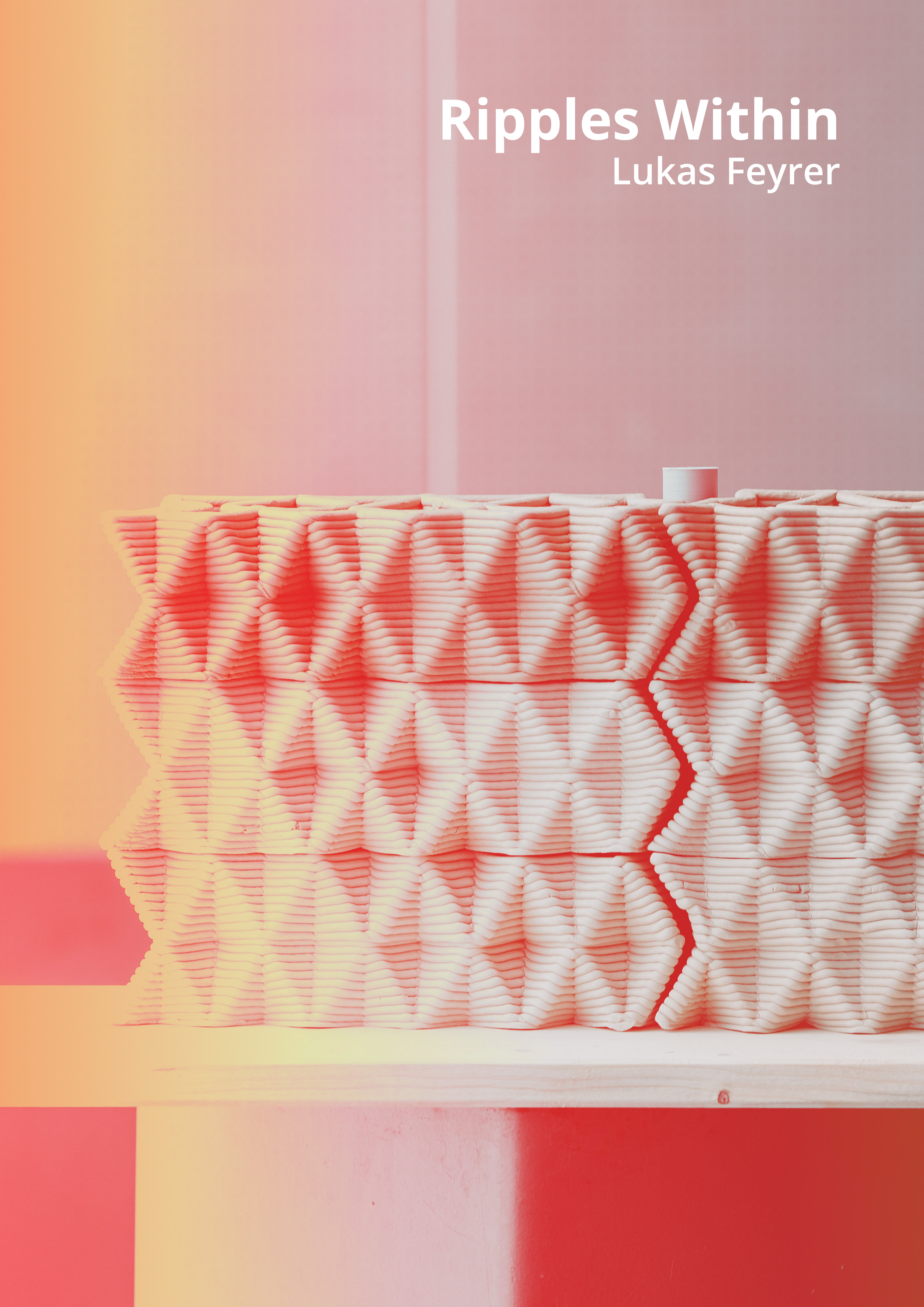
16 Testprint manipulated surface and infill

17 Front view facade



Ripples Within

Lukas Feyrer



Ripples Within

A clay printed facade system with integrated dry joint assembly logic and multi-layered surface design

1

1 photo of the final demonstrator wall section printed at half scale on display during the final presentation.

Preface

Ripples Within was a modular ceramic 3D-printed façade system that was designed and fabricated utilizing advanced digital technologies such as parametric modeling and additive manufacturing. The task was to develop and realize a 1:20 scale façade wall that was segmented into parts and informed by the investigated experimental processes such as parametric design, assembly, interface connection, and functional integration.
Besides developing the overall form, the focus was on producing a sectional demonstrator that showcased the architectural and structural details of the façade, such as openings, connections, assembly method, material integration, and surface expression. To fully embrace the potential of the advanced 3D clay printing method and allow for a unique form and structural expression, my façade design was entirely parametric. From the design of the surface pattern to the development of the individual brick segments, all steps were parametrically coded to allow for easy customization and adaptability of each parameter. The design featured a multilayered surface pattern that created a different impression depending on the viewing angle and lighting conditions. Additionally, I developed a dry-joint assembly method that allowed for easy assembly and disassembly of the individual bricks without the need for any additional binders.

Early Explorations

Since this had been my first introduction to digital fabrication and additive manufacturing in general, I started the project by learning the parametric design tool Grasshopper, which was used in this course. Through an introductory workshop, I gained the base skills required to develop my façade design, which I then began to further explore through various experiments. The iterative nature of the parametric design process allowed me to test my initial design ideas and quickly develop different surface variations.

To gain an understanding of the potential as well as the limitations of the clay extrusion technique and the robotic printing setup used, I began printing multiple small test specimens, exploring various printing parameters such as layer height, extrusion speed, and material properties like shrinkage during the drying process. These experiments proved to be very valuable for assessing the feasibility of my surface design explorations.

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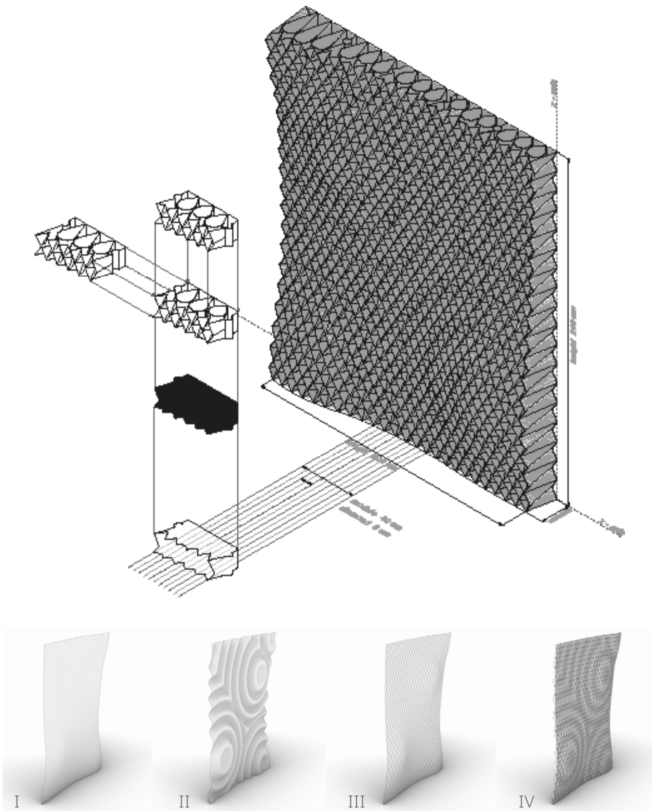
Surface Design

For the surface design, I wanted to create a multilayered pattern that changed its appearance depending on where the observer stood relative to the façade, as well as on the changes in light and shadow cast by the sun throughout the day.

In order to achieve the desired effect, I created three separate surface deformations that, layered on top of each other, formed the final façade surface. The first step was to give the façade an overall deformation, creating three high points that the surface draped around. This was the first level of perception visible when observing the façade from a greater distance, as this deformation defined the overall shape of the wall. The second pattern was a water ripple effect applied to the curved base surface at the locations of its high points. In the final step, the diamond pattern was applied to the surface, and the midpoints of the diamonds were moved inward, creating the three-dimensional surface pattern that became dominant when observing the wall from close up.



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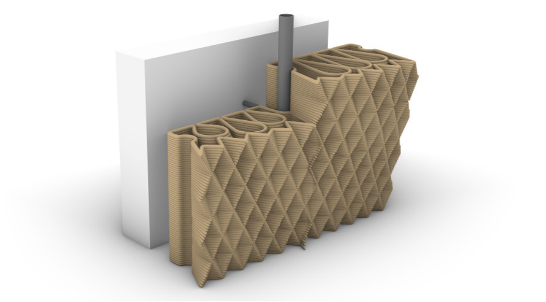
2 early prints experimenting with extrusion parameters and first design ideas

3 diagram of the diamond facade pattern. Multiple layers of depth are combined to create the final surface pattern



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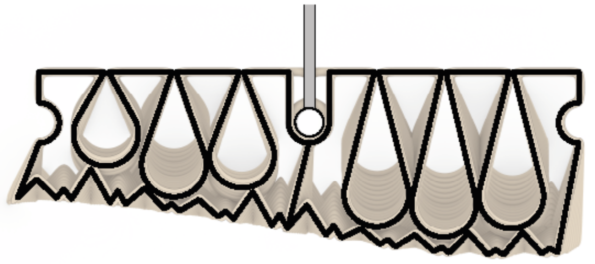

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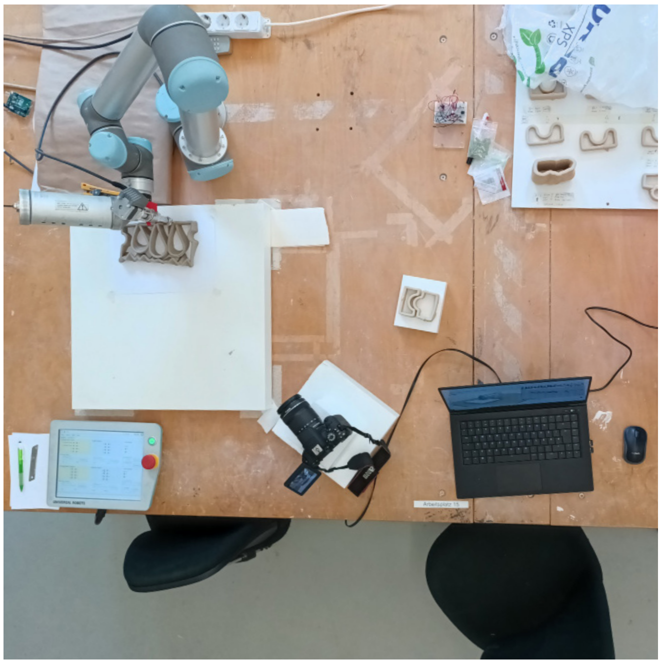

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4 facade assembly diagram including dry joint and surface mountig support tube

5 dynamic infill loops follow the curvature of the brick's surface

6 impression of the fabrication setup during final production at modell-bauwerkstatt. A UR 5 Universal Robot with Lutum Clay Extruder end effector was used for the fabrication process

The depth of these diamonds was defined by the depth of the ripples in the second pattern. The combination of these two patterns created the illusion of ripples emerging within the wall when stepping further away.

Assembly & Infill

The façade was divided into individual bricks with a width of 40 cm and a height of 13.3 cm. The brick depth varied from brick to brick due to the curvature of the surface, making each brick a unique specimen. With traditional manufacturing methods, the complex surface geometry, along with variable brick dimensions, would have significantly complicated the fabrication process. The additive manufacturing method, however, was particularly suited for such operations, as no unique formwork was required. Each brick consisted of three parts: the patterned surface, a semicircle connector on each side of the brick, and the back wall with three infill loops to strengthen the brick. Like the façade design, the bricks were fully parametric as well, allowing for complete customizability of each brick component. The infill loops were generated with a custom approximation script, which enabled them to follow the geometry of the brick face, thus providing a capable support structure.

The connection and assembly system of the façade was designed to enable cradle-to-cradle material flow using dry joint connections that did not require any additional binders. Male and female connectors on the sides of each brick were used to form a strong brick-to-brick connection. Every third brick, a structural tube was inserted in a female-to-female connector combination, structurally locking the façade segments into place and providing a tie-in point to anchor the façade assembly.

Fabrication Process

Setup and Parameters:

A Lutum Clay Extruder with a 0.5-diameter nozzle attached to a Universal Robots UR 5 robot arm was used for the brick fabrication. The printing path was generated from the individual brick geometries within Grasshopper, and the printing parameters were set based on the material properties of the clay used. The parameters available to control the robot and the extruder were: layer height, extrusion speed, and printing speed.

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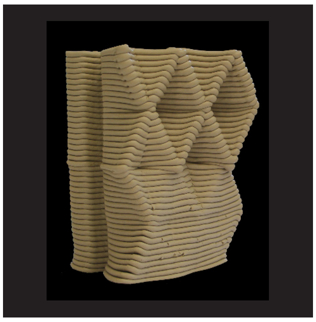

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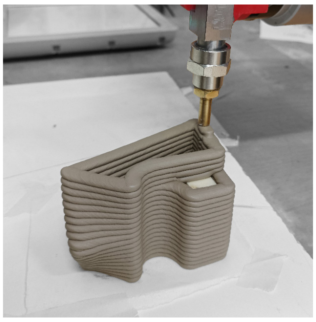

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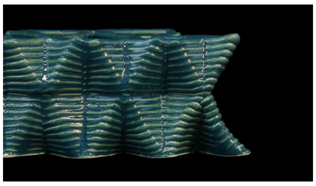

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The final Demonstrator

An eight-brick section of the wall was selected to produce the sectional demonstrator. For the printing of each brick, the printing path and parameters were converted into g-code and sent to the robot for printing.
After printing, the bricks were dried and fired. To minimize the risk of cracking and uneven shrinkage, they were covered in plastic foil while drying. Firing the dried bricks significantly improved their strength and durability. To further explore the surface expression of the façade, one brick was selected to be glazed and refired. The glaze completely transformed the brick visually and functionally, as it became water-resistant, revealing new potential applications.

7 impression of the clay extrusion during printing

8 experiment to print onto a previously printed brick after refillingthe clay cartridge required due to its limited volume

9 using custom support to extrude over a void part of the brick to create a cavity for the wall support anchor

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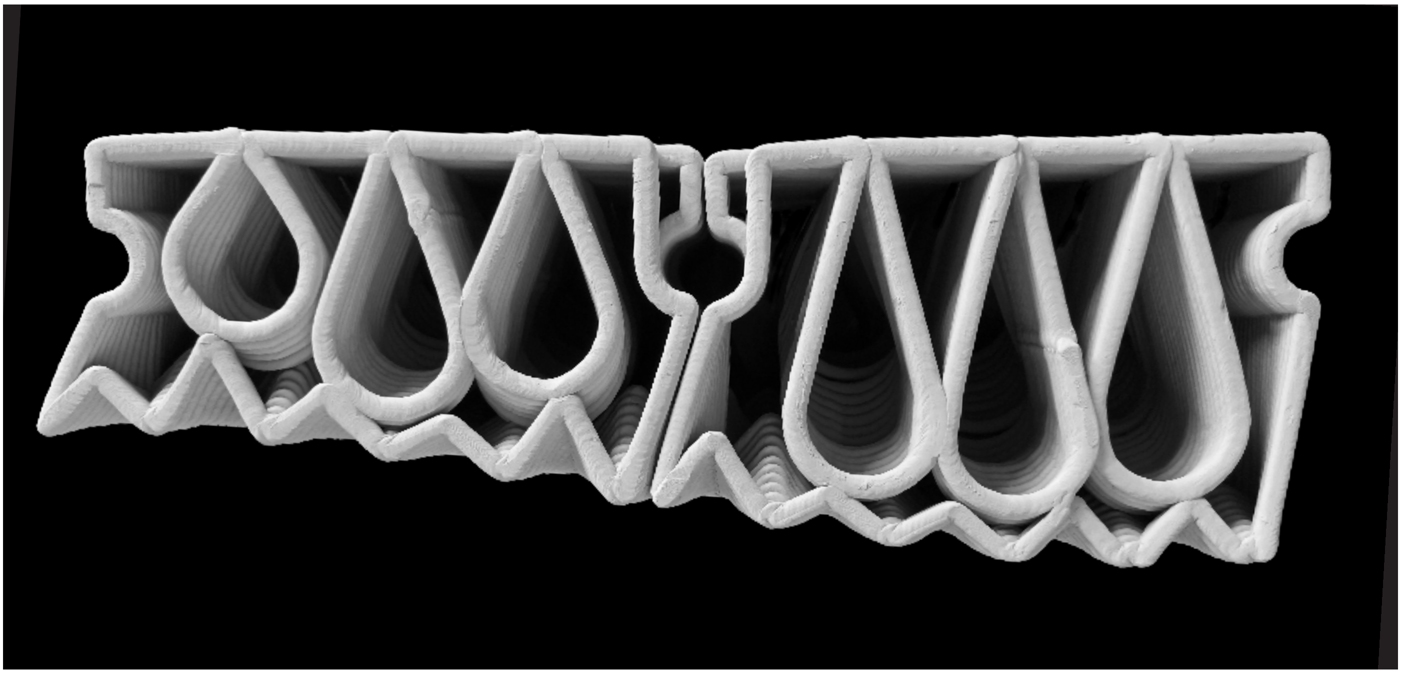
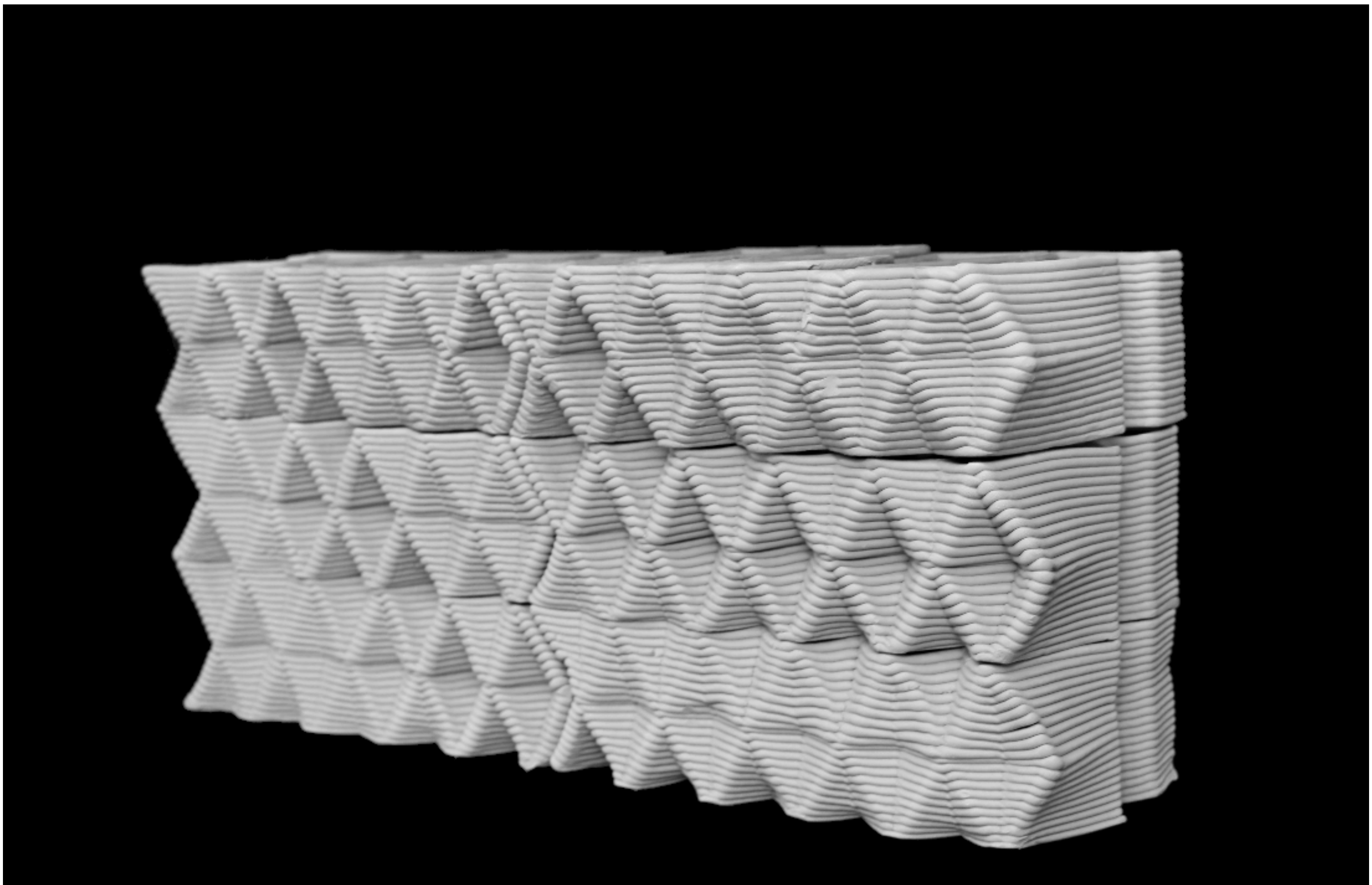
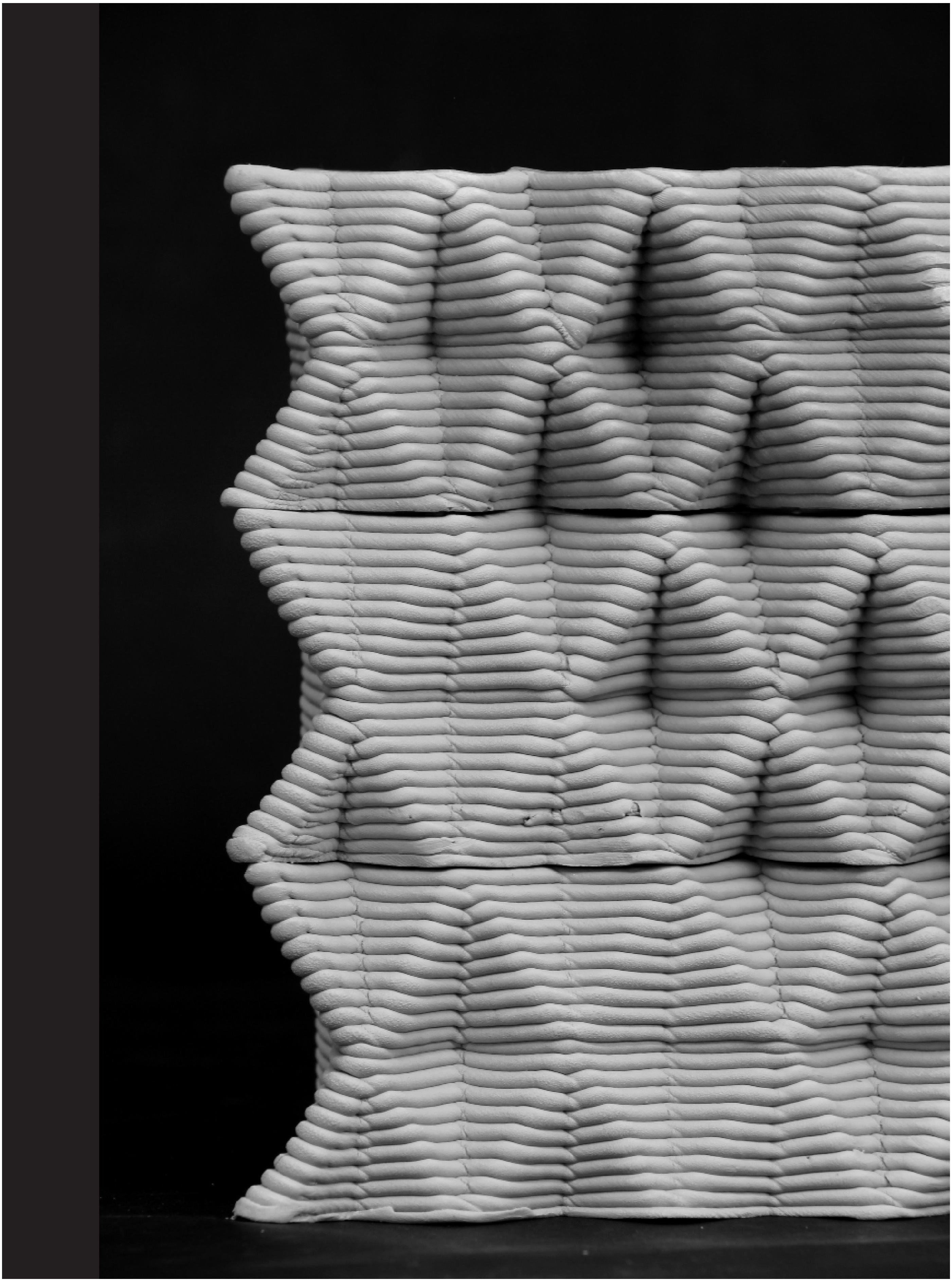
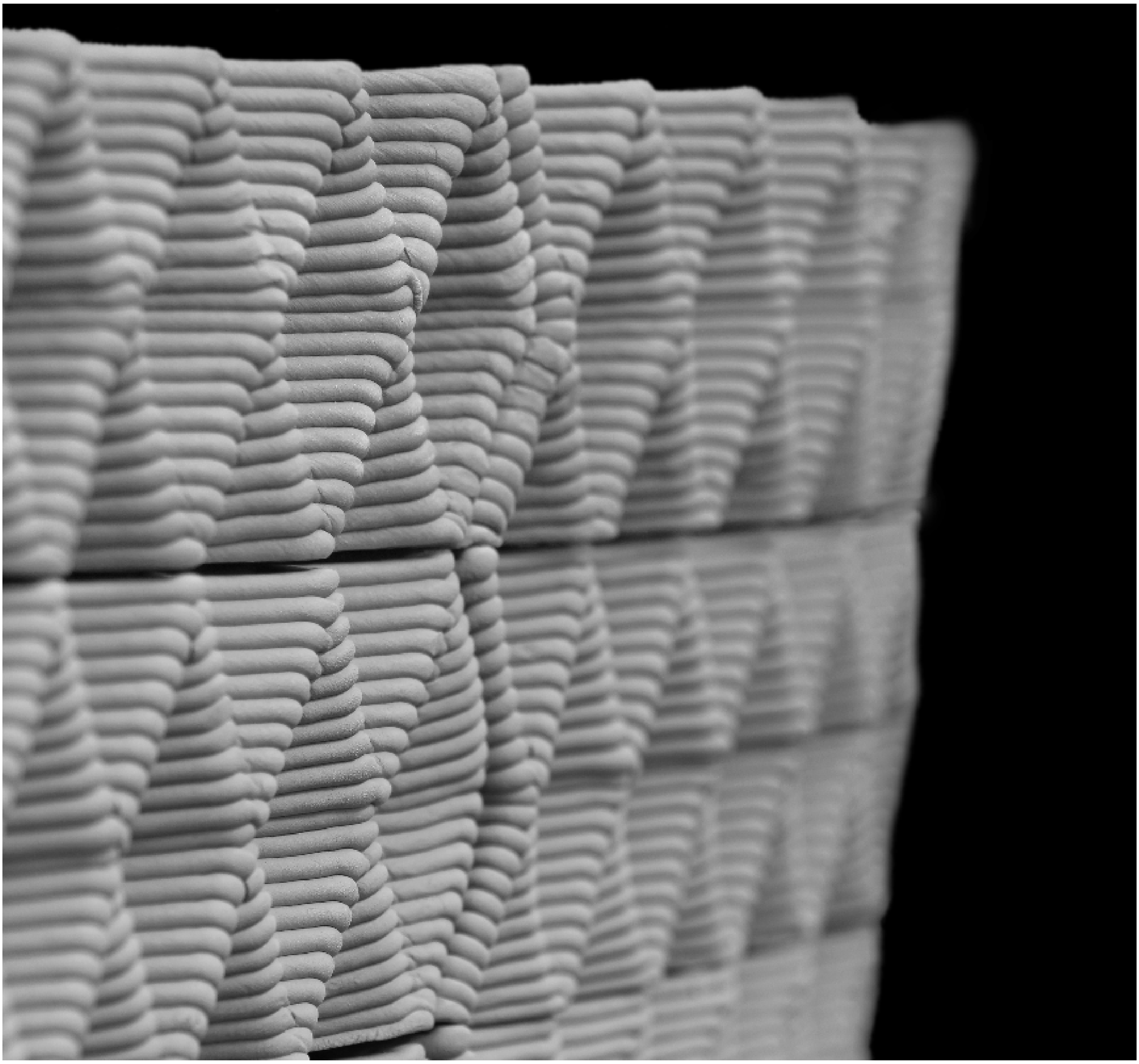
11 glazing a fired brick to seal the surface

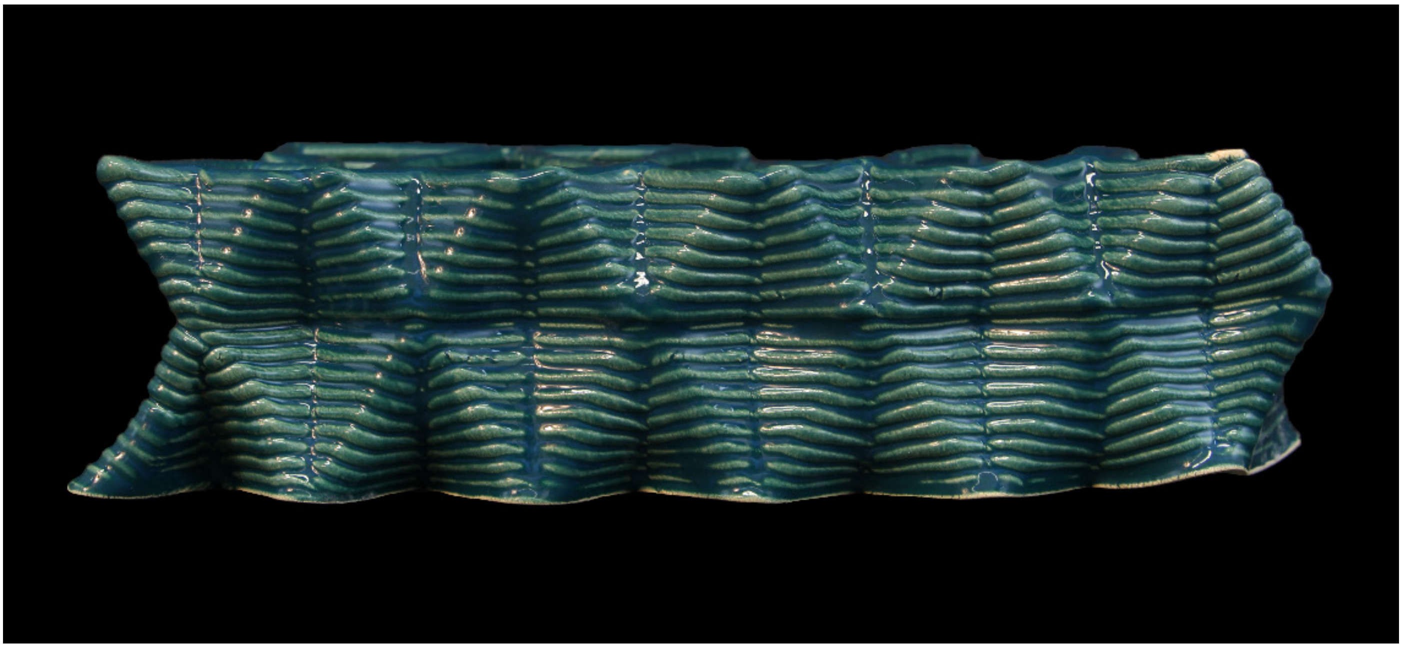
12 impression from the final presentation

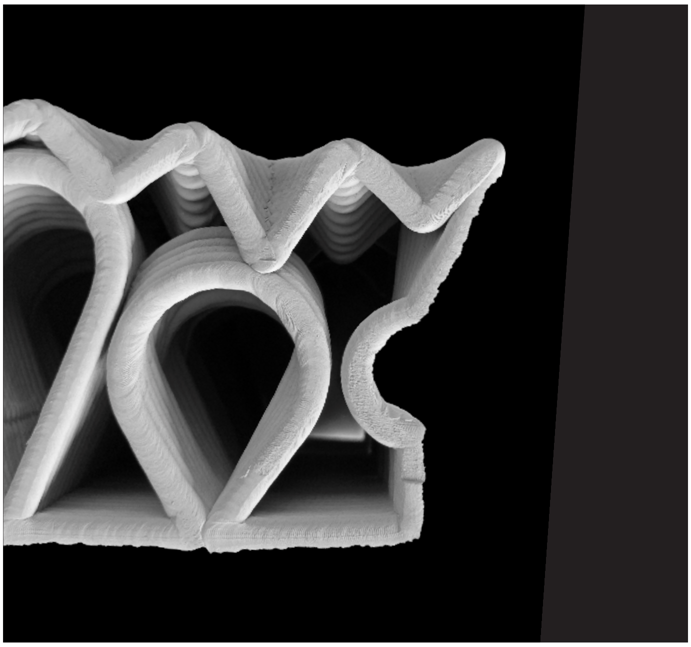


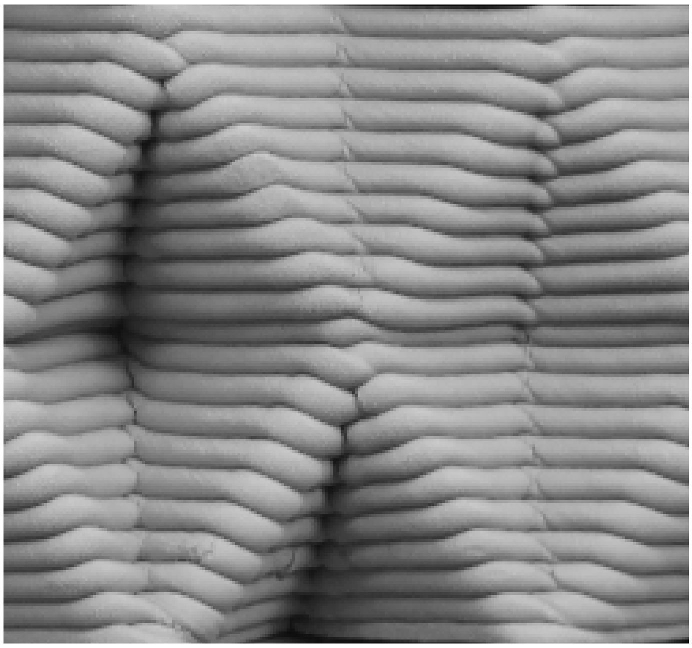












Architecture in Motion

Solia Stamer

Moving Architecture

Creating a surface structure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Changing the original Layer Structure

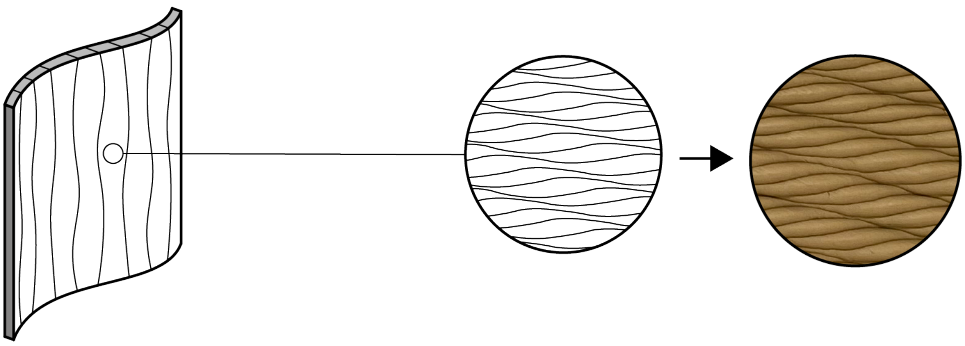
Earth printing is a process of layering, resulting in every layer being visible in the final outcome. This creates a very unique surface structure. As a first step, I attempted to modify the existing structure and give it more dimension.I increased the curvature of the robot’s path and shifted the curve slightly in every layer. As a result, the clay appeared to change its thickness throughout the layer, creating an interesting surface texture from the beginning.

During my research, I discovered that multiple parameters affected the visual outcome of the structure. Firstly, there was the possibility of pushing out the curves to add more dimension. Additionally, I adjusted the shift between the curves and reduced the layer thickness from 3.2 millimeters to 3 millimeters. This compressed the layers more and made the individual layers less distinguishable.

1 Surface structure of my first printing test.

2 Surface structure of my final wall design.

3 Piktogram of the pattern in a bigger scale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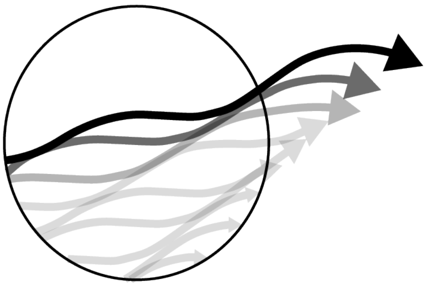
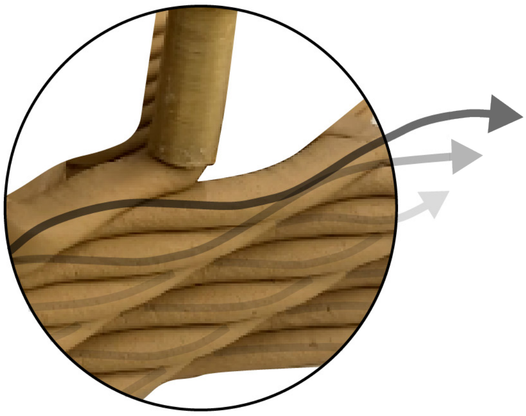
How does the robot move?

Usually, the robot repeated the same path over and over again for each individual layer. Whenever the path was changed between layers, the still-wet clay received less or no support.
In my case, the robot printed the same path but shifted it slightly in every layer.





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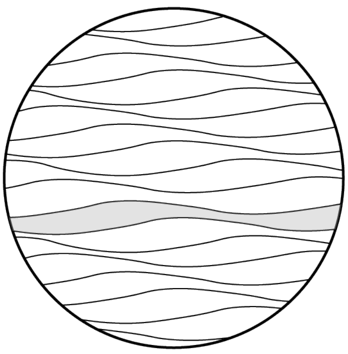
How does the layer thickness changes visualy?

The amount of clay the robot pushed out depended on the pressure, speed, and consistency of the clay. The robot compressed the layers at a preset height. All the parameters usually did not change during the print. However, in this case, the clay was not equally compressed at the edges, creating a wavy pattern on the surface.



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2 Robot Movement

3 Visual change of layer thickness

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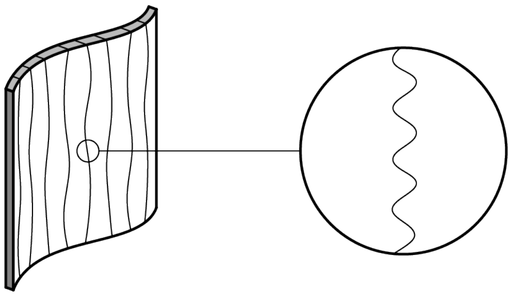

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Happy mistakes - interesting solutions

Sometimes, unexpected results and mistakes led to unusual solutions.
In this case, the pattern created a very interesting curvy effect at the edge of the brick.
Starting the same pattern in reverse on the next brick resulted in a unique joint line pattern.

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7 unexpected brick edge

8 Brick edge

9 Piktogram of the joint line

10 Pattern of the joint line

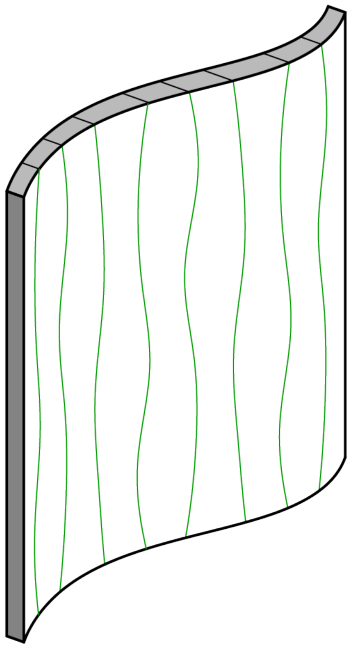
11 Piktogram of the pattern scale

Joint line in a bigger scale

What worked on a larger scale also worked on a smaller scale.
When looking at the whole wall, it became evident that the vertical joint lines were also curvy. This naturally prevented the bricks from vertical movement and made the design more visually interesting.

Same curve - different scales

The same shifted curve pattern could be found at different scales throughout the entire wall. Starting with the overall wall shape and the joint lines at various scales, and of course in the surface pattern.



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12 Piktogram of the joint lines in the wall

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11 Render of a wall piece

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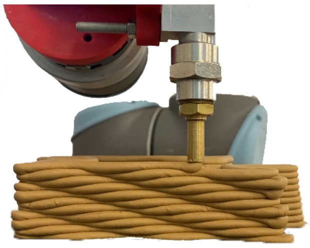

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Testing the methode

The material clay was a highly traditional building material. There were numerous possibilities for processing it, which were continuously being further developed and explored. One of these methods was Earth Printing. Processing such a natural material like clay with modern devices was challenging. Therefore, it was important to regularly conduct print tests with the robot during the design process and interact with the design and the given printing parameters. We conducted a variety of tests with the robot, including firing and glazing individual bricks.

7 Brick airdried and after the first fire

8 Glacing process

9 Robot setup

10 Fitting test

11 Surface test

12 Fired bricks

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12 Glaced bricks

13 Earth printed wall segment and glaced bricks

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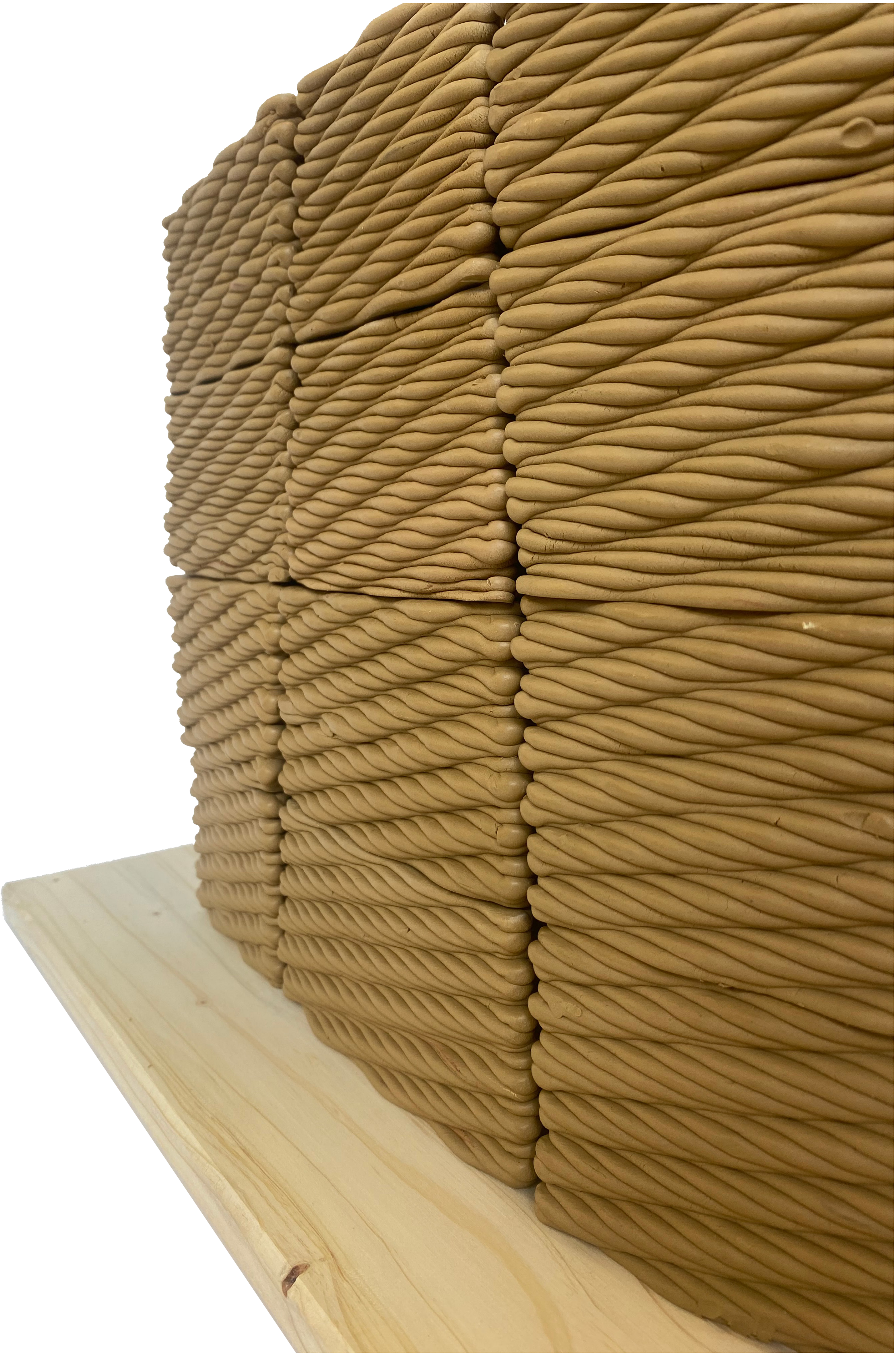
13 Earth printed wall segment and glaced bricks



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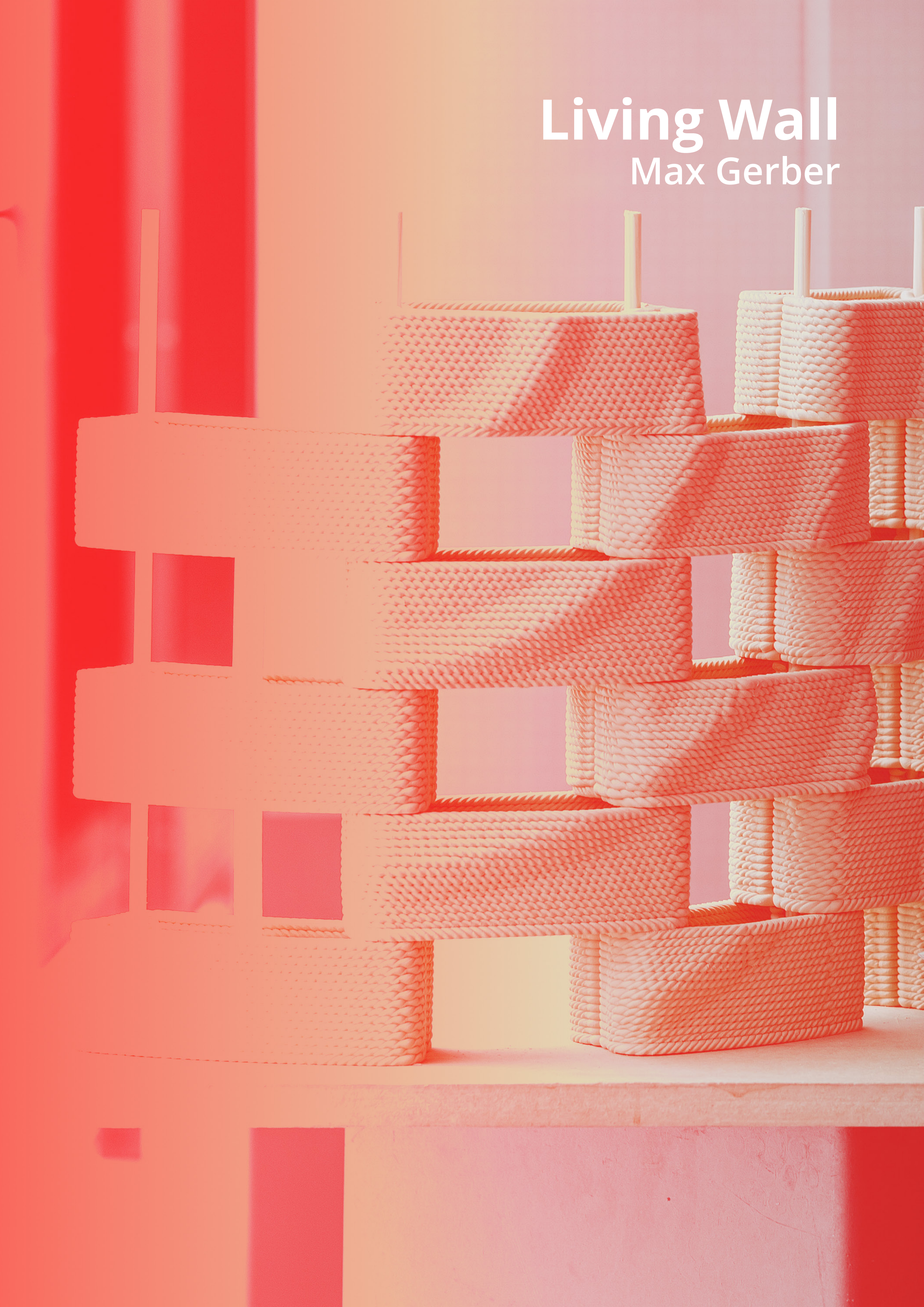
14 Printed wall segment

Living Wall

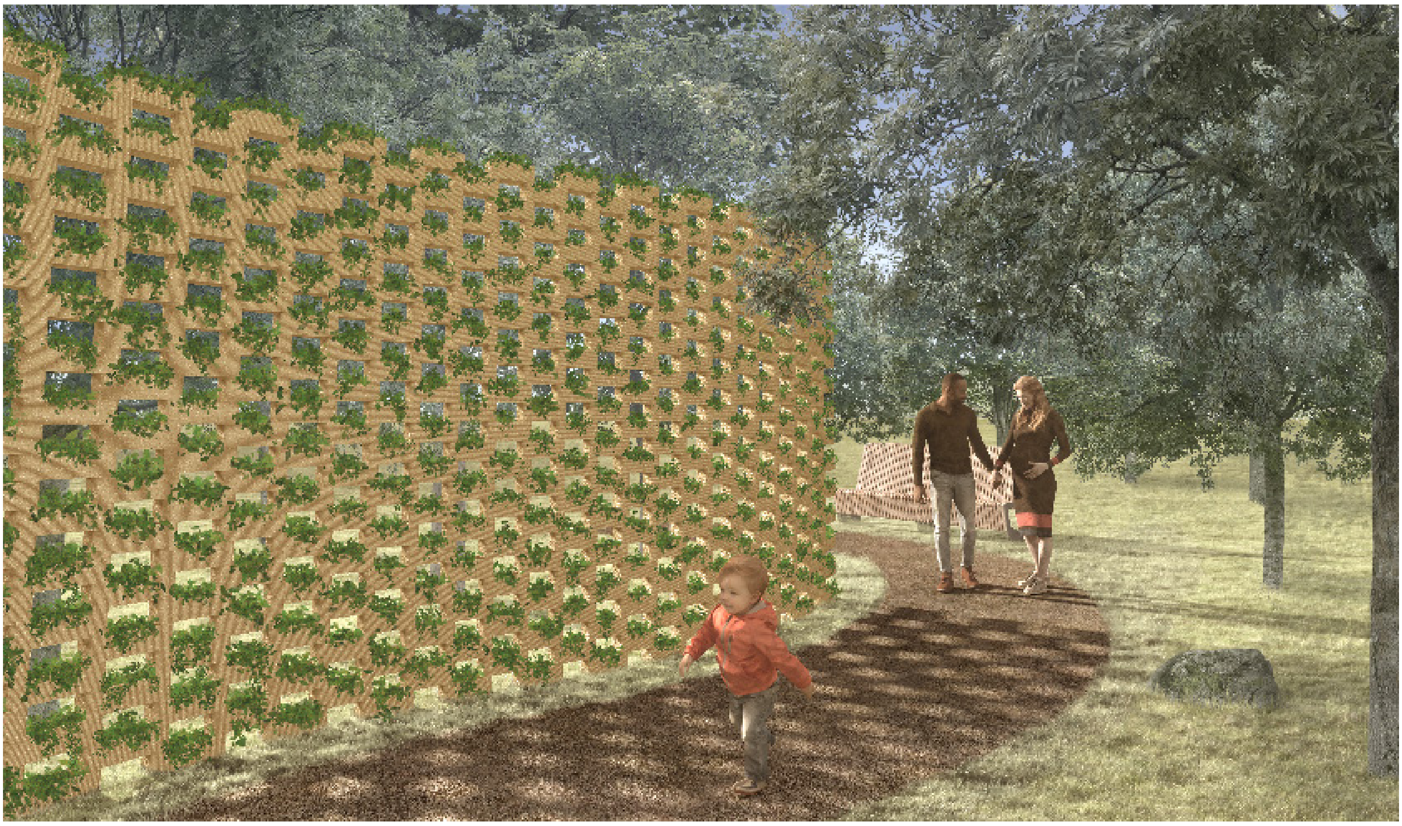
Max Gerber



Living Wall

An exploration of traditional building practices and living with nature

"Perfection is shallow, unreal, and fatally uninteresting." ~ Anne Lamott



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1 Visualization of Living Wall in an open-air context, for example in a park.

Preface

As technology advanced, so did humanity's desire to search for ever-new forms and materials in the architectural space. Parametric design explorations, as well as the material sciences that inevitably needed to accompany them, set the groundwork for the next architectural revolution.

With this in mind, it was important, however, not to forget the value of tradition—the inherent knowledge and building practices that had been passed down and perfected over many thousands of years. There could be no future without the past, and any push toward advancing architectural and engineering practices, without first considering their cultural implications, inevitably hindered societal development and the acceptance of new technologies rather than accelerated it. This was due to the inherent need for familiarity, especially when it came to the built environment. While technology was objective, architecture needed to remain subjective.

Unfortunately, the focus on constant technological advancement under all circumstances often underestimated the role that space occupied in people's lives. Architecture existed in a higher reality of being, a state that was unattainable for the everyday object—and even for most art.

The value of architecture and space

Architecture needed to inspire, and not in the ordinary sense in which inspiration could come from any form of art, but in a much more universal sense. For space was not nothing. People inhabited space and were, in turn, inhabited by the images of it. While a painting or a sculpture, for instance, could inspire, remind, and make one think, people were always only faced with it. The pervading sense of unreality, of something artificial, prohibited them from fully dissolving into the experience. Art could show the ideals of intimacy, desire, and repose, but only inhabited space wove them into the very fabric of life. And it did so through the ingrained associations that had been bestowed upon people by past generations.

Architecture, because of its omnipresence and because it challenged mind and body to an eternal dialogue from the time people were born, did not merely belong in the domain of matter but in the domain of what mattered. As the French poet Noël Arnaud once wrote, “I am the space where I am.”

When thinking about the inherent emotional value of architecture, superimposed with the obvious need for constant improvement and pushing toward the next technological milestones, there was no either-or. They needed to be considered in synergy rather than separately.

Ceramics, for instance, had a rich history of being used as a construction material for many thousands of years, starting in ancient Mesopotamia, where the Sumerians and Babylonians developed techniques for producing fired clay bricks around 4000 BCE. Since then, the applications for the material had been refined throughout many cultures, such as in ancient Greek or Islamic architecture, where the versatility of ceramics was explored to create intricate designs and patterns.

More recently, there had been many examples of everyday brick architecture, such as in New York, where bricks were made a mandatory construction resource in 1835, as well as countless not-so-common examples of breathtaking contemporary architecture, such as Antoni Gaudí’s buildings, Frank Lloyd Wright’s experimental houses, or Francis Kéré’s educational infrastructure in West Africa.

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2 Project presentation at TU BS on the 26th of May 2023.

3 Living wall at the Mark der Möglichkeiten exhibition at TU Braunschweig on the 15th of June 2023.

4

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4 Unfired bricks with attractor curve pattern during the project presentation at TU BS on the 26th of May 2023.

5 Fired bricks, photographed from the flat side, fired and filled with plants.

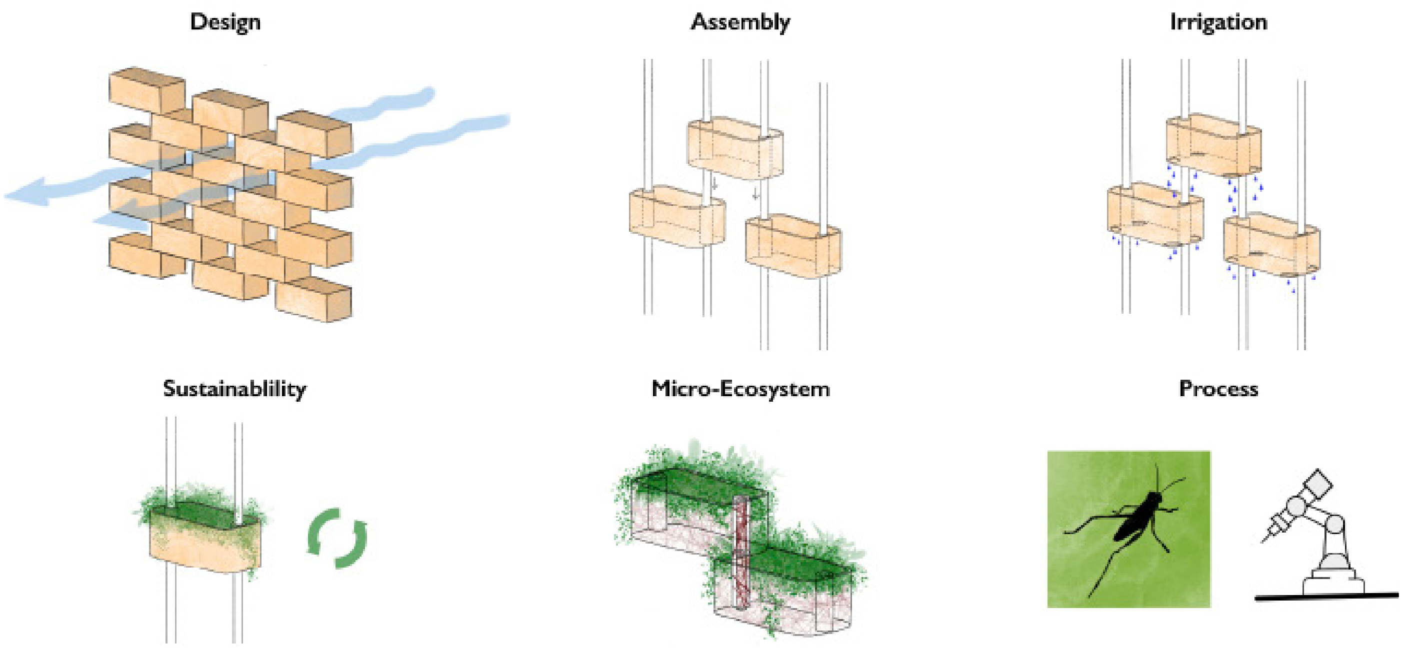
6 Prototype of the basic module, fired, glazed and filled with plants and soil.

That being said, the use of clay and ceramics in architecture was inseparably tied to the cultural and technological development of the human race. An in-depth exploration of the importance of these materials for architectural practice, as they gave form to past and future cultural expressions, had been carried out at another point. Suffice it to say that there were few materials, whether naturally occurring or artificially created, that could reproduce the inherent connection to nature, the rich history of craftsmanship and building tradition, the aesthetic possibilities, the favorable material qualities such as durability and thermal comfort, or the cultural value of clay and ceramic bricks.

Living Wall: Concept

The design concept for "Living Wall" was based on the assumption that the last thing needed at the time were more walls that separated us from each other and from nature. With the idea of a perforated brick façade came the first critical issue: the assembly. Since there were no horizontal connection points between the individual bricks, a circular tube joint was designed at the intersection of the layers where a rod could be fed through from top to bottom. The advantage of this was that even if it wasn't a tight-fitting rod at all points, due to slight differences in the joints caused by the printing process or during the firing, the rods could be secured in the ground beforehand and the bricks could be threaded through one by one from above. This way, the construction remained stable, as horizontal forces due to wind were minimized by the spaces in between the bricks. Additionally, the connection was hidden once the bricks were filled with soil. Next was the irrigation system. Since each brick could be considered a tiny plant pot, it was crucial to prevent water from pooling at the bottom. Also, it would have been rather impractical to water each brick individually. To solve this problem, four small trickle holes were located next to the joints where the bricks overlapped, where they would also be hidden but served to allow the water to trickle down the whole wall once the soil in each layer was saturated. This way, the wall could be irrigated from above and even by rain without certain layers staying dry and others being too wet.

In comparison to traditional brick construction, the design was much more sustainable as it was based on efficient design and production methods that could be optimized for mass production without



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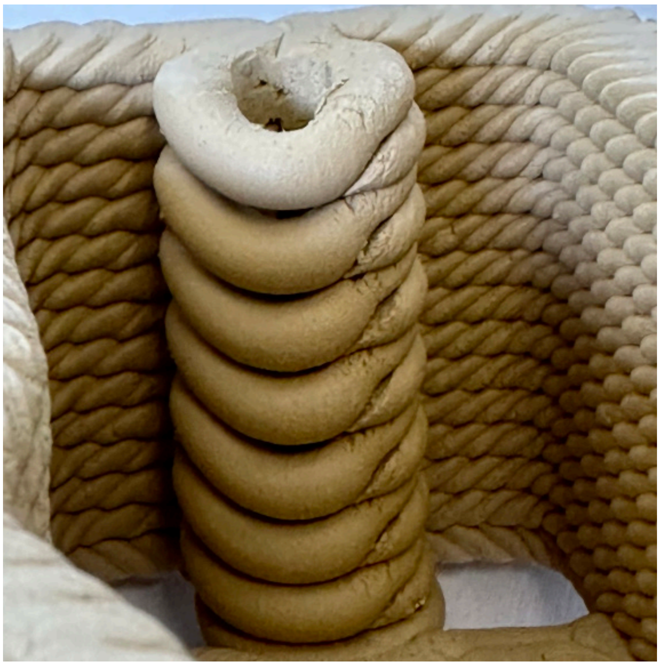

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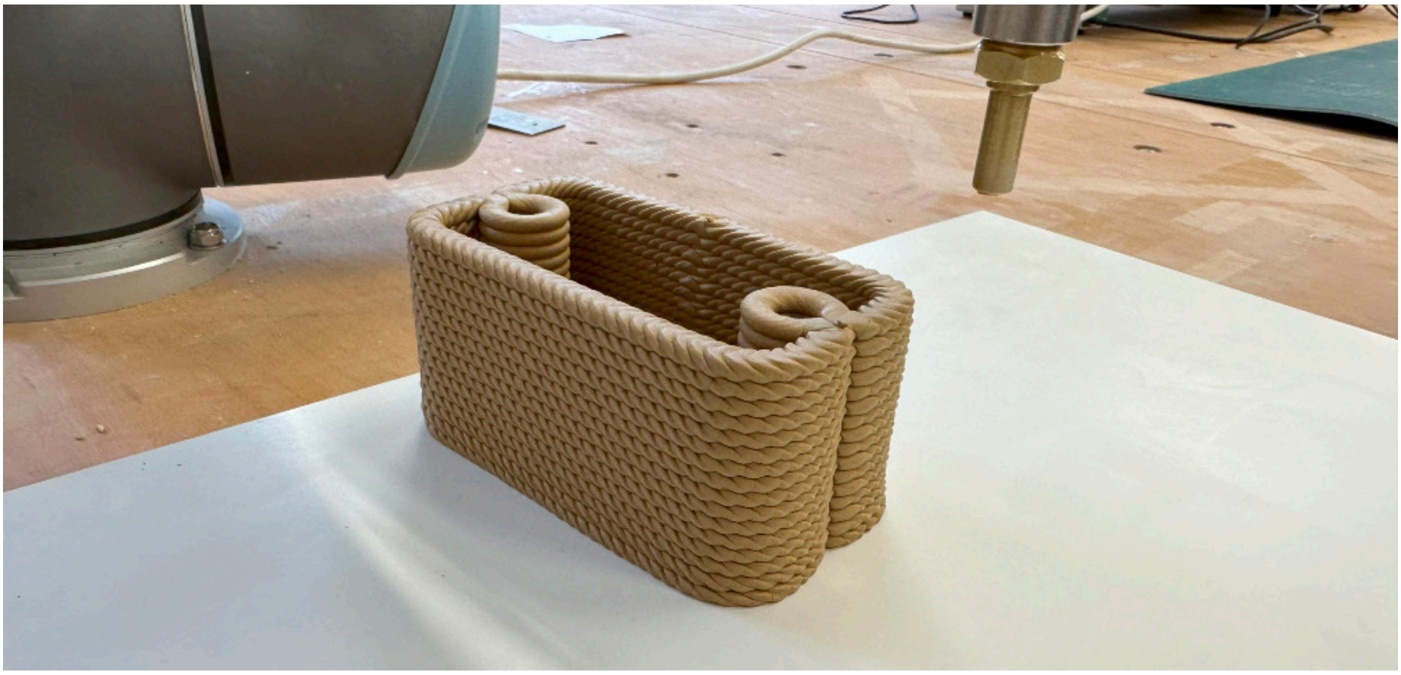
significant material waste. Unlike traditional brick-laying, no cement was used in the construction, and the rod was made from wood or another biological material. The idea — which was intended to be the subject of future research — was that the roots would eventually grow through the trickle holes as well as through tiny openings in the joints, where they would, over time, degrade the rod and ultimately form the connection between the bricks themselves.

The goal was not just to design a perforated brick wall decorated with plants but to create a living ecosystem where interconnected roots could transfer nutrients across the structure. The rod would provide initial stability before serving as nourishment for the roots weaving through the joints and linking the layers. To enable this, entry points were incorporated into the cylindrical joint. A start-stop algorithm in the extrusion process omitted certain path points on every other layer, creating small slits as clay drooped from the layer above, allowing roots to penetrate.

7 Concept sketches for the main themes of the project.

8 Prototype of start-stop algorithm in order to leave out parts of the joint loop for roots to grow through.

9 Initial concept idea for the root chanel and how the plants will grow through the entire wall in order to create an interconnected ecosystem.



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10 Printing of prototype.

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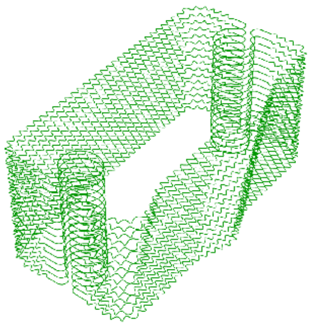
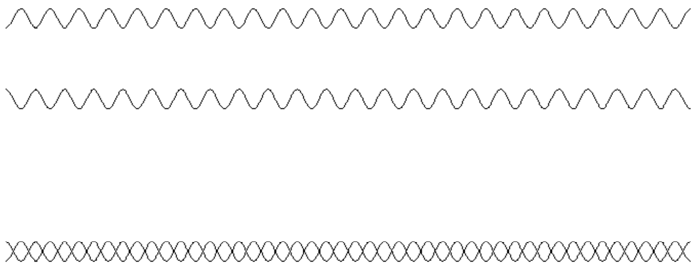
11 Putting together the model for the first time in the workshop.

Both parametric design technologies and automated production processes were used to take advantage of and explore the newfound possibilities of recent advancements in 3D printing with clay and ceramics. The weaved pattern was a result of two wave-curves, superimposed and shifted by half a wavelength.

To demonstrate the possibilities of the parametric design process, a pattern of circular attractor curves was applied to one side of the entire model, introducing another level of scale and connecting the individual bricks through the pattern.





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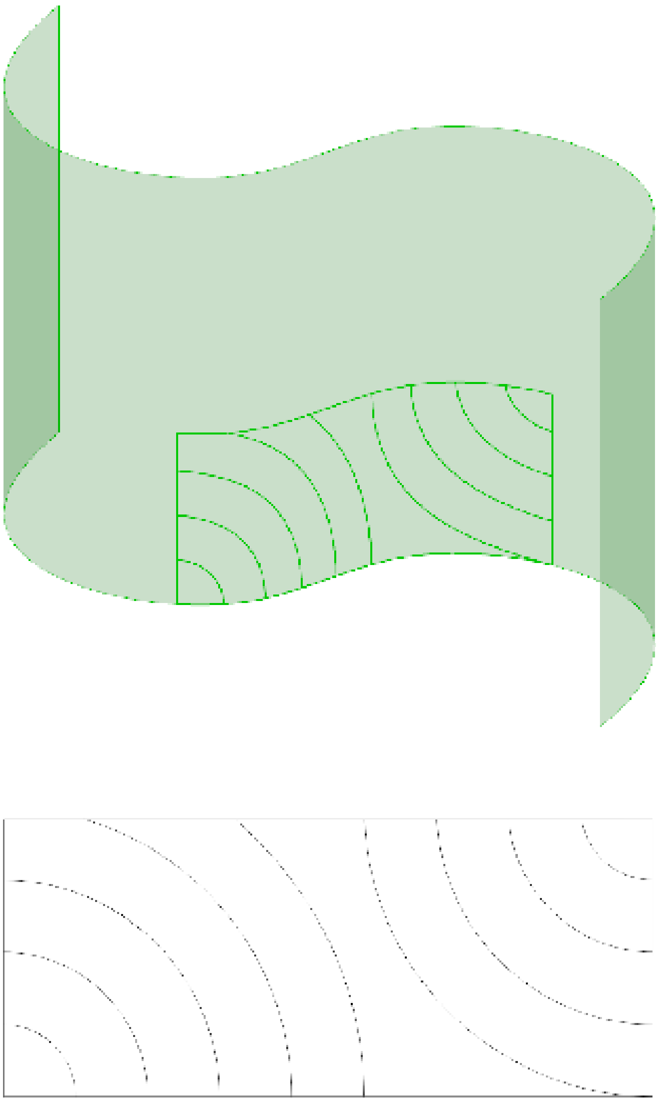

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13 Curve pattern applied in Grasshopper.

14 Curve pattern on finished model

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15 Unfired bricks with attractor curve pattern during the project presentation at TU BS on the 26th of May 2023.

16 Fired bricks, photographed from the flat side, fired and filled with plants.

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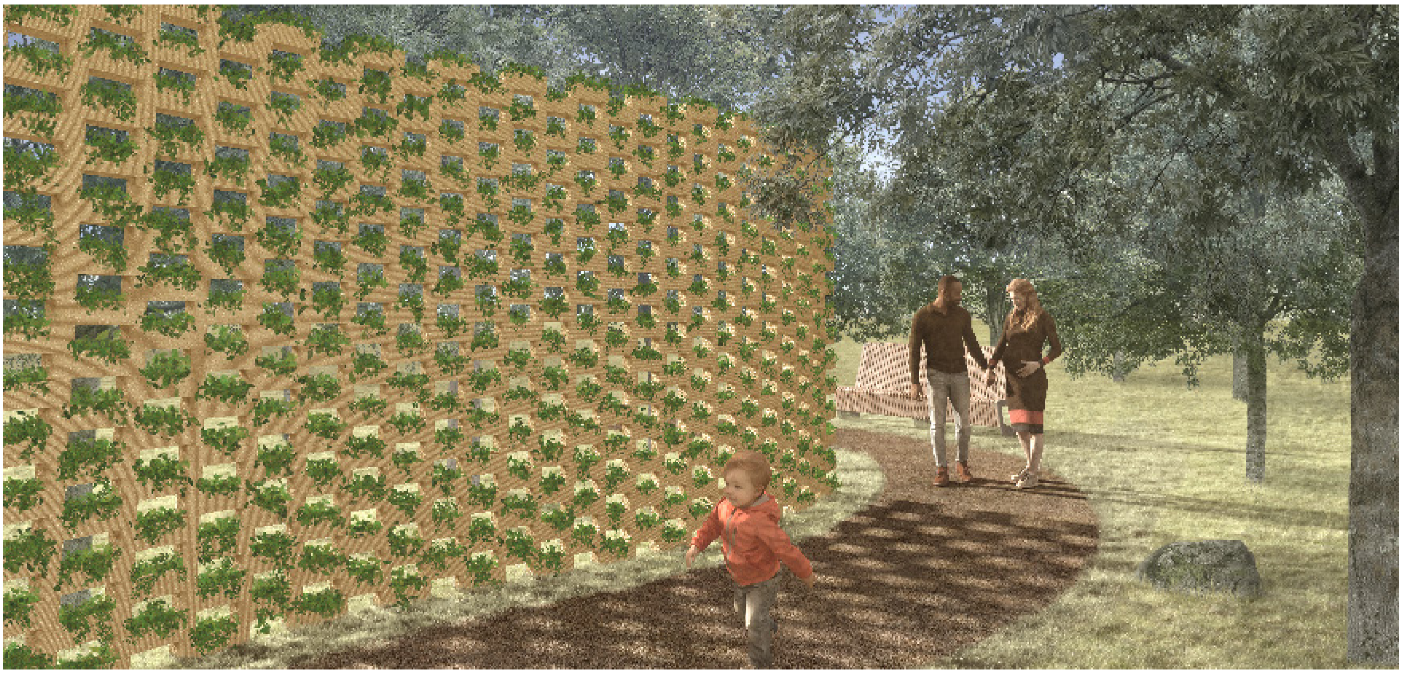

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17 Living Wall during the exhibition Markt der Möglichkeiten at TU Braunschweig on the 15th of June 2023.W

18 Visualization of Living Wall in an open-air context, for example in a park.

Vertical Landshape

Lisa Jagermann

Vertical Landshape

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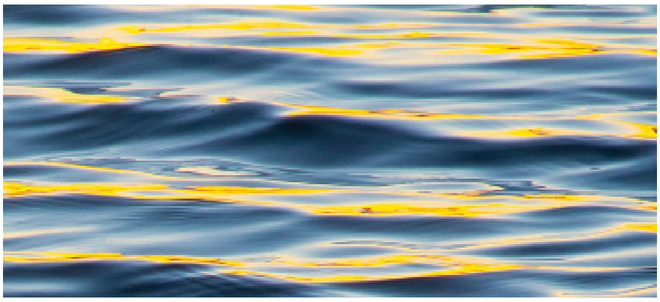

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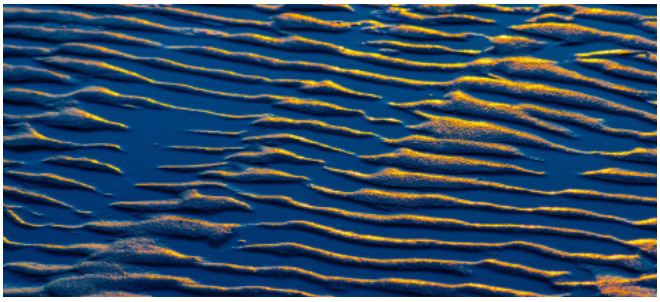

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Preface

Facing the task of designing an individual brick wall with a self-designed pattern, I came up with the idea to combine the beauty of well-known traditional brick architecture with the imperfectness and beauty of nature. Starting with the idea of designing a wall that creates the illusion of a beach, the sand, the sea with water and waves, and then setting the focus on the phenomenon of the Wadden Sea. The Wadden Sea was something very special, a UNESCO World Heritage site, the largest tidal flats system in the world, part of it belonged to Lower Saxony in Germany. Every day, the flood carried sand, clay, and silt into the area of the Wadden Sea. The sand of the Wadden Sea got thereby shaped by the ebb and the flow, creating an amazing, interesting, and especially unique pattern.

1 Printed wall segment.

2 Inspiration picture (Vecteezy.com - Ozean Wellen).

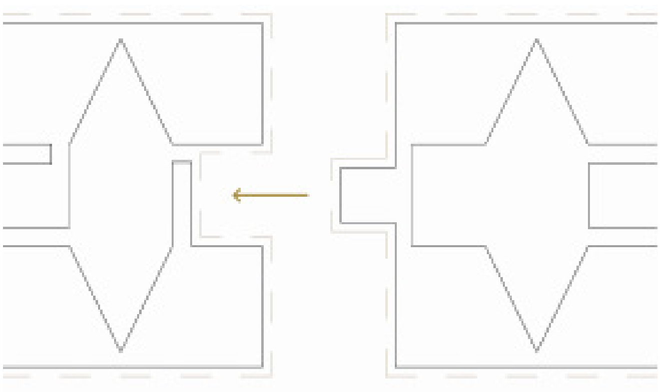
3 Inspiration picture (https://pixabay.com/de/photos/ebbe-strand-ab-druck-meer-242485/).

Design of the pattern

With the inspirational idea of the pictures of water, waves, and the Wadden Sea, I created a pattern with Grasshopper that was able to transfer the desired illusion. Segmenting the wall section with lines, creating points on these lines, and then manipulating the position of the points in the x- and z-direction to create the curves of the pattern. By adding a tool to also manipulate the depth of the points in the y-direction, the 3D effect of the facade appeared. The pattern could be assigned to the front and the backside of the wall, making the design usable for freestanding walls.

Wall segmentation and connection

The wall segmentation and the brick layout followed the rules of the classical brick bond. Each brick had dimensions of 40x24x15 cm (w/d/h) and could be horizontally connected by plugging the squared bulge on the short side of one brick into the provided slot of the adjacent brick.



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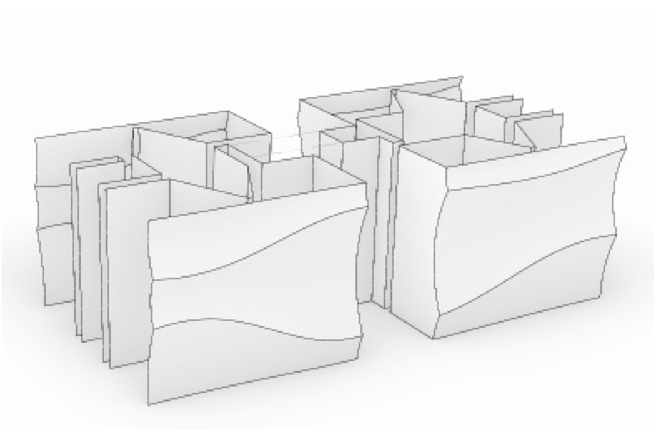

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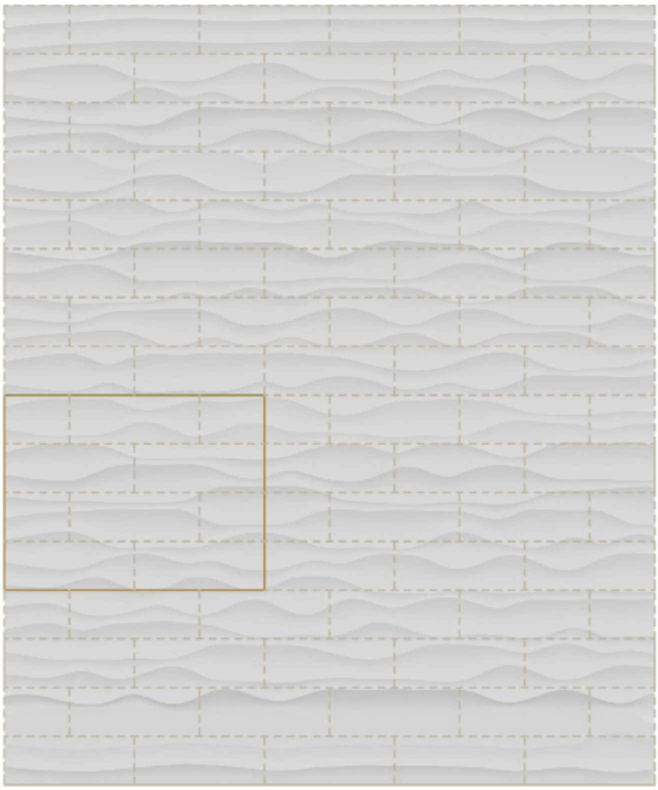

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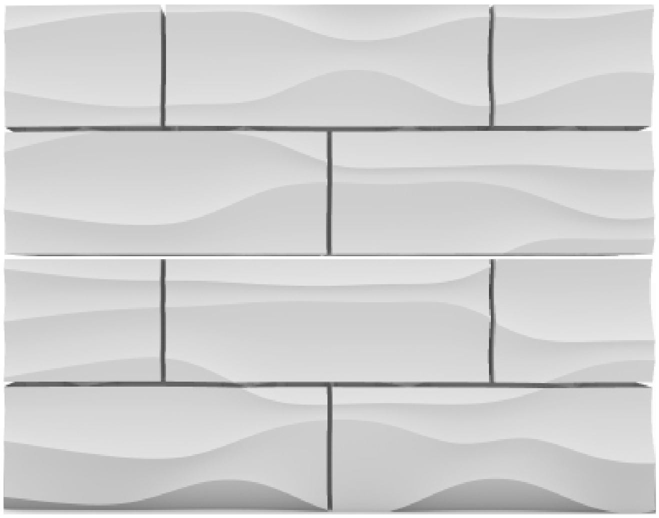

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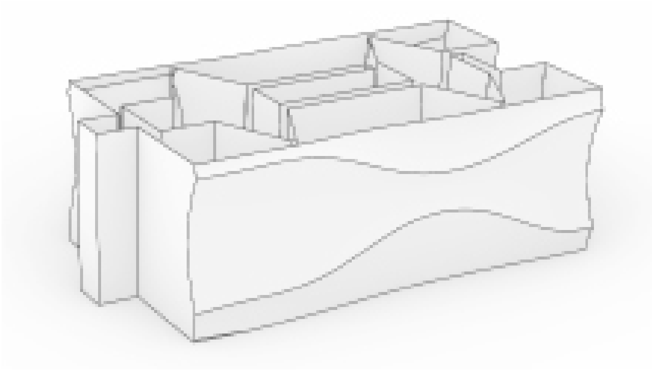

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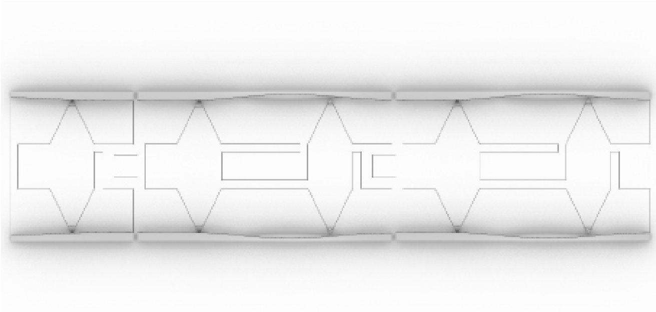
4 Connection between bricks - top view.

5 Connection between bricks - perspective.

6 Full wall design with brick segmentation and segment for printing.

7 Wall segment 80x60cm. 8 Brick example-perspective view.



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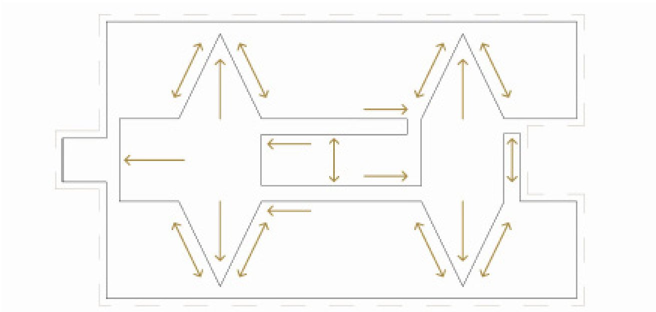

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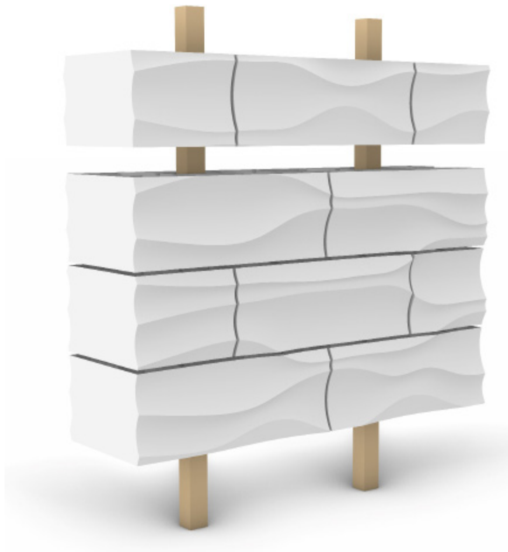

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9 Brick row with connection - top view.

10 Example brick top view drawing- infill tension forces.

11 Wall segment - vertical connection.

12 Wall segment - building and domestic installation.

13 Wall segment - insulation.

Structure, building supplies and insulation

The infill design of the bricks was created with a focus on factors such as statics, tension forces, strength of the bricks, and further technical and architectural additives. The triangular parts of the infill stabilized the outer lines of one brick at two positions on each side and stabilized it against compressive forces, while the inner part of the infill was also there for the stabilization and stiffness of the whole brick itself. Additionally, it created room for the vertical connections between the brick rows. For the vertical connection, depending on the height and the requirements of the whole wall, there was space to insert either wooden sticks or squared steel rods. The infill also included spots for building and domestic installations like electric cables if needed, and the rest of the space could be filled with insulation, such as rice-husk shredding or other loose insulation materials, for either thermal or acoustic purposes, depending on whether it was an outer or inner wall.

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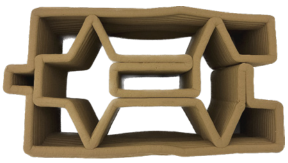

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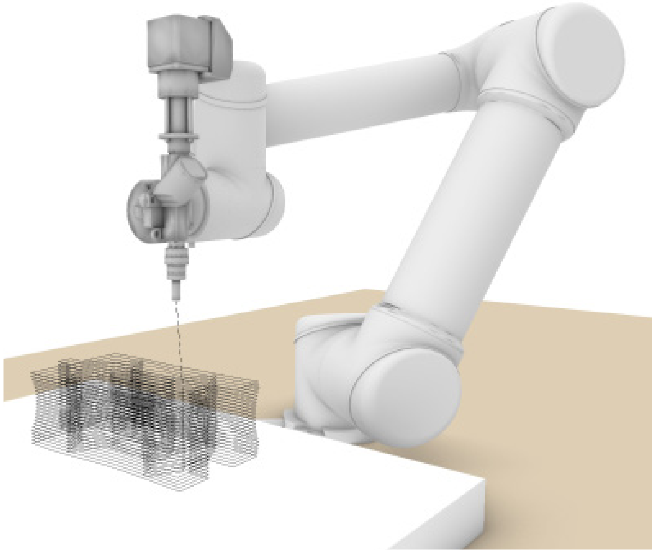

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Printing process

Starting with connection and design tests to improve the printer settings and determine the optimal offset for a stable infill, a fitting connection, and the desired design outcome. The very first prints were printed with a 3mm nozzle before switching to a 5mm nozzle to achieve a more realistic brick dimension for later prints. The final bricks were printed with a nozzle diameter of 5mm, a nozzle height of 16.5mm, a layer height of 3.2mm, and a speed of 15mm.

14 Final wall segment piped - digital model.

15 Final wall segment piped and split up into seperate bricks.

16 Design test trio without infill.

17 First brick with the combination of the facade design and the infill.

18 Depth facade design testing in a bigger scale.

19 Connection test prints.

20 First test brick for the final facade scale 1:2.

21 Robotic setup and printing lines of one brick - digital simulation.

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22 Picture of the final wall segment with regular lighting - front view.

23 Picture of the final wall segment with direct light from above - front view.

24 Picture of a section of the final wall segment with direct light from above - front view.

25 Picture of the final wall segment with direct light from above - perspective top view.

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Final facade - light and shadow

A significant and by now not mentioned feature of the facade design is the fact how the look is influenced by the light. Depending on the position of the sun if the wall is used as an outer wall or the position and amount of the artificial lighting if it is placed in a building the design gets more intense and the waves stand out a lot more. The light creates an interesting shadow pattern and the desired design effect gets even more intense. Another mentionable effect is the energetic and sustainability-relevant benefits a self-shaded facade has especially for warm climate zones and with regards to the issue of the global warming. If the sun reaches it’s maximum height in the middle of the day the facade is almost fully shaded by their own curvatures which helps to keep the surface of the wall cooler and leds to the fact that the building

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26 Final wall design digital visualization.

27 Fired and glazed bricks(left one glazed once, right one glazed twice).

28 Fired and glazed bricks(glazed once).

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Acknowledgment

We would like to thank Fanny Doberauer and Sandra Bödecker from the Ceramic Workshop at the Braunschweig University of Fine Arts for supporting and guiding the glazing process of the 3D Printed Clay Bricks

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Big thanks to the photographer Tjark Spille for documenting the final presentation of the students and photographing their models.


Earth Printing
Conclusion
FAIL BETTER