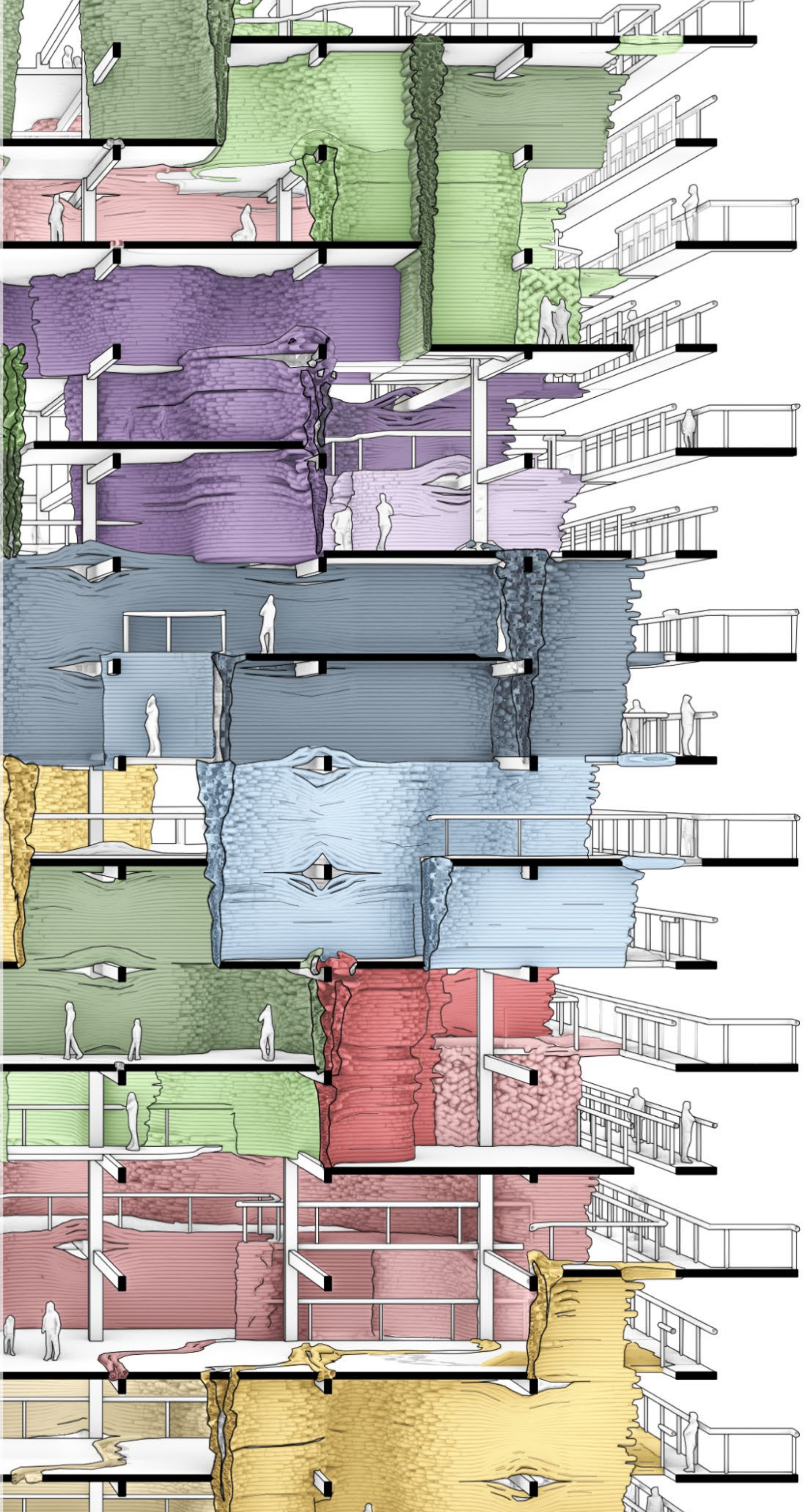

JITTER

The Humanization of Digital Manufacturing

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ABSTRACT

The digital age is currently evolving to a point where fabrication is making a seamless leap from digital data to physical objects, made possible through applications such as additive manufacturing and autonomous robots. In this beta period of Industry 4.0 where efficiency and low cost is prioritised, it may be easy to lose sight and relevance of the individual and the biology, which is perhaps not represented in the final manufactured object.

This thesis explores the convergence between human and machine through a series of experiments, with the intent to increase autonomous customisability within the process of digital manufacturing. By digitally simulating the imperfection and randomness inherent in the hand-crafted object, the 3D printer is able to fabricate unique objects, employing the computer as a predictive tool that imitates handicraft. Exploiting this method enables new design possibilities where architectural elements reveal themselves through the process of manufacturing.

The explored method is applied in the context of mass production, where pre-cast fabrication techniques currently used in public housing, particularly in Singapore, imposes monotony and anonymity in the living typology. In developing the method and exploring possible design components, a catalogue of spaces is formed resulting in a strategy that reinterprets the backyard into high-rise structures.

This thesis therefore responds to evolving manufacturing technologies by proposing a new method involving digital manufacturing while offering customised elements in place of pre-cast fabrication.

THESIS QUESTIONS

How can a digitally manufactured object appear hand-crafted?
How can these objects be constructed and mass produced autonomously?

1 Introduction

What is the purpose of this thesis?
What are the delimitations?
How has this thesis been researched?
1.1 Mass Customisation
1.2 Fabrication Methods

Purpose

This thesis breaks down the conventional method of 3D printing in pursuit of unique objects that can be used in the context of mass production, exploring the translation between 3D modelling and 3D printing. In doing so, the thesis aims to explore and showcase spatial possibilities in pursuit of strategies of mass customisation at the autonomous level in fabrication and in spatial qualities.

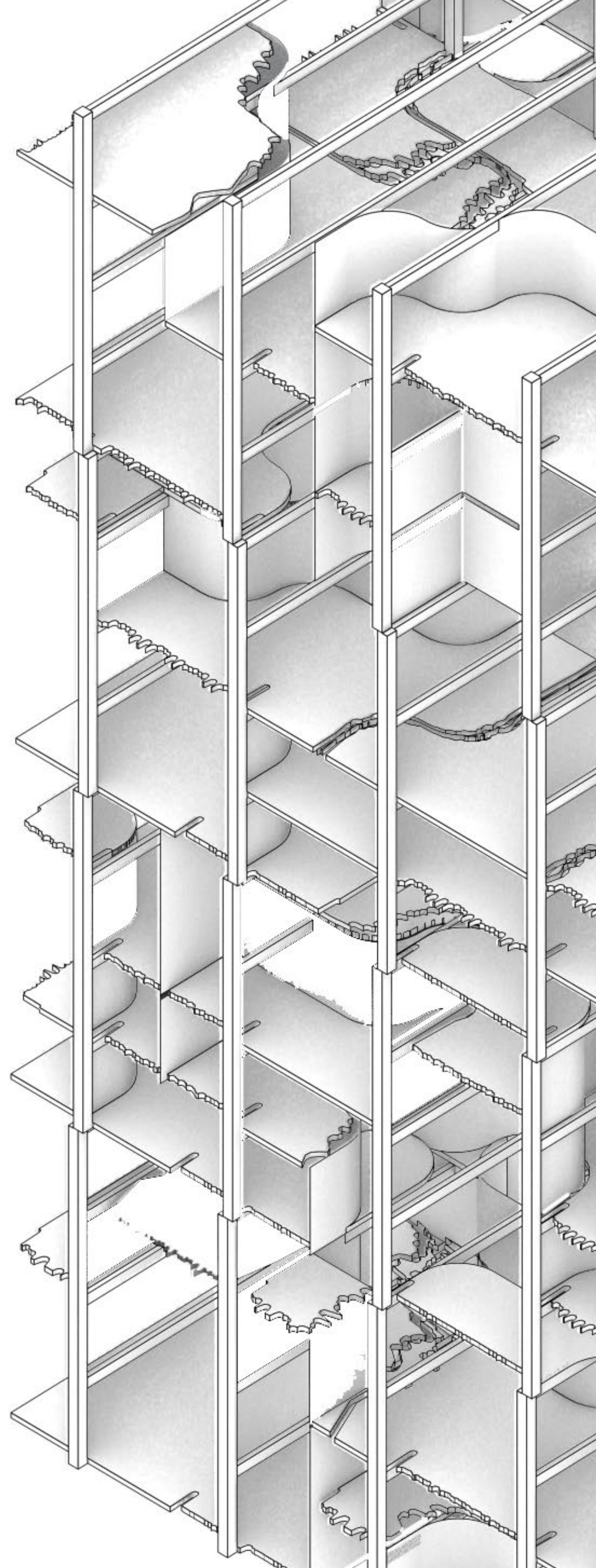
Through a series of physical experiments that aimed to introduce 3D printing into mass production, techniques were developed that involved the jittering of toolpath coordinates resulting in unique 3D printed objects joined together with a standardised blocks. These techniques were developed digitally to create a catalogue of customised objects that were able to be mass produced.

As a result, a proposal was developed that showcased an autonomous method of creating customised spaces and customised fabrication methods in the form of a 16 storey light yard.

Delimitations

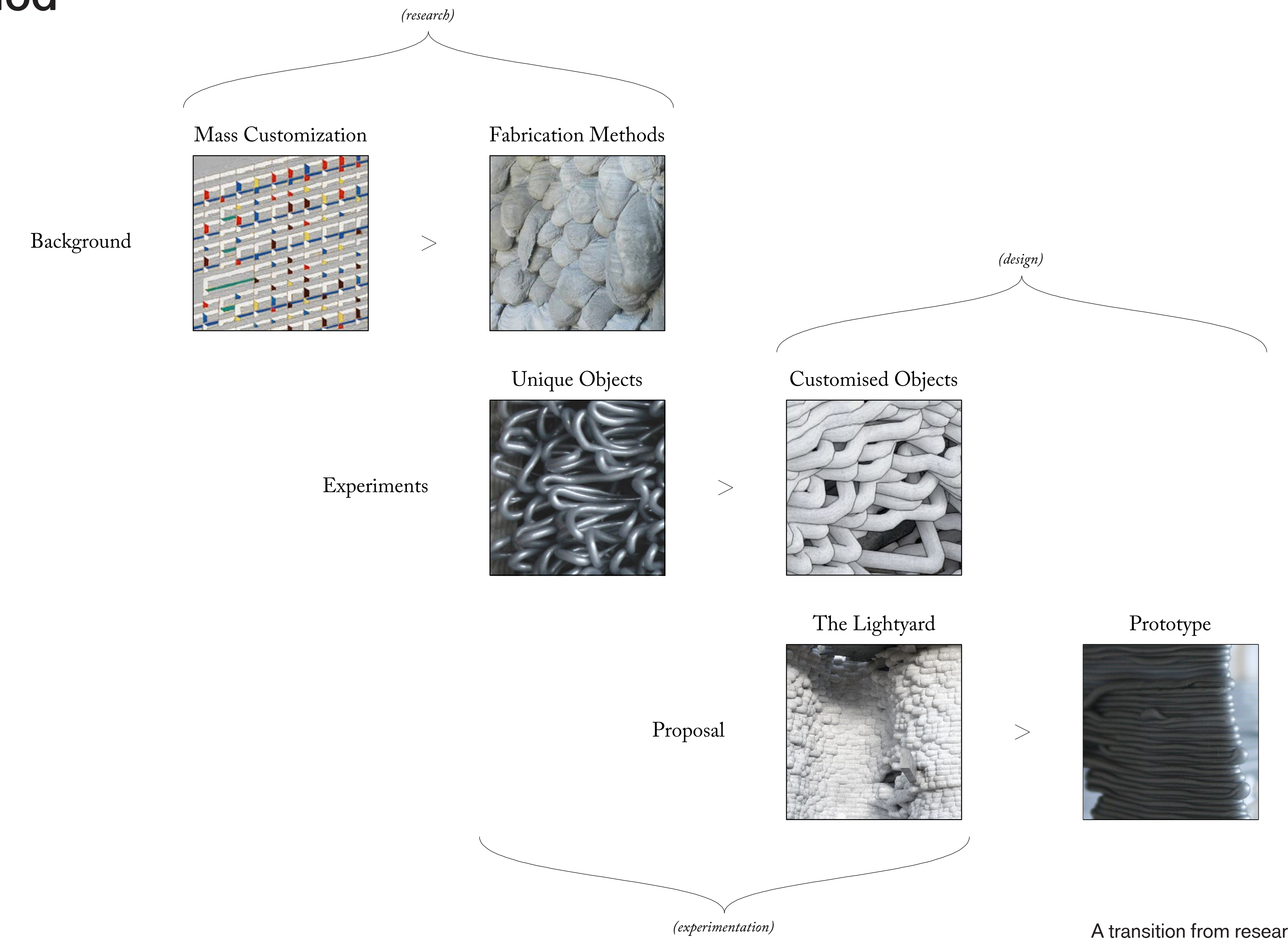
This thesis focused heavily on the digital 3D printing method, it does not account for other modes of additive manufacturing and materials. The experiments conducted are limited to polylactic acid (PLA) and an FLSUN Delta Kossel 3D printer.

It was more attentive to the autonomous possibilites in customisation and its spatial developments, so it did not necessarily strive for a working full scale method.



Standardising 3D Printing (3.1 Unique Objects)

Method



A transition from research into design

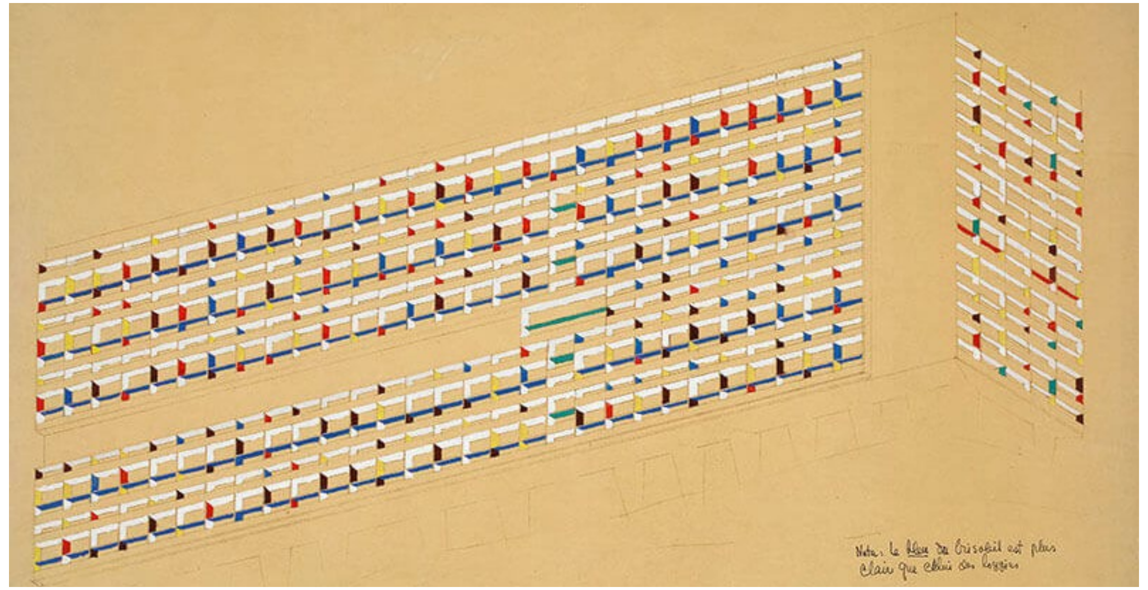
1.1 Mass Customisation

The phrase 'standardised homes' is almost an oxymoron, as 'home' gives the impression of a place that is personal and almost individualistic, not mass produced and alike. With good intentions, companies and governments are looking to do more with less, in order to achieve 'better, faster, less expensive greener' buildings (Deutsch, 2017, p. 170). With a huge shift of people moving to urban areas, architects are challenged to facilitate places of work and living with limited space - in China alone, over 300 millions rural inhabitants are expected to move to urban areas over the following decade. Today, ideas of mass production are being developed to facilitate this shift.

The plethora of new tools and materials discovered in the early 20th century gave way to the idea of mass production, seeking to build healthier and more productive cities. Production techniques during the World Wars gave birth to ideas of mass production of major building components and industrialisation. Walter Gropius was an early advocate of mass production as a response to the growing number of dark and crowded tenements, believing industrial processes could 'meet the public's desire for individuality and offer (them) the pleasure of personal choice'. (Piroozfar & Piller, 2013, p. 28) As a result, many residents found themselves in better conditions in quieter and cleaner neighbourhoods, however, the modernist towers and the shift from 'on-site craft to mass production of major building components ... resulted in relentless monotony with anonymous places of living, (and) working…' (Piroozfar & Piller, 2013, p. 29).

Despite its success in providing most of its residents with adequate housing in a cost-effective way, it can be argued the monotony of mass housing loses some of the richness and individual diversity found in its preceding dwelling types. Part of the answer, it seems could be the ability to customise on the mass scale. In doing so, abstract ideas in art and crafts can be reintroduced into an area that is driven by function.

(right) 'Corridors of Diversity' showcases communal corridors that run along Singapore's housing blocks (Sy, 2019)



Le Corbusier's Unite d'Habitation is a multi-family high-rise housing project that aimed to provide a high-quality sense of living into post-war Marseille. While using large building components, Le Corbusier managed to offer 23 different apartment layouts for buyers, also giving the ability for people to pick out their own colour schemes.

Top image (Fondation Le Corbusier, 2020)
Left image (Kozlowski, 1997)

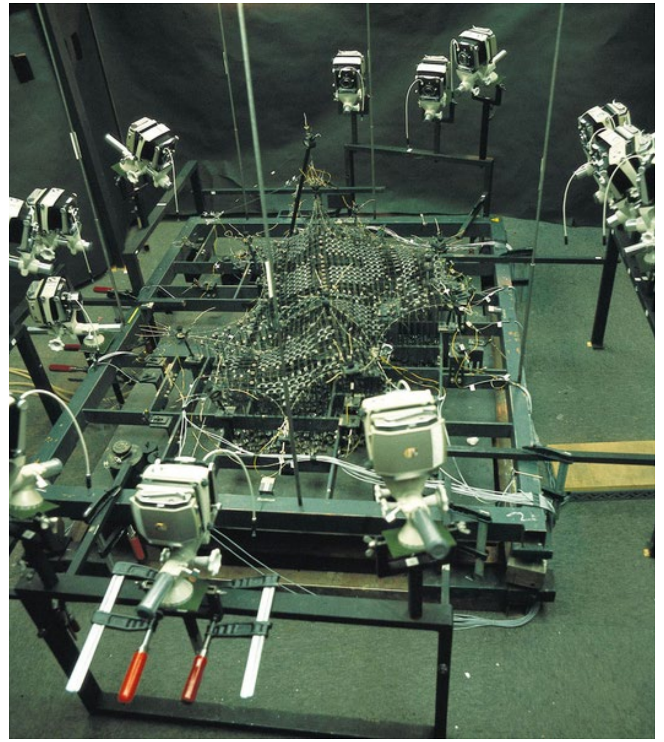
1.2 Fabrication Methods

Mass customisation could not be possible without the utilisation of machinery as a tool to mass produce prefabricated building elements. A level of design, however, is required to guide the machine in its endeavours - the machine is able to produce many building elements at high precision with optimal material usage only when programmed to do so. The symbiotic relationship between human and machine demonstrates the extent of what can be achieved with sufficient control and finesse. In contrast to this, primitive buildings that do not require modern tools or machinery can be appreciated for their craft. Human control and knowledge of a material that lead to a beautiful sculpture or a building that fulfils its function well may be considered to discern craft. When concerning mass production, does the replicability of large building elements account as craft? Can machine fabricated buildings even be considered as beautiful?

The notion of craft, historically, can be defined by the people who possessed it. Master builders were people who possessed the skills of both the artist and the labourer simultaneously, i.e. they could master the most important materials at the time while leading the process of construction, incorporating those materials with ingenuity into their building.

Hauschild and Karzel suggests that while the industrial revolution brought with itself enormous technical possibilities, this required immense skills in the handling of the machines and techniques. (Hauschild & Karzel2012, p7). In France, this led the master builders, or the modern day architects, to be split into either of two camps: focusing on the Fine Arts (Ecoles des Beaux-Arts) or on the demonstrable facts (Ecoles Polytechniques). It can be argued that today, the Fine Arts and Science are being reunited through new technologies and ideologies. It is hard to say that a physical master builder exists today with the emergence of robotics - perhaps it is the collaboration between people and machines that is appreciated today. Digital tools such as building information modelling, optimization tools, laser scanning and robotics provide a wealth of information designers can utilise to analyse, iterate and optimize their ideas. Hauschild and Karzel (2011, p7) name Antoni Gaudi, Pier Nervi and Frei Otto as modern-day master builders in offering beautiful solutions because of their 'logical and material order'.

(below) Atelier Frei Otto Warmbronn using cameras to optimize the roofing system of Olympiastadion
(Atelier Frei Otto Warmbronn, 1972)



Digital Grotesque II is a 3D printed sandstone structure that seeks to evokes a new relationship between human and machine. The machine is programmed to evoke emotion and stimulate the beholder.

Top and bottom images (Hansmeyer, 2018)

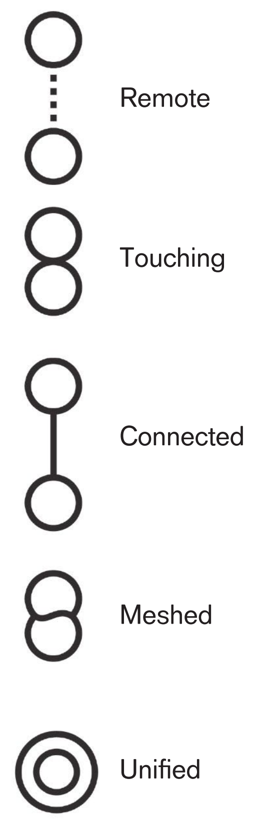
Deutsch writes about this convergence between human and machine as humans being challenged to realize meaning within the constraints of computational tools (Deutsch, 2017, p. 14). The convergence taking place between the Fine Arts and Science, the human and machine, or the client and the builder goes beyond the process of simply combining the duos. How and at which stages of the design process they are combined are important variables to discern craft of the modern-day building.

Quite often in mass housing, the emotive loses out to science, the human loses relevance to the machine and the client becomes unimportant so early in the process. Technologies, tools and processes can have different ways of interacting when working with one another. Described as Industry 4.0, the digital age has evolved to the point that manufacturing can make the seamless leap from digital data to a physical object using applications such as additive manufacturing, advanced materials and autonomous robotics. (Sniderman et al., 2016, p. 10) This added dimension could pose both opportunity and challenge for mass production, where what is planned digitally can translate more seamlessly physically, rather than relying on the restrictions of pre-casted elements. It can even be speculated that an object could lose more of the human element when manufactured using complex machines such as 3D printers. After all, the convergence between man and machine heavily relies on the machine user interface and its ability to give and receive legible feedback loops. Additionally, additive technologies require a large amount of data, as each printed voxel requires a certain level of design and calculation (Carpo, 2017, p. 75). This notion of accuracy, however, can be challenged as modelling and scripting programs such as Grasshopper and Repetier-Host allow for iterative and simulative feedback, where designers have the freedom to test their work before fabricating, as Golparvar-Fard put it, using design as a predictive tool (Deutsch, 2017, p. 161).

The leap between 3D modelling and fabrication is becoming less restrained and designers are starting to value additive manufacturing for its potentials in manufacturing methods and resulting surface conditions, rather than pure geometric form.

(below) Deutschs Relationship Types Diagram outlines how new and embraced technologies are interacted with. In the case of 3D printing, humans are perhaps connected to but not meshed and unified to the fabrication method.

(Deutsch, 2017, p. 24)



Zach Cohens research into machine in 3D printing led to an architectural approach focused in the constructive and aesthetic possibilities in practice. Time-based deposition, or, dripping, is an introduced example of how Cohen achieves this.

Top and bottom images: (Willmann, Block, Hutter, Byrne & Schork, 2018)

2 Proposal

2.1 The Lightyard

2.2 Prototype

The Lightyard aimed to demonstrate the methods discovered in the experiments in the form of large scale structures. They are to be constructed as new structures on the sites of multi-storey carparks, spread across Singapore. A single 16-storey structure is showcased in this section, followed by a physical model revealing a chunk of the structure.

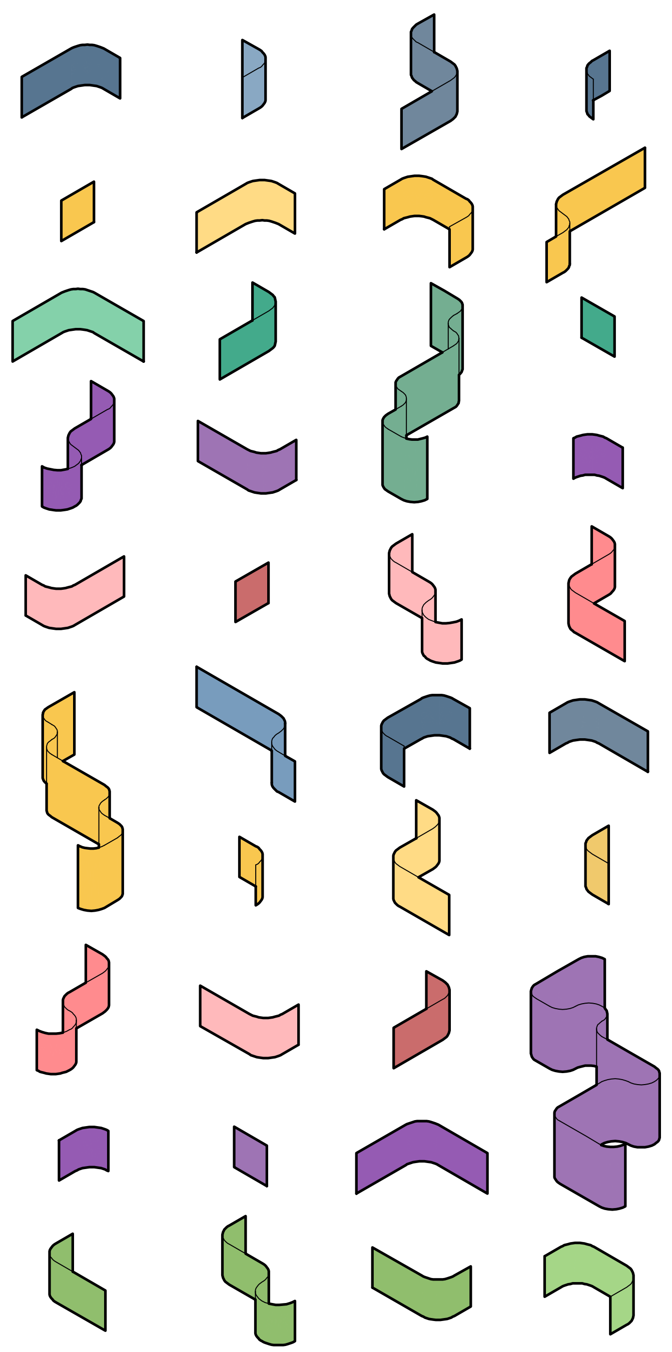
Singapore houses over 80% of its population in high-rise public housing (Housing & Development Board, 2018). An efficient network of housing exists that connects different shapes and sizes of apartments with their corresponding owners. The Lightyard aim to diversify this network by offering shared 'backyards' that is offered to families when buying their apartment.

The country utilises prefabrication techniques in order to fulfil the extensive housing needs of the population, where most building components are manufactured in factory and assembled on site. The Lightyard introduces 3D printing to the existing collection of precast building elements, utilising methods learnt from the experiments offering customisation in both fabrication and its spaces.

The structure reinvents the courtyard as customised open air spaces made up of a range of nuanced chambers. These 'backyards' are a breath of air between activities, reinstating the compact courtyards found in traditional Chinese housing. 3D printed surfaces act as lightwells that collect light through the base of the 3D print, filtering light out through the jittering of the layers.

The spaces are customised through a collection of a range of curved surfaces, generated as a result of a script, analysing three generations of nearby families. The resulting spaces aim to reflect the complexities of family connections, instilling a gradient of boundaries that exist between them. Of course, as family trees change over time, the structure reassigns and adapts its spaces, similar to how apartments get sold and bought over time.

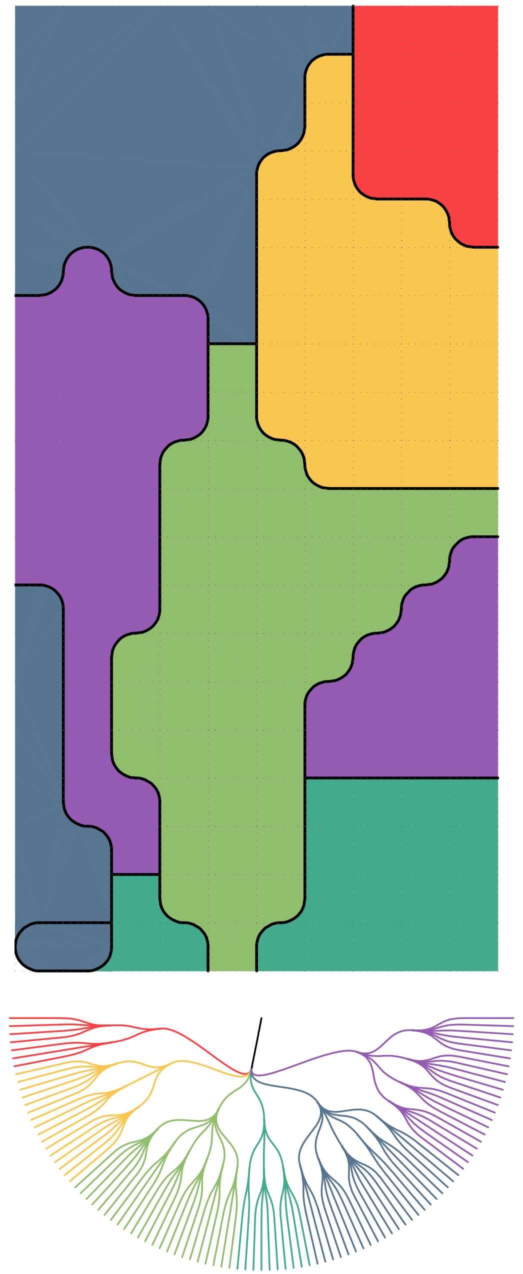
How can these objects be constructed and mass produced autonomously?



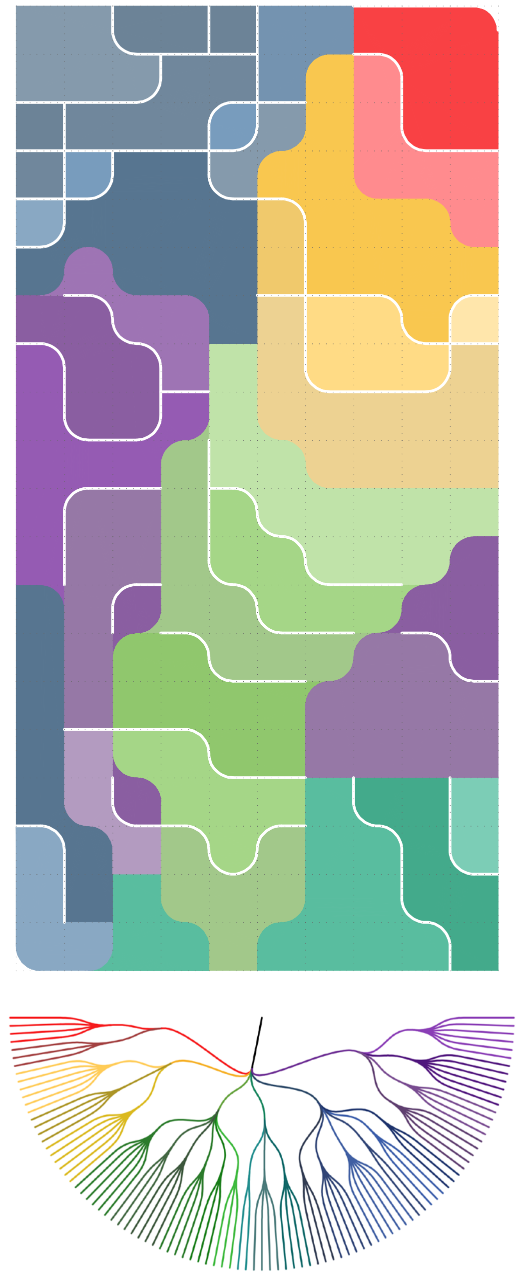
2.1 The Lightyard

The Lightyard is laid out onto a grid and is based on the analysation of three generations of nearby families. The spaces are separated by hard and soft boundaries (curves)that exist on family size. Hard boundaries separate families at their third generation while soft boundaries separate families at their second generation. Spread across two floors, the hard boundaries are extruded across both floors while the soft boundaries are extruded over either a single storey or left as curves.

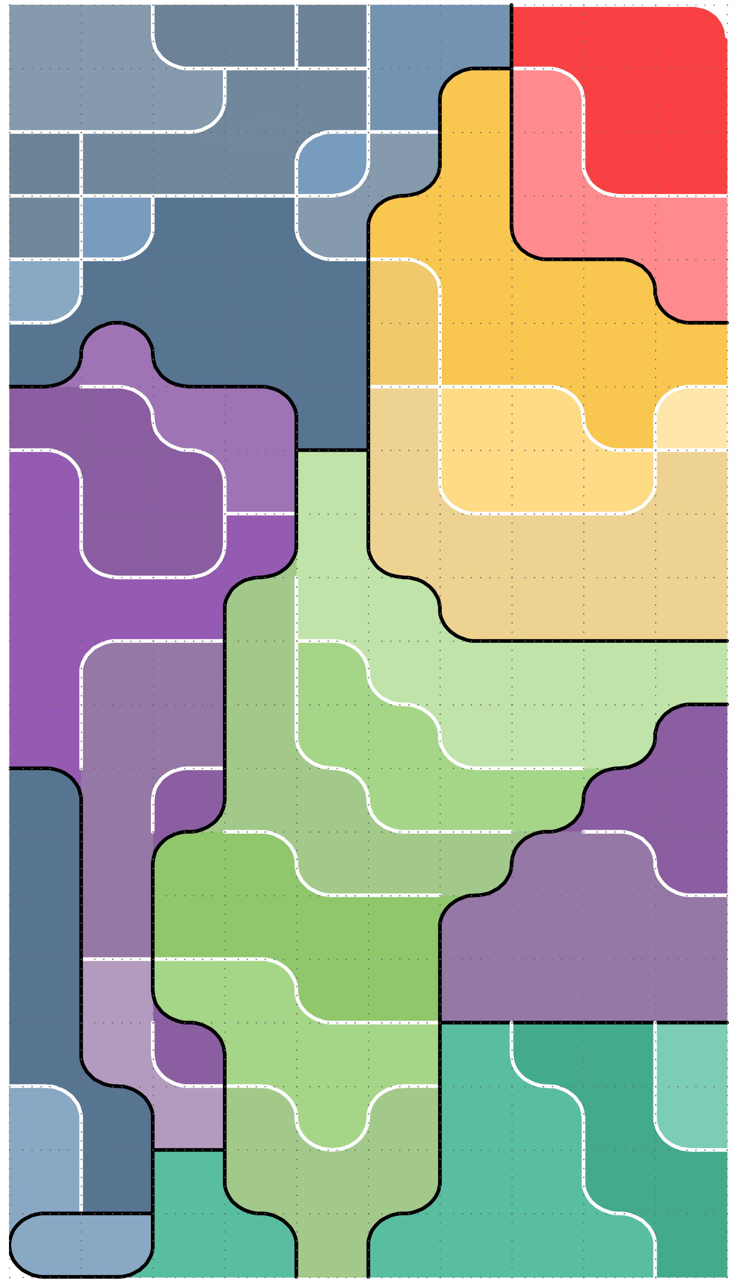
The resulting surfaces are interpreted by a script that analyses the surrounding building elements (beams, columns and concrete slabs) and outputs them as unique 3D printed objects that join together with their surroundings. Multiple double-layered plans can then be stacked to form a cohesive structure, where an exterior corridor runs along the perimeter of the building, connected by stairs and lifts. The resulting spaces give the impression of a building but remains open-air.



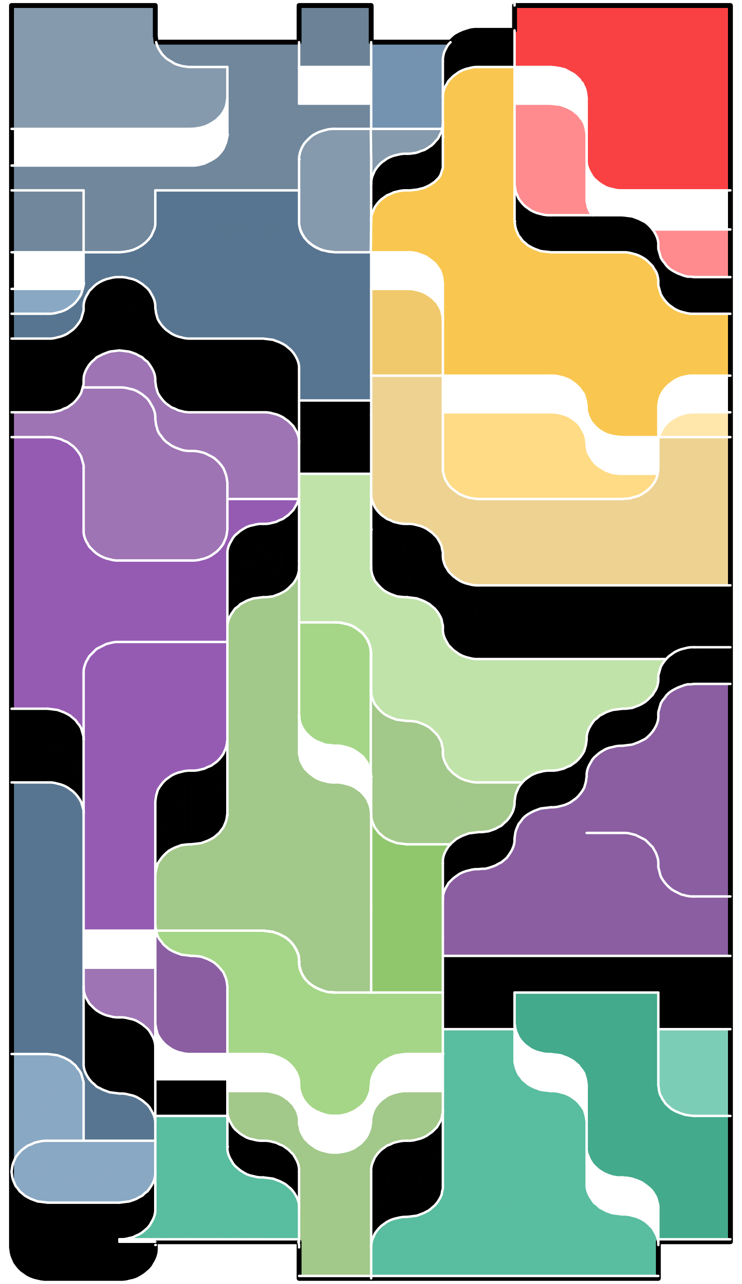
Hard boundaries



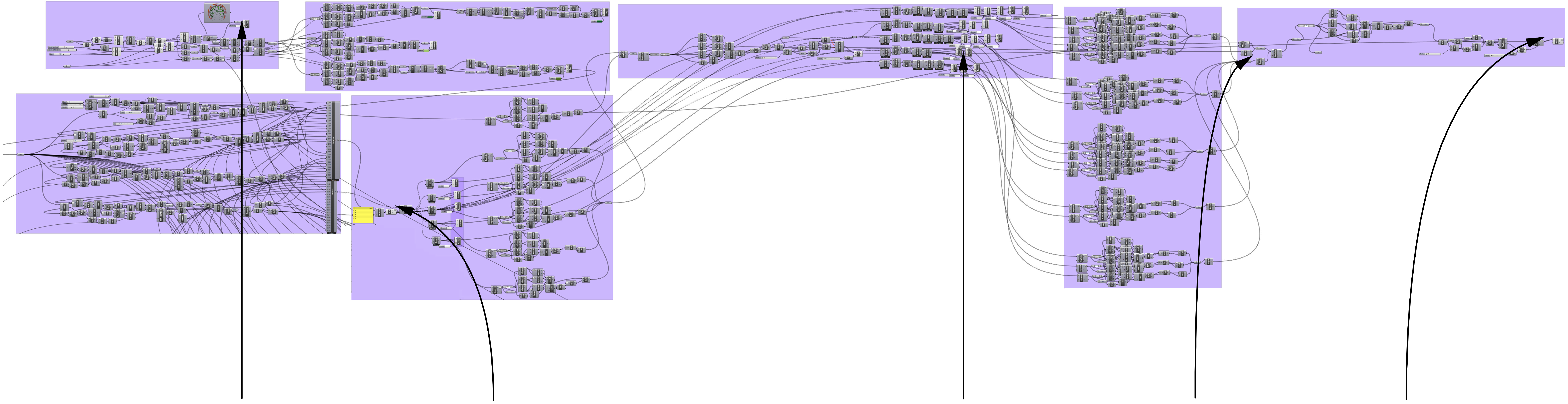
Soft boundaries

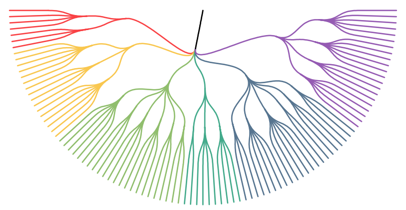


Hard and soft boundaries

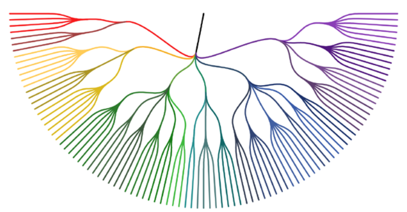


Boundaries extruded over 2 floors

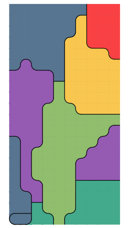




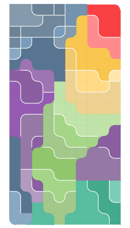
Family trees



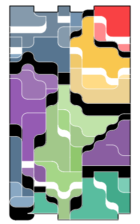
Analysed family trees



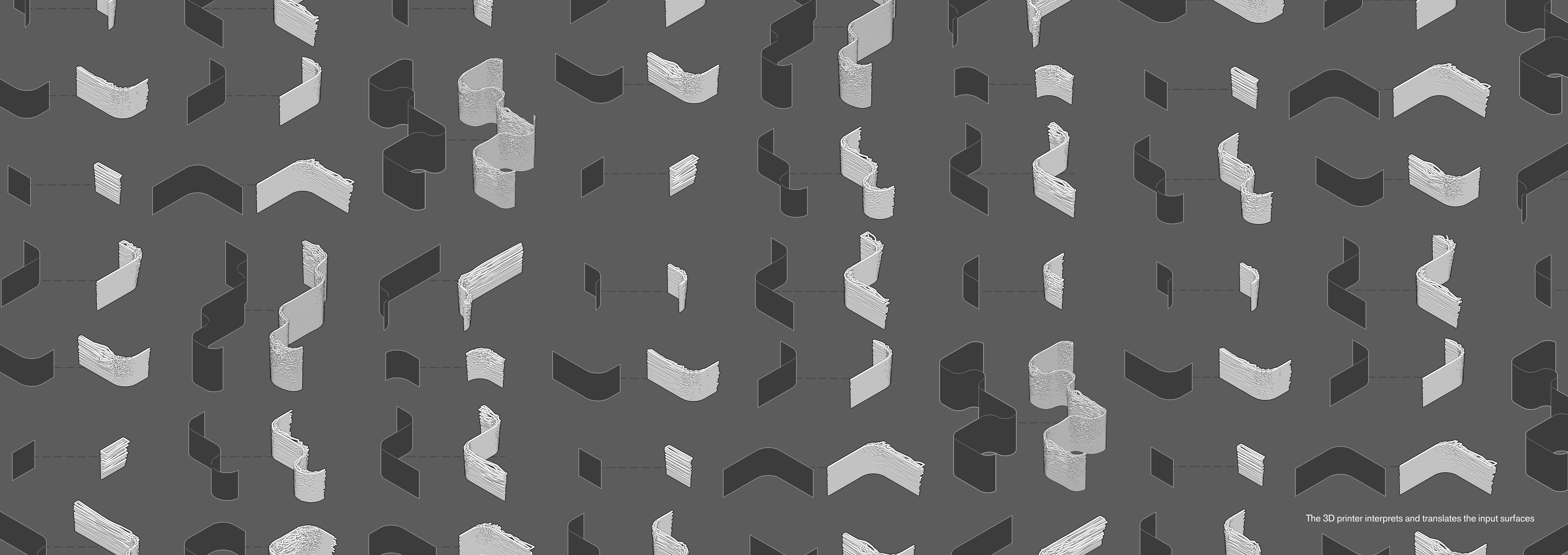
Hard boundaries



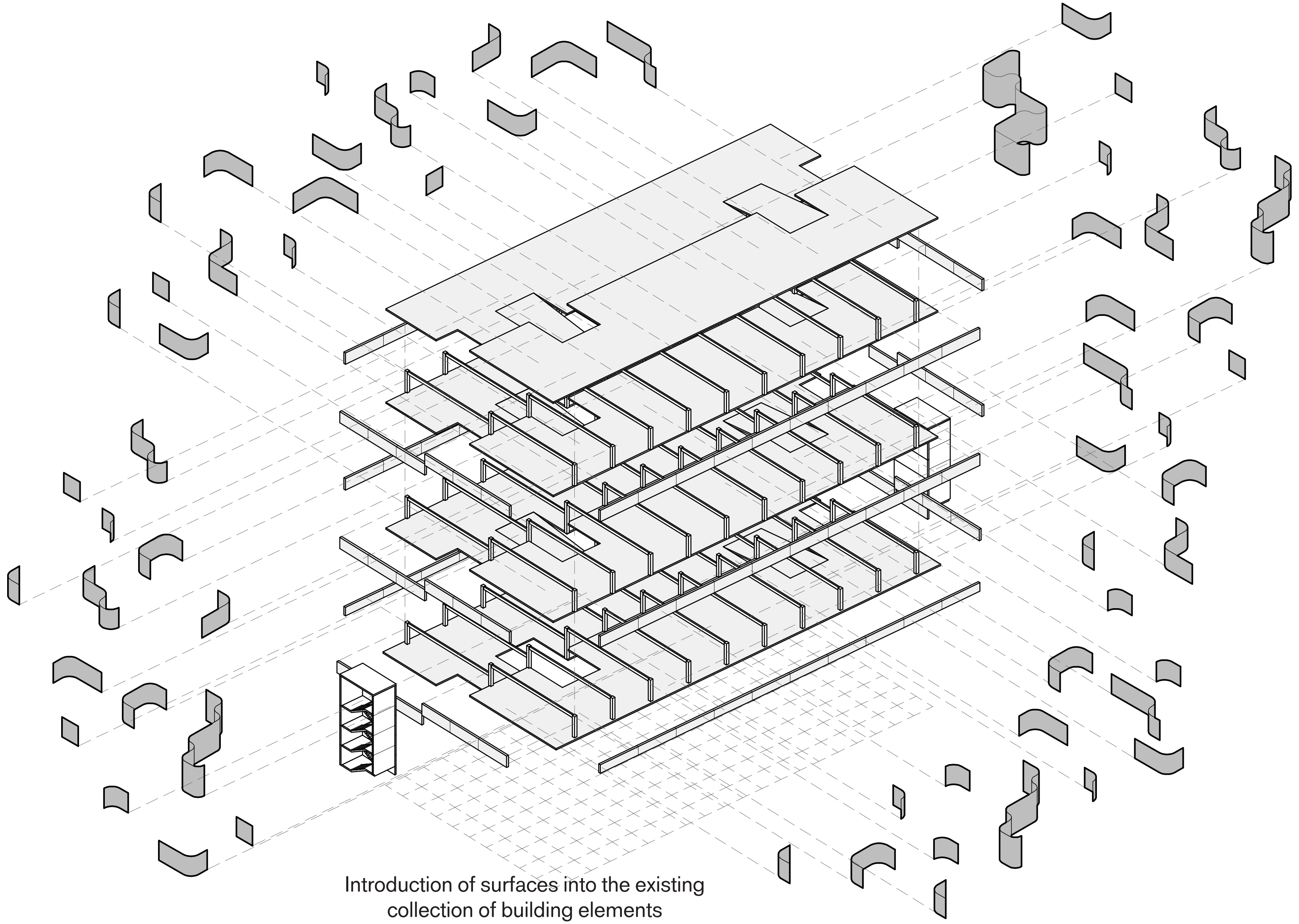
Soft boundaries



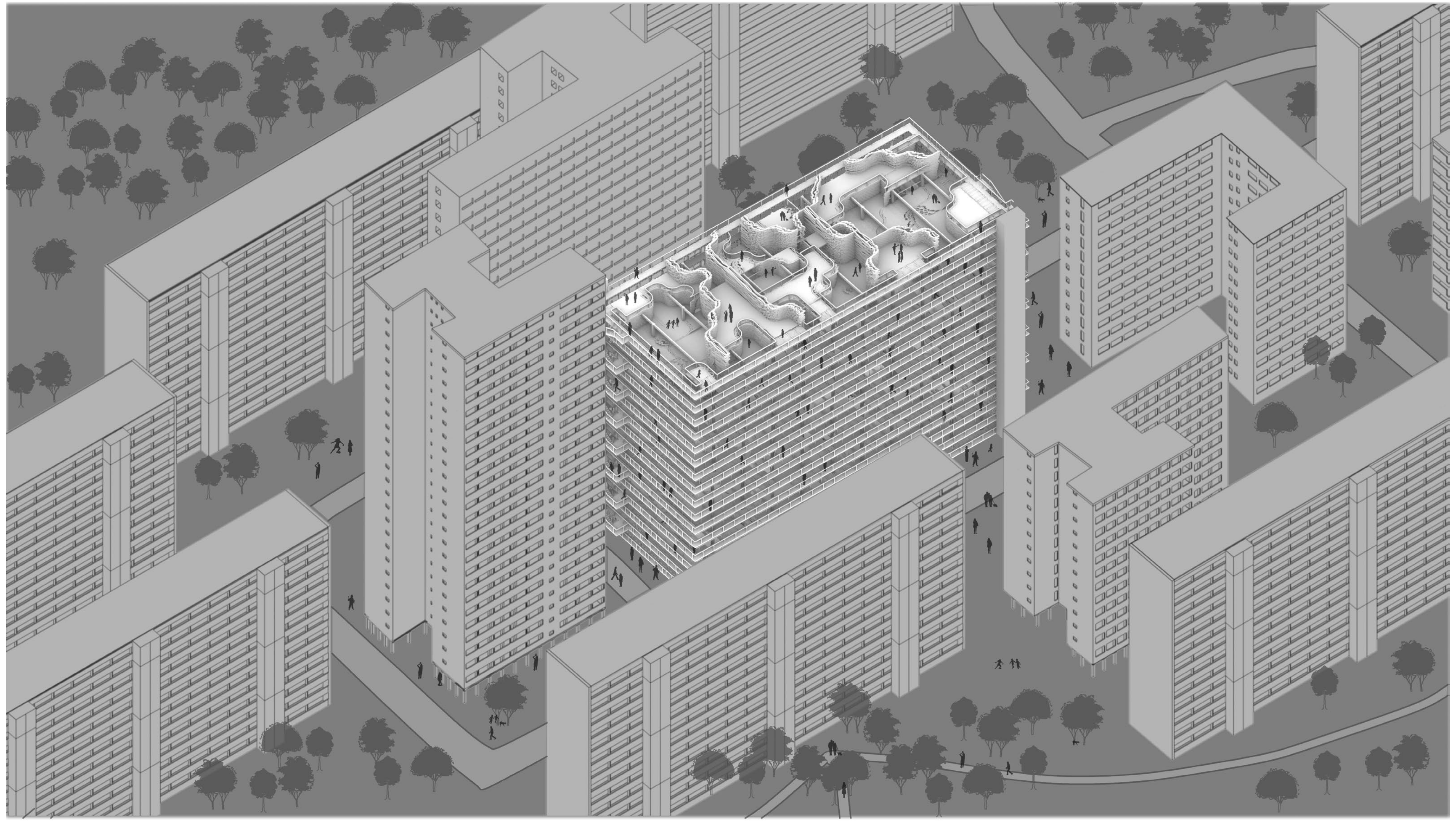
Extruded boundaries



The 3D printer interprets and translates the input surfaces



Introduction of surfaces into the existing collection of building elements



A new typology in Singapore's existing urban fabric

Plan 1-2

Plan 3-4

Plan 5-6

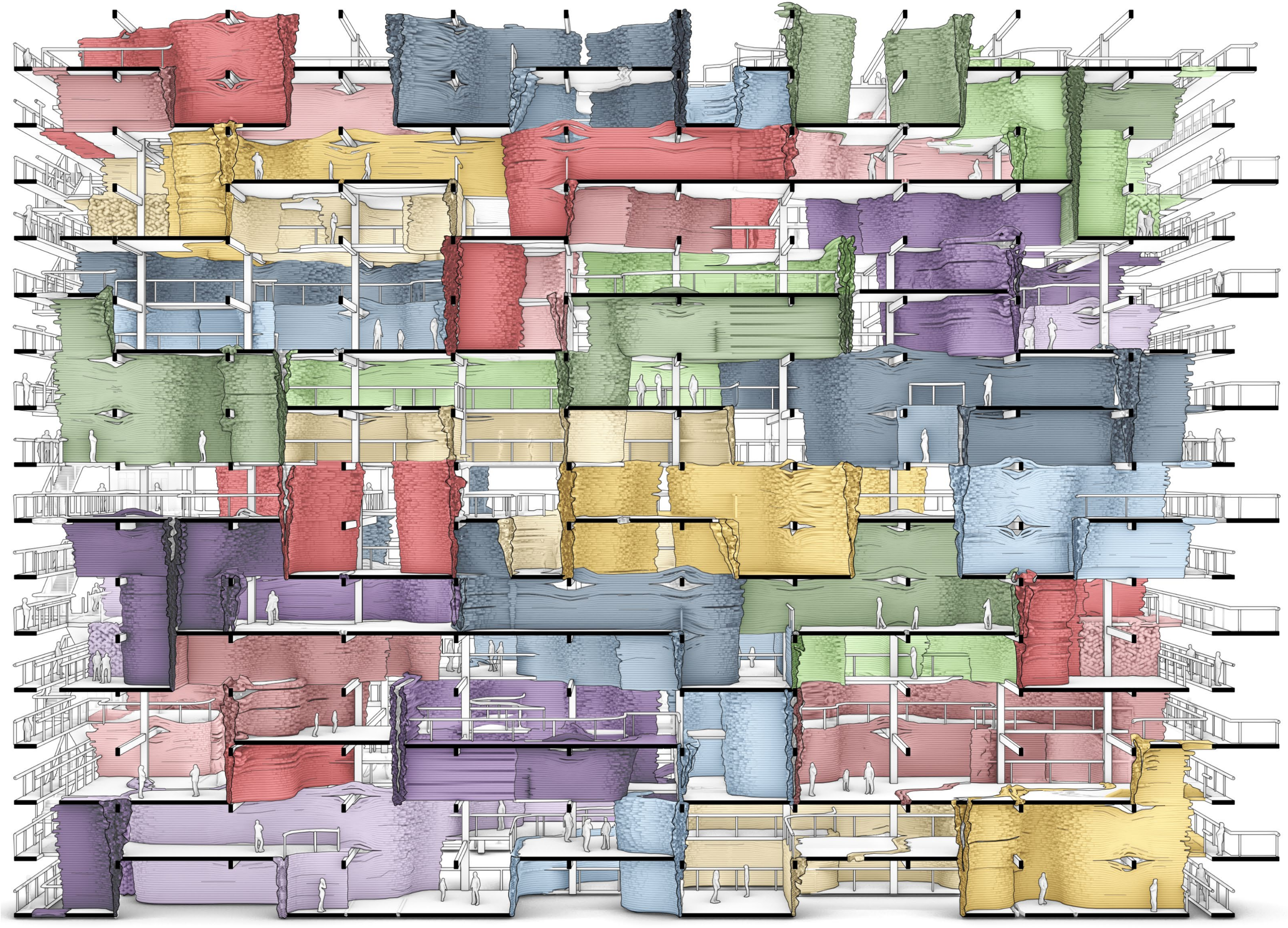
Plan 7-8

Plan 9-10

Plan 11-12

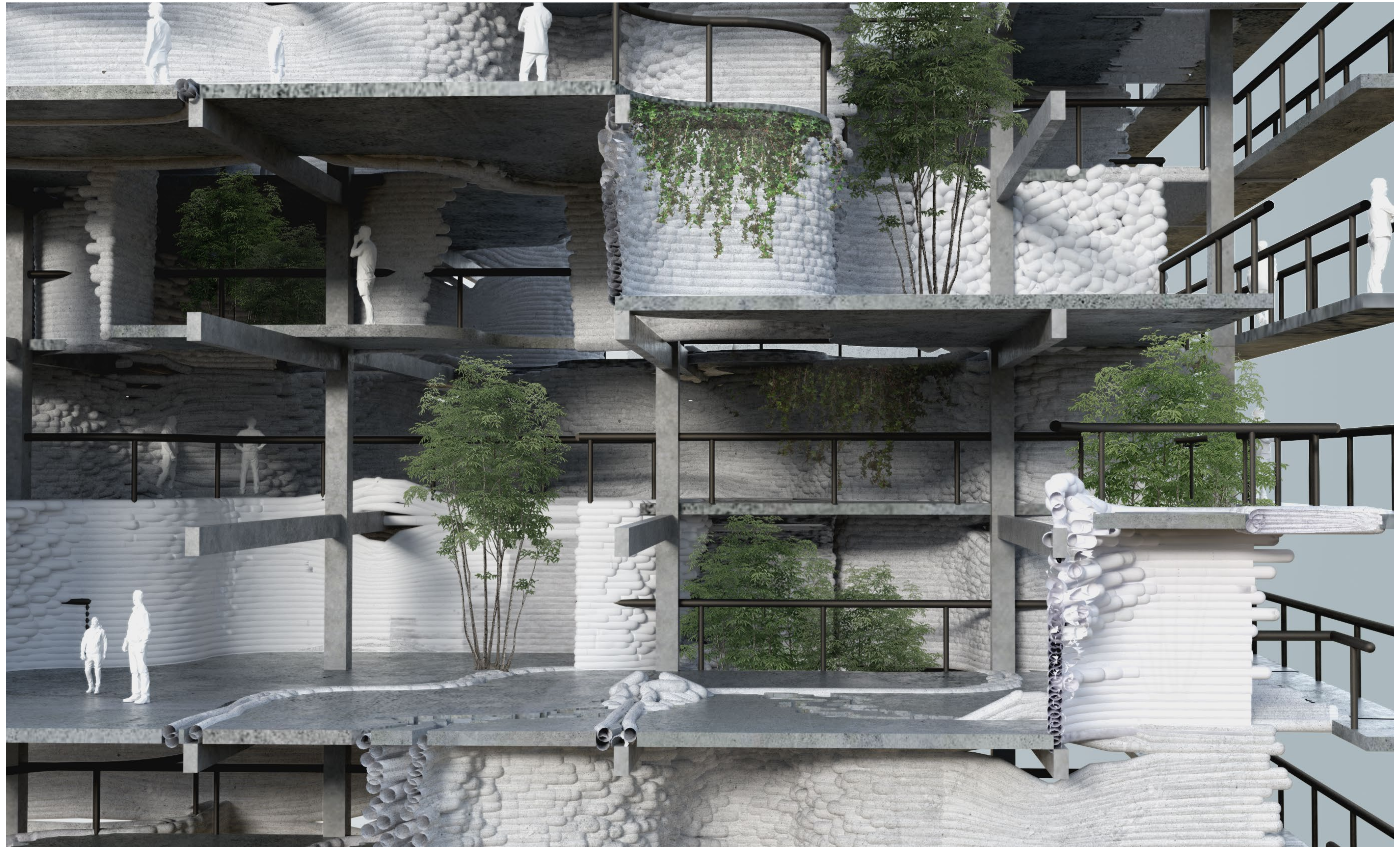
Plan 13-14

Plan 15-16



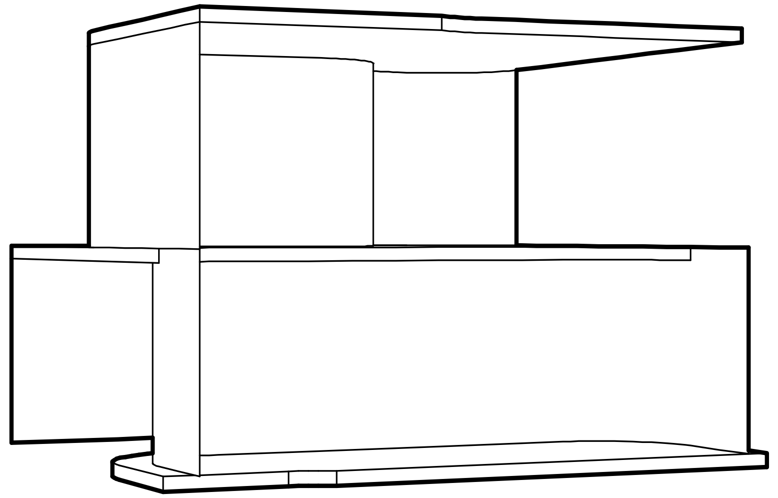
Apertures at various sizes provide light, despite high density

View from 9th -11th floors

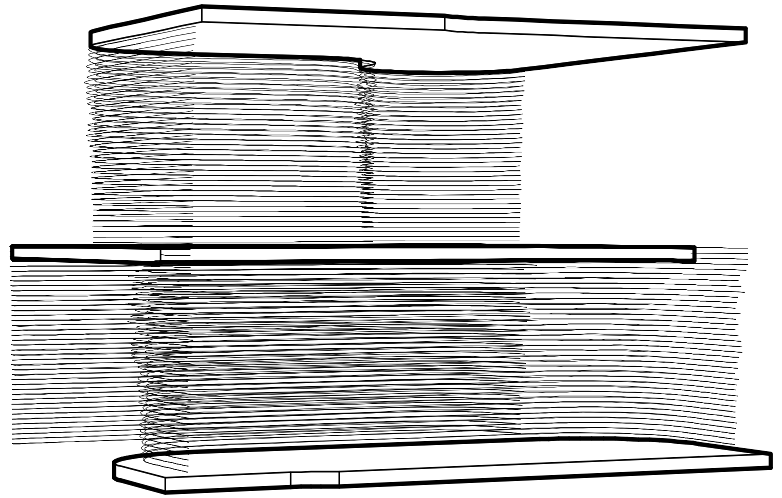


View from 3rd - 5th floors

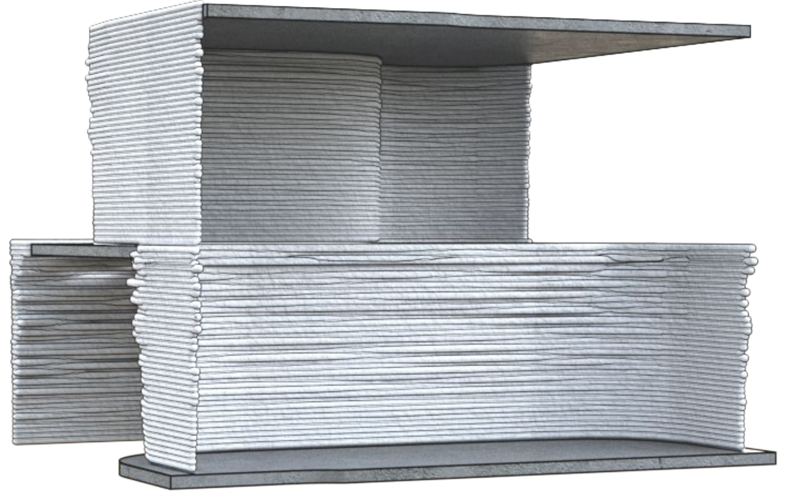
2.2 Prototype



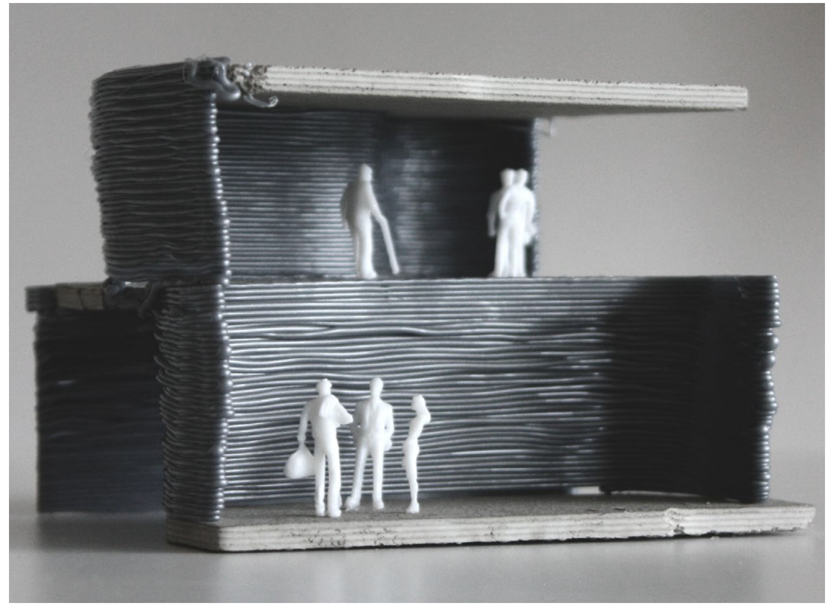
Generated standardisedsurfaces



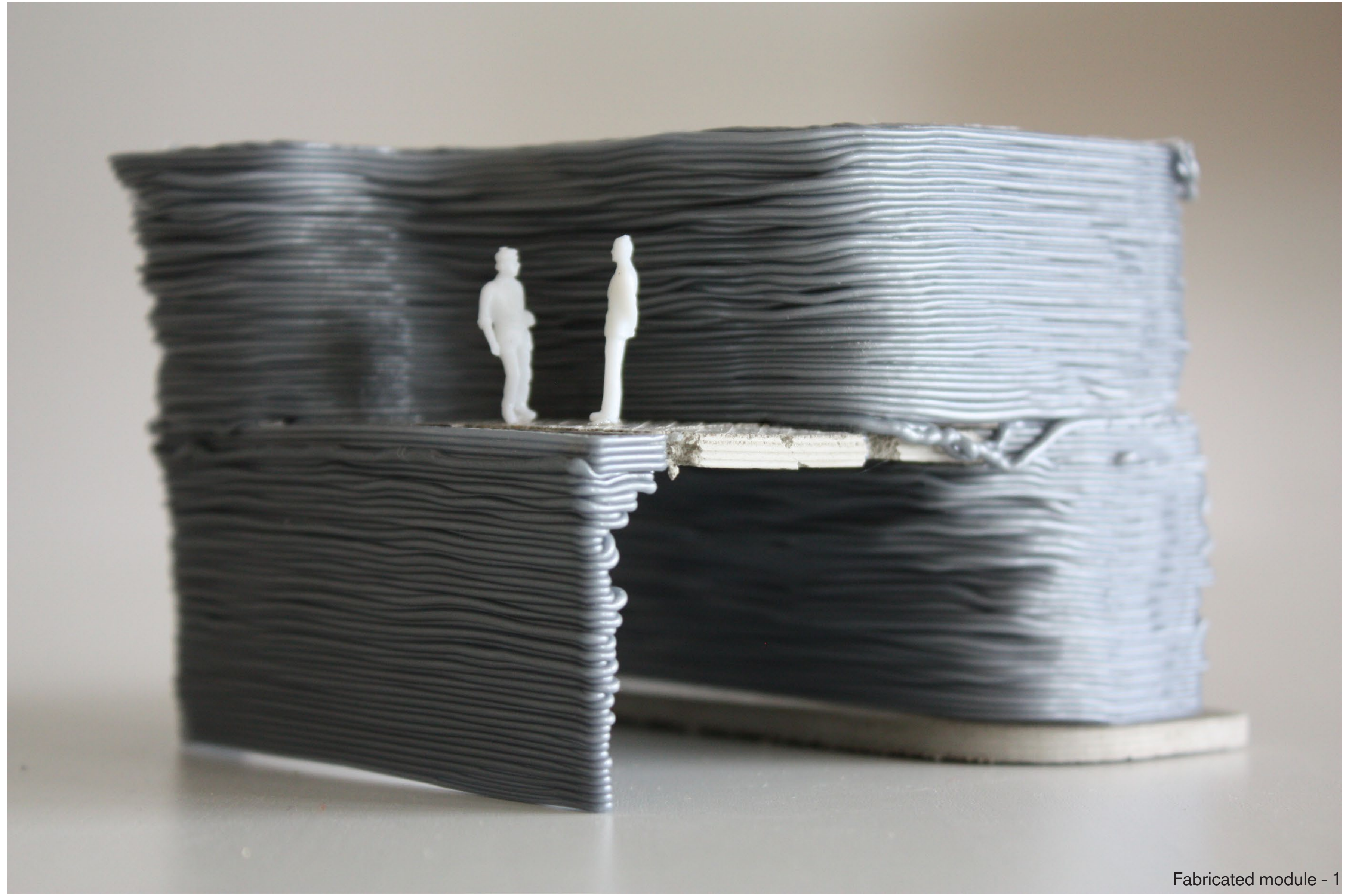
Jittered toolpath



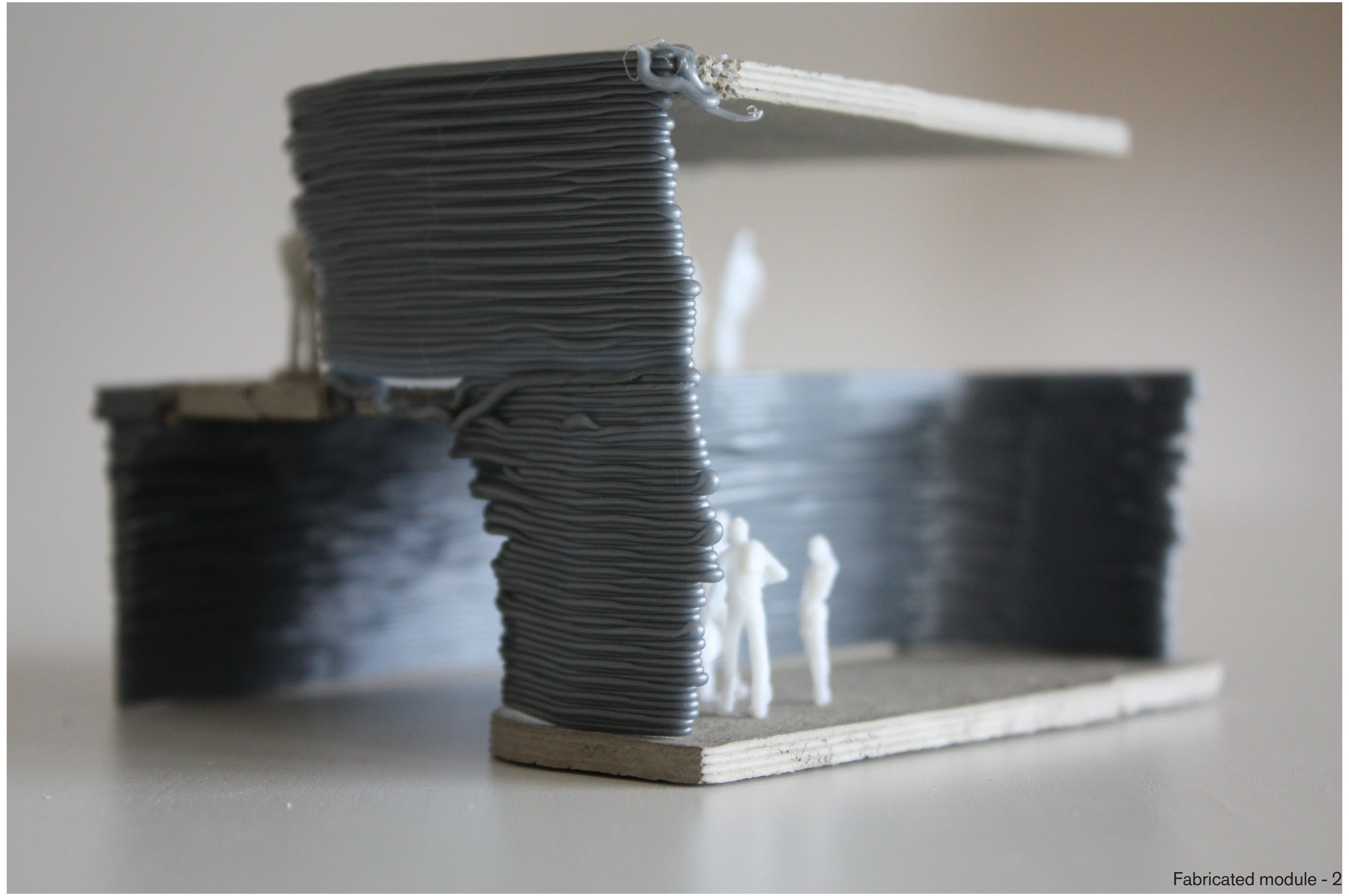
Approximate 3D print



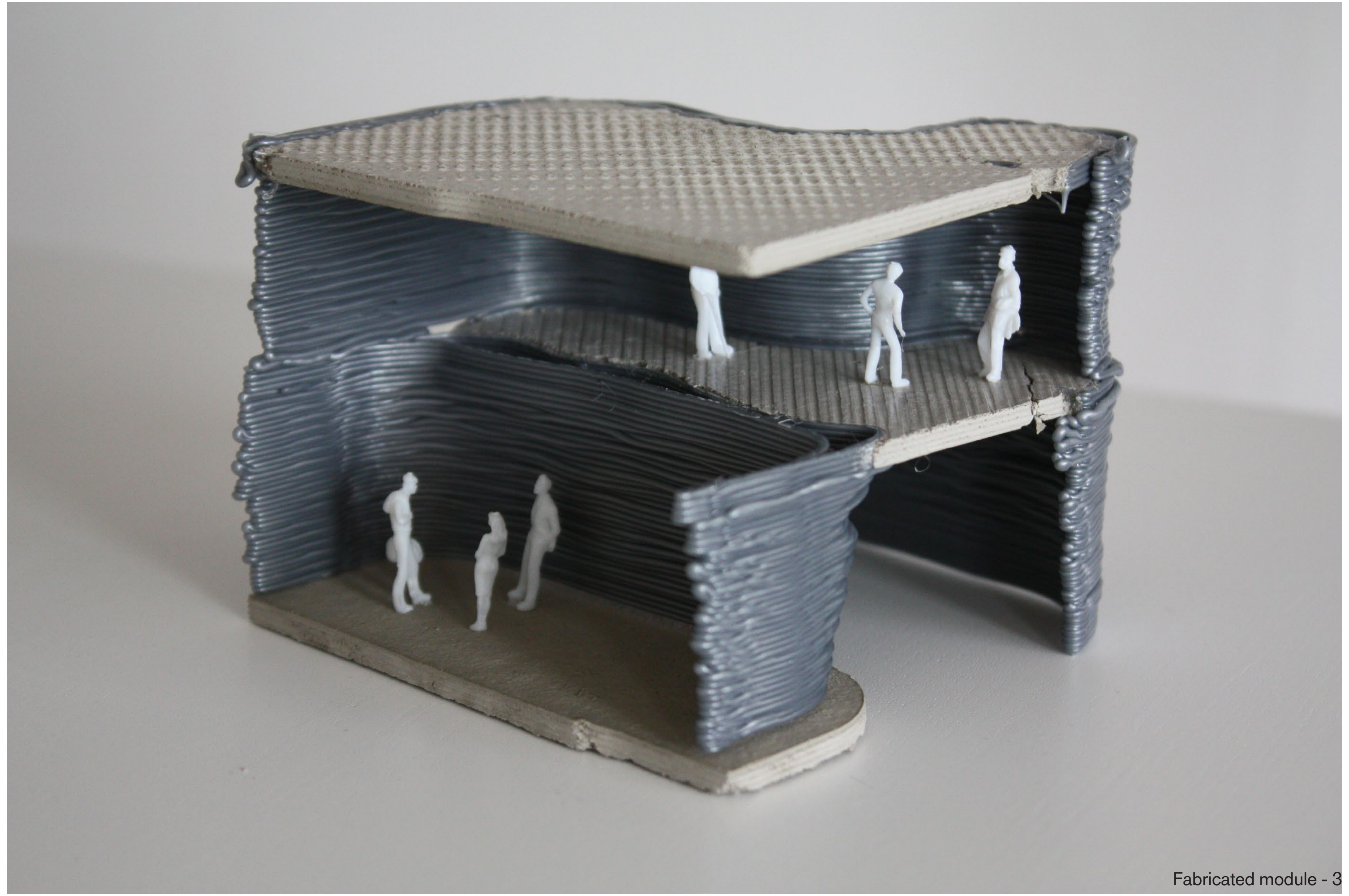
Actual



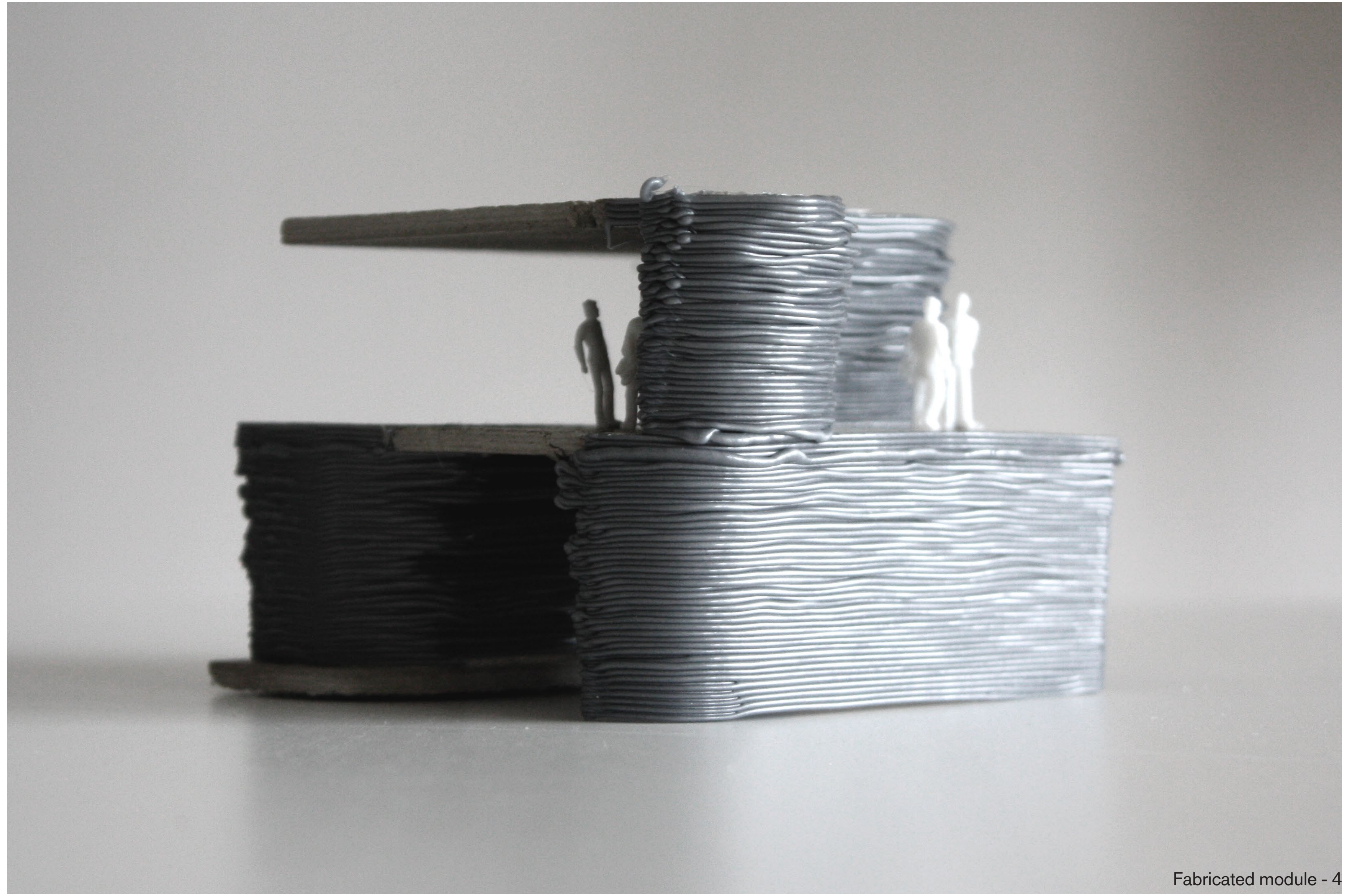
Fabricated module - 1



Fabricated module - 2



Fabricated module - 3



Fabricated module - 4

3 Experiments

3.1 Unique Objects: Fabrication Methods
3.2 Customised Objects: Toolpath Manipulation

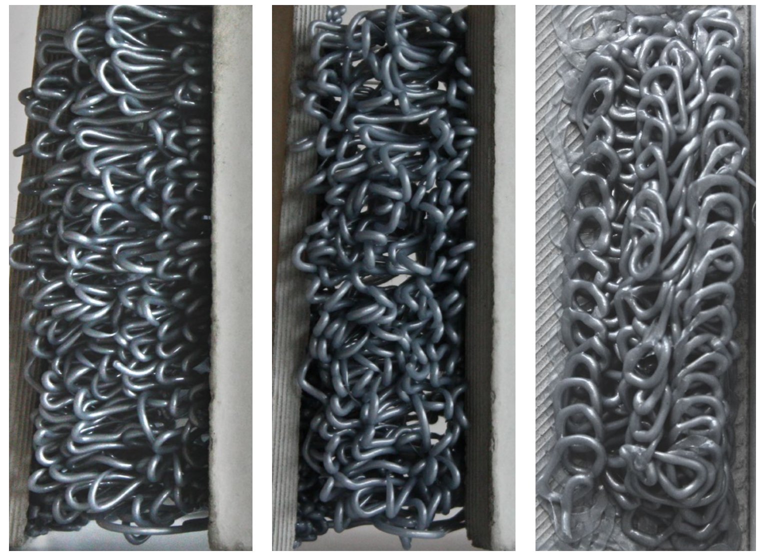
The aim of the experiments were to explore and investigate the potentials of hand-crafting a 3D printed object in the context of mass production. 3D printing is inherently a repeatable process where a computer-aided 3D model can be manufactured over and over again resulting in identical, predictable physical models, while requiring minimal human effort. These genetic properties of 3D printing may be beneficial in mass production while offering a new platform to design new typologies at a mass scale. Of course, customisation in 3D printing can be achieved at a small scale by the input of different computer-aided 3D models, however it can be challenging to input unique 3D models to a mass scale without the implementation of extensive human effort and design.

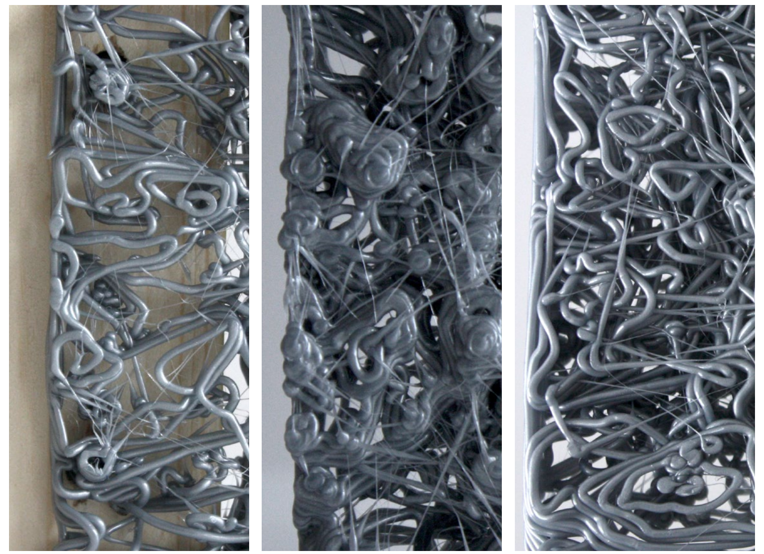
Typically, a 3D model is exported from the 3D modelling software as an STL file where it is processed by a slicing software which converts the 3D model into a series of contoured layers. These layers contain coordinates and instructions that output as a G-code file that a 3D printer reads during the 3D printing process. The initial experiments seek to bridge the gap between 3D modelling and 3D printing, encouraging a translation in how the 3D printer reads and interprets the input 3D model. It does so by manipulating the coordinates and instructions in the G-code file that is generated. This resulted in a series of fabricated objects, made up of 3D printed geometry joined together with standardised blocks.

The second series of experiments explored how these methods of fabricating unique objects can be achieved digitally, reducing the need of human effort while promoting predictability and understanding. It seek methods in how precast beams and concrete slabs can be intertwined within the 3D printing process, while fabricating unique 3D printed objects. The established method enable surfaces to be interpreted by a script that analyses the surrounding building elements and outputs them as unique 3D printed objects that join together with their surroundings. When introducing these ideas into the context of mass production, there exists a possibility of fabricating unique objects while maintaining low demand for time and labour.

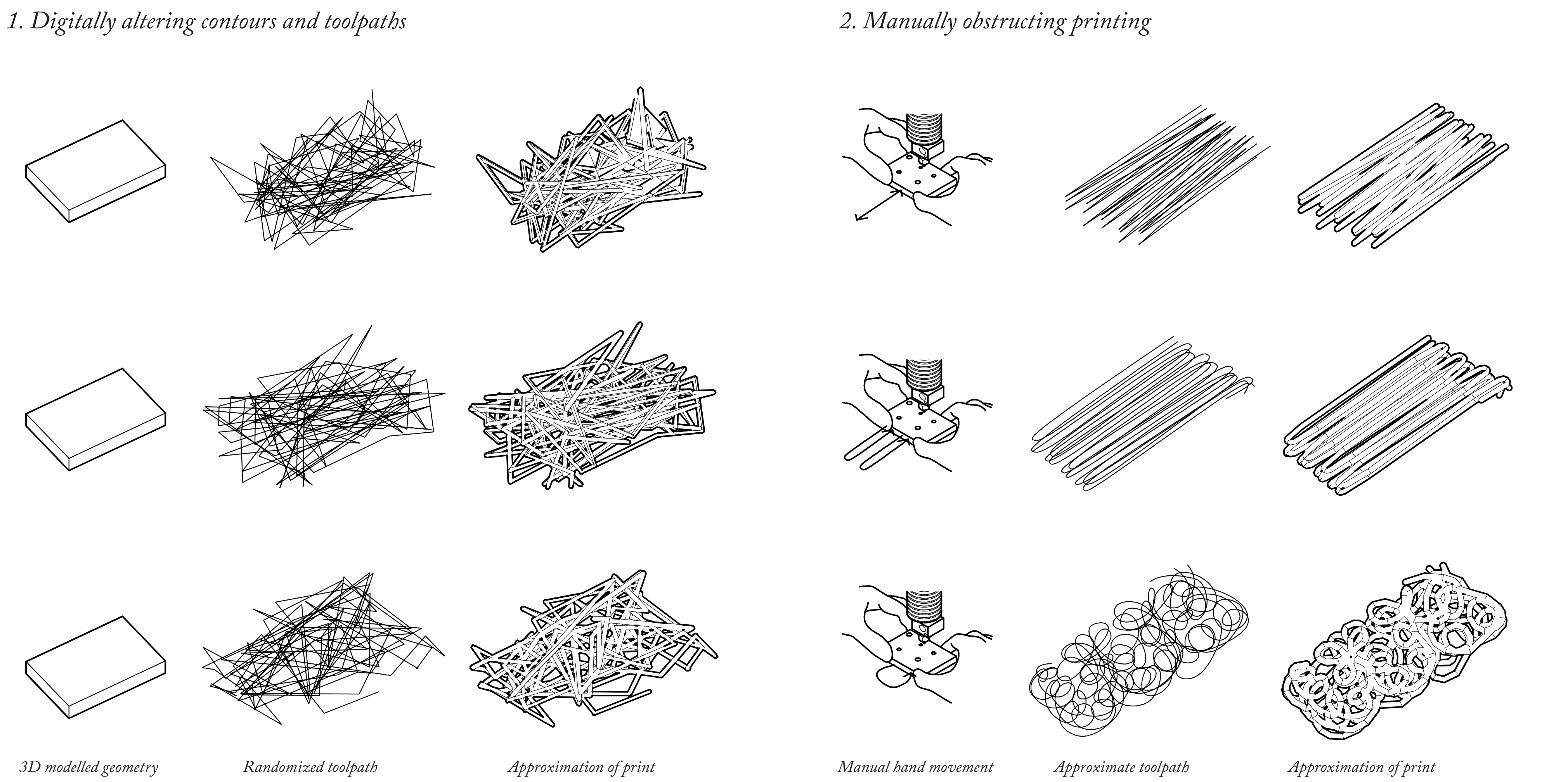
How can a digitally manufactured object appear hand-crafted?

3.1 Unique Objects: Fabrication Methods





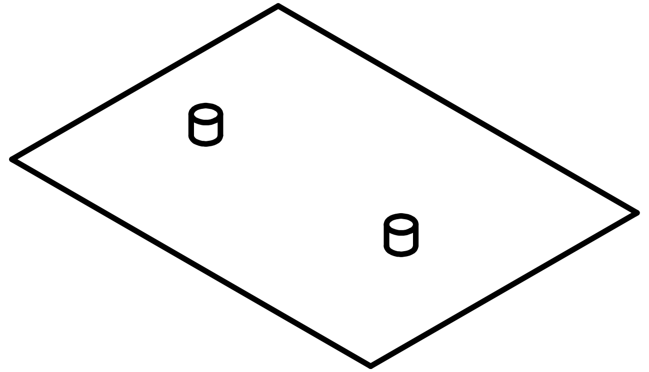
In order to introduce a level of customisation into the mass production manufacturing method, the 3D printing process was pursued as the customised geometry, while offcut wooden blocks and precast concrete pieces were used as the mass produced object. Two distinct strategies were developed to 3D print a unique object without changing the 3D model. The first was to digitally alter the toolpaths by editing how the 3D model is contoured; either by applying displacement on the geometry or editing the control points of the contoured curves. The second strategy was to run the 3D printing process as normal, but to manually obstruct the platform or bed in which the printer was printing on. These methods were combined in the end to construct a cohesive space.



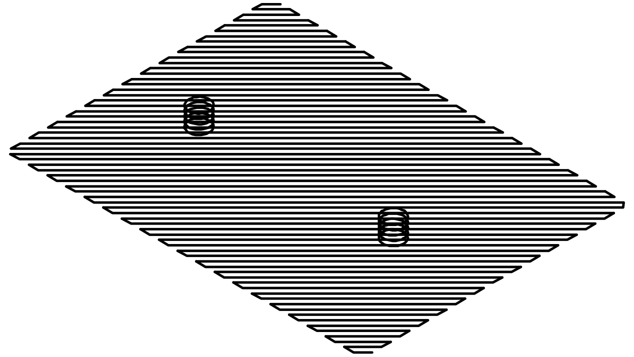
3D printed bulb fixes print onto wooden piece

Flat 3D printed geometry

Experiment 3.1.1



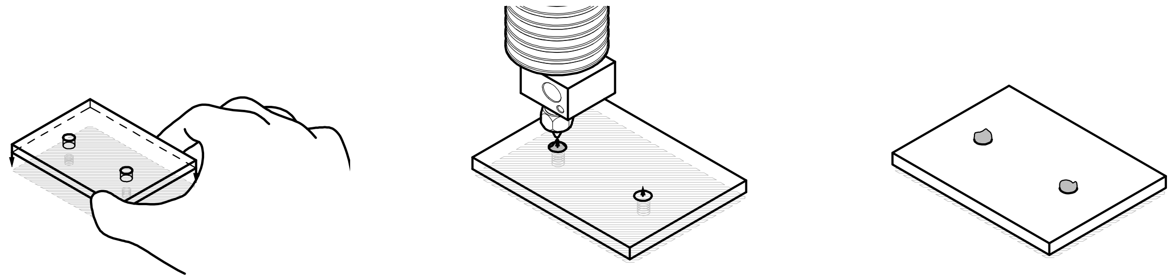
3D modelled geometry



Generated toolpath

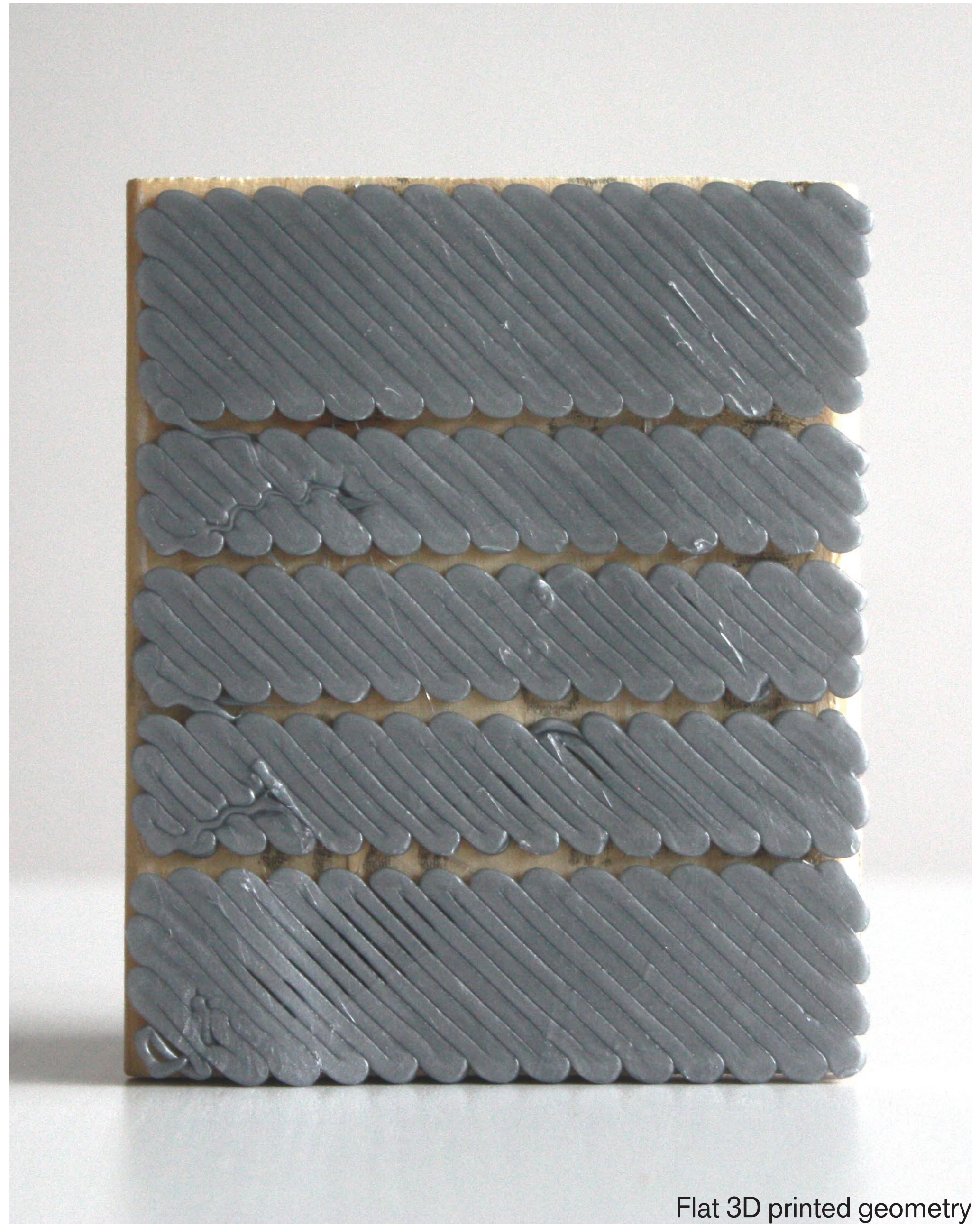
The first experiment involved printing a surface that was to be joined to a wooden block. A raft was generated using the *Filler* component in the Silkworm plug-in for Grasshopper, using a rectangular surface input. Two cylinders were modelled and contoured, placed above the raft. The wooden block is then placed on top of the flat geometry, where the 3D printer drips filament into the holes, attaching to the initial 3D printed geometry. The bulb that forms drips beyond the perimeter of the hole, setting itself onto the wooden block.

Method



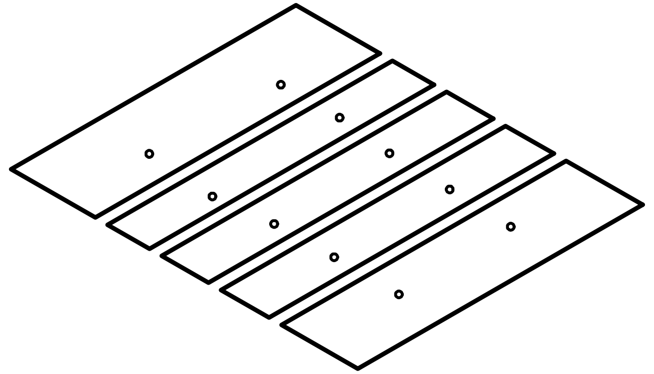
Place object over print *Let filament drip into hole*

3D printed bulbs fixes print onto wooden piece

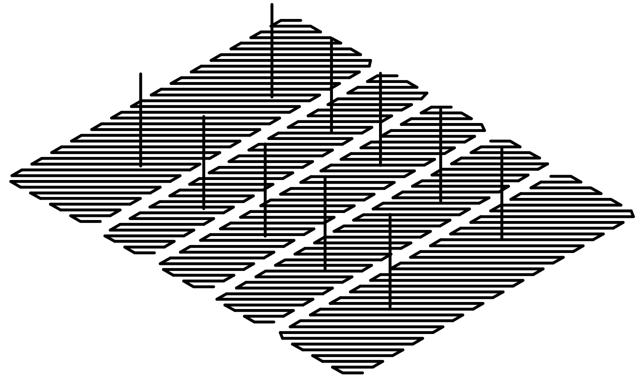


Flat 3D printed geometry

Experiment 3.1.2



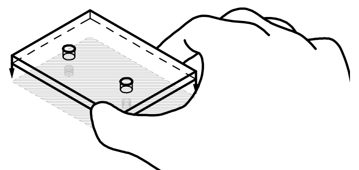
3D modelled geometry



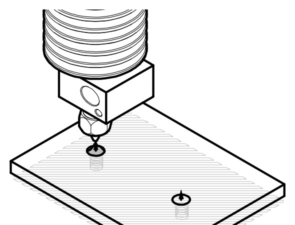
Generated toolpath

This experiment attempted to remove the need of modelling cylinders over the flat skirt. In its place, points were placed at the centre of each drilled hole of the wooden block that gave the 3D printer coordinates in which to drip filament into each hole. A vertical line is modelled from each of the points that act as a toolpath for the 3D printer to move along, each at various speeds. Slower speeds result in more filament volume released in the hole, giving indication of the appropriate speed needed to secure the geometry.

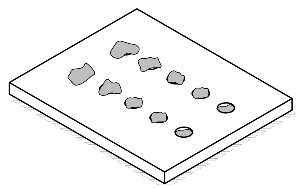
Method



Place object over print



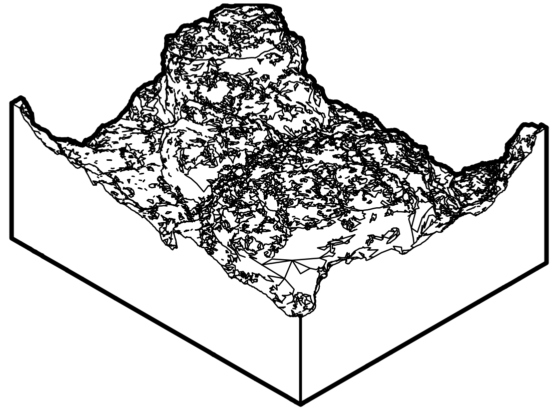
Let filament drip into hole



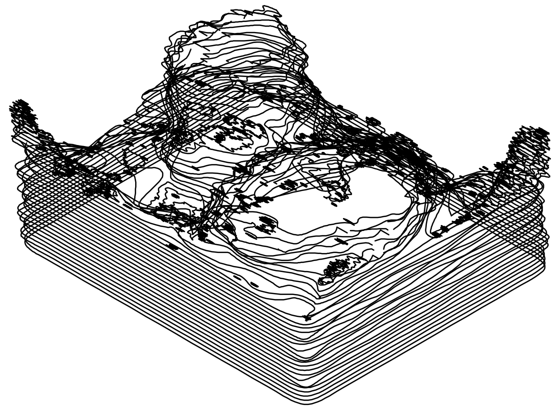
Amalgamation of joinery and geometry

Split 3D modelled geometry

Experiment 3.1.3



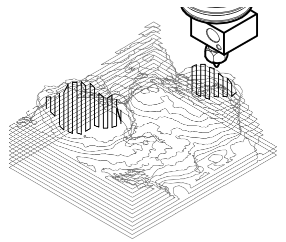
3D modelled geometry



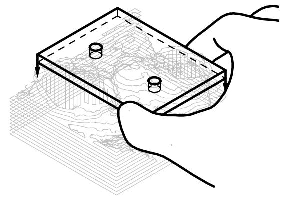
Generated toolpath

This experiment investigated the digital manipulation of slicing and contouring. An input geometry was contoured with control points extracted and rebuilt into NURB curves. This resulted in softer corners and simpler closed curves and in turn, more predictable 3D printing. The straight edges of the generated toolpath also appeared to have slight deviations compared to the 3D modelled geometry.

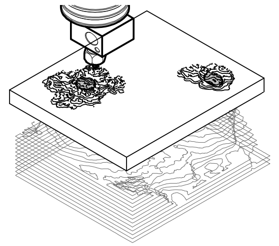
Method



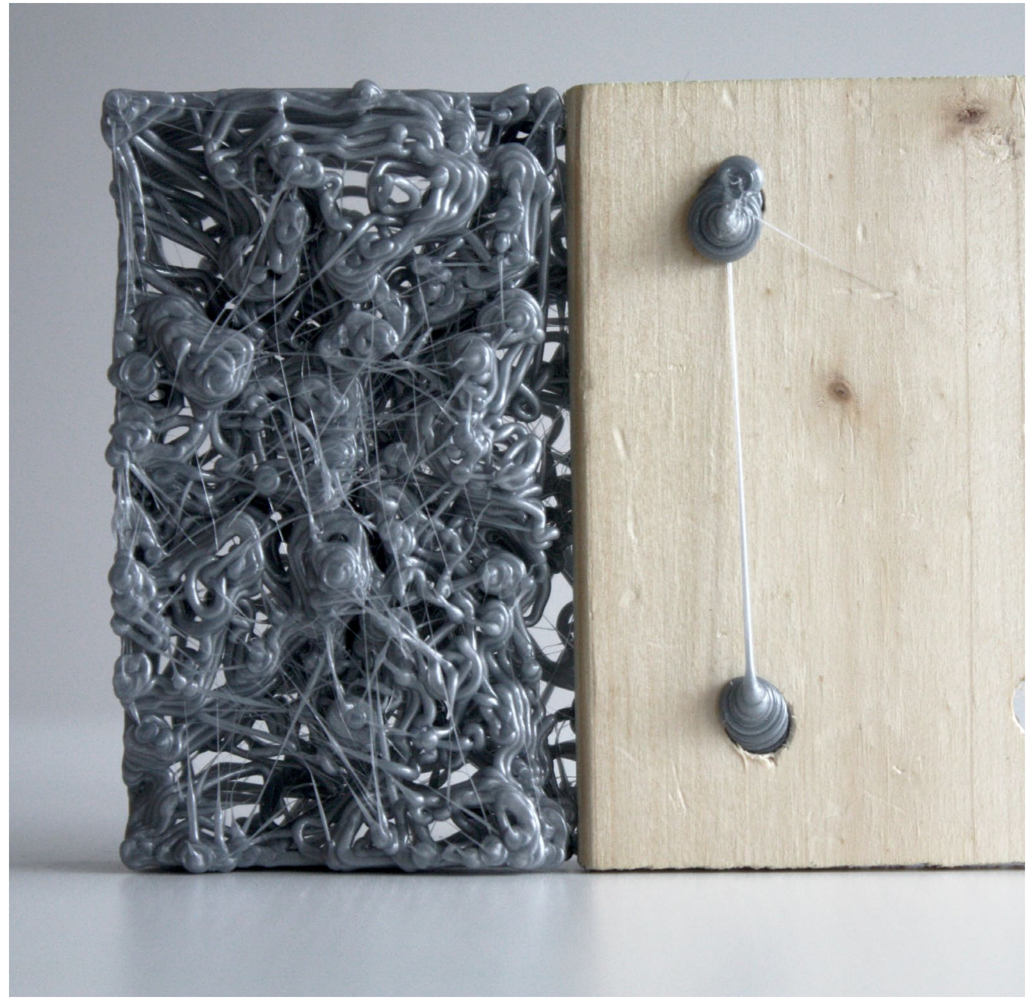
3D print bottom toolpath



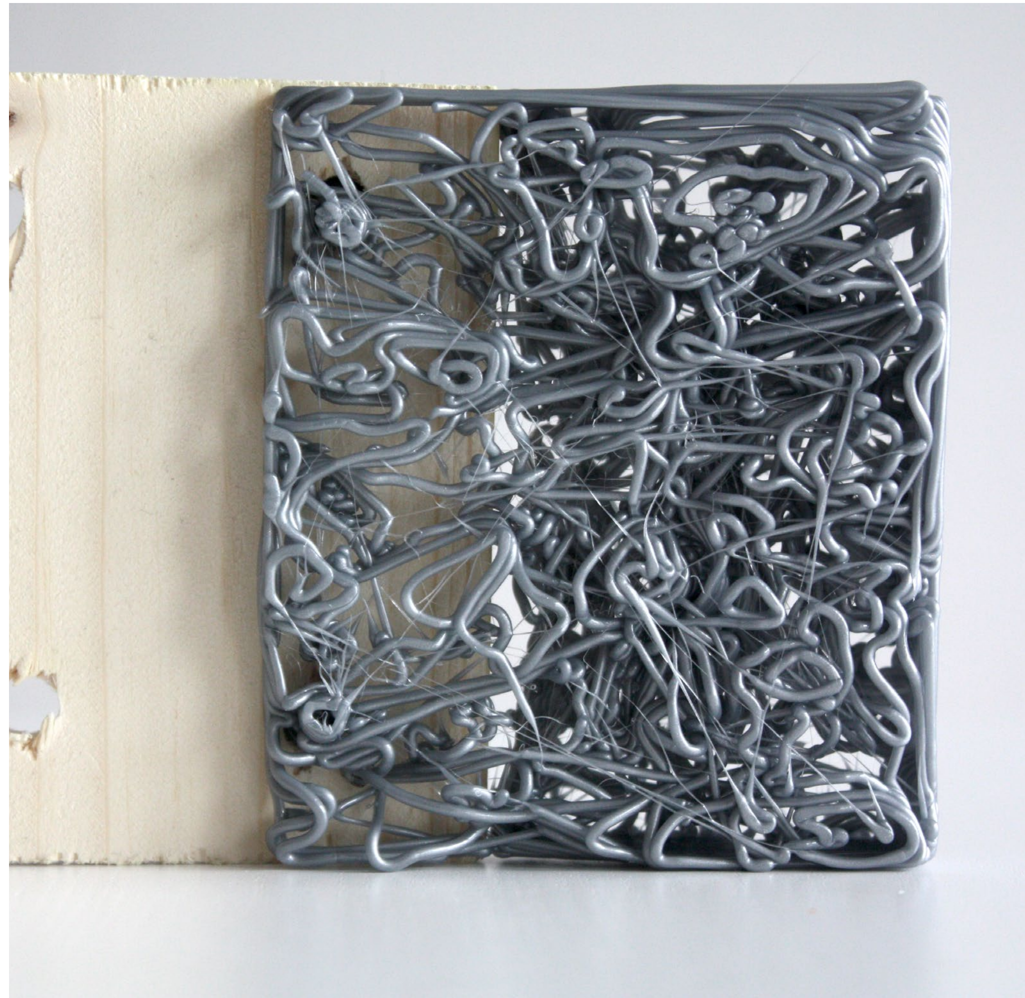
Place object on top of print



3D print remaining toolpath

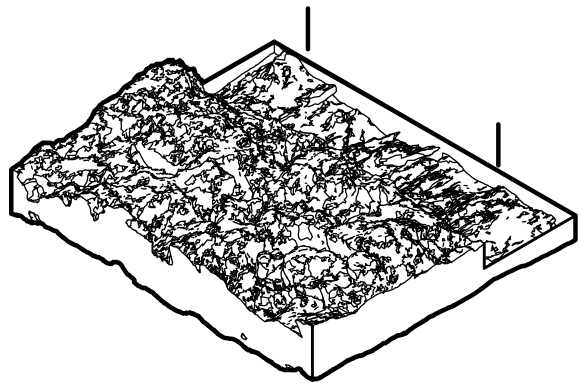


3D printed geometry reaches behind wooden object

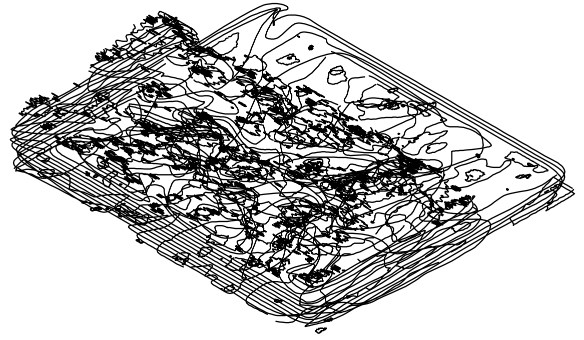


Joint hidden within 3D printed geometry

Experiment 3.1.4



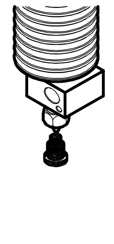
3D modelled geometry



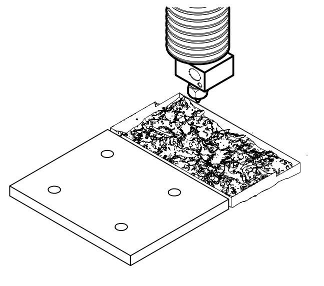
Generated toolpath

In addition to transforming contour lines to NURB curves, less contour lines were taken in attempt to hollow out the geometry. Split into two separate toolpaths, the top layers were printed above the wooden block. This resulted in a 3D print higher in porosity, barely holding its shape together. The resulting 3D print did not resemble the 3D modelled geometry, although its global geometry does.

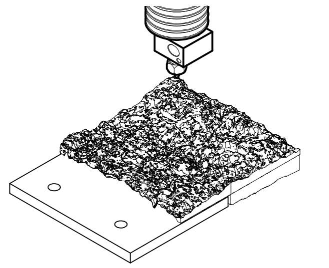
Method



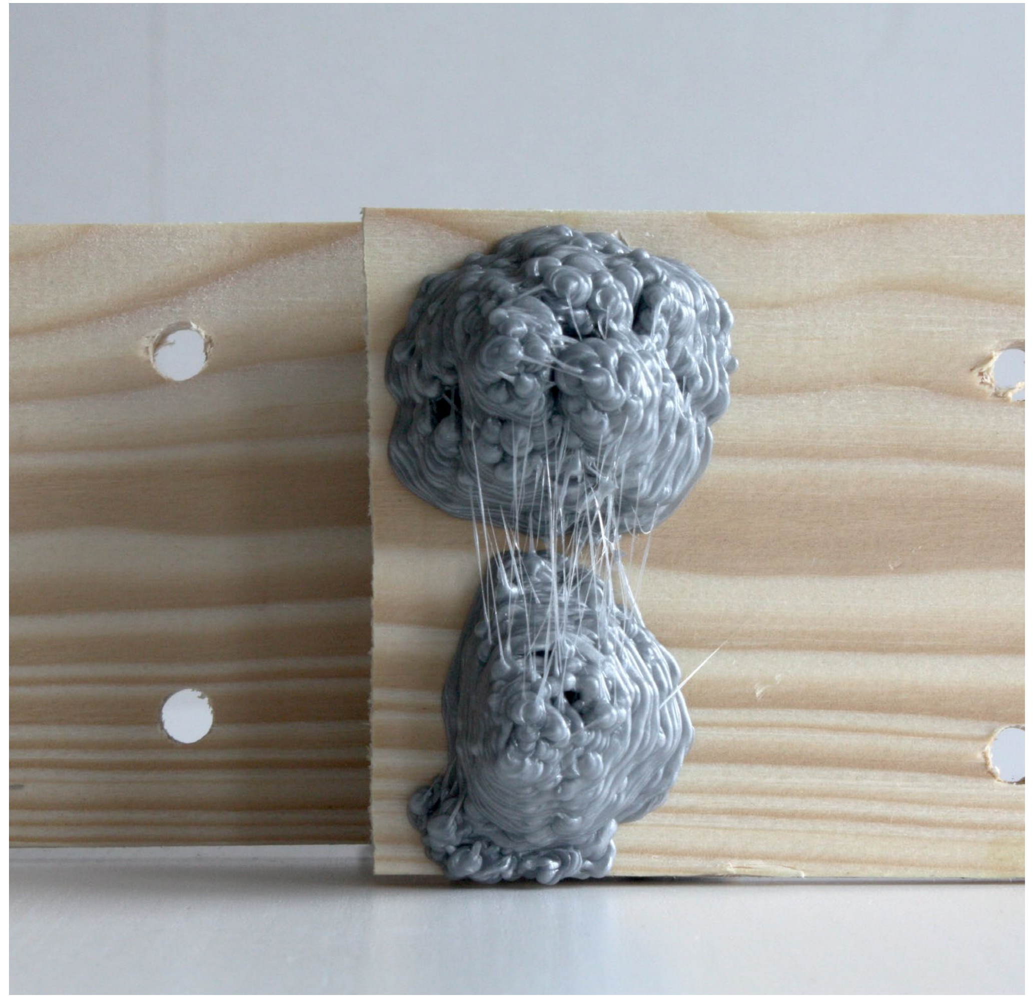
3D print bottom plugs



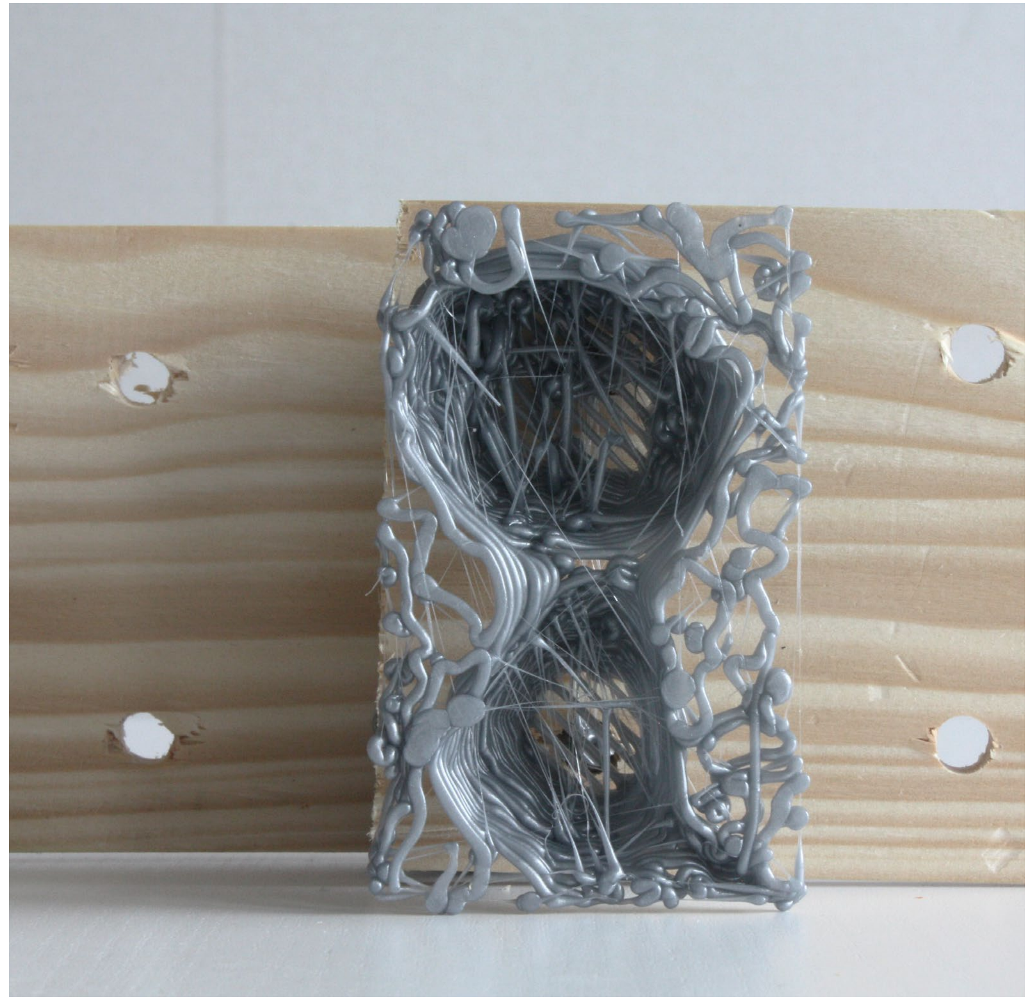
3D print bottom geometry



3D print top geometry, connecting to plugs

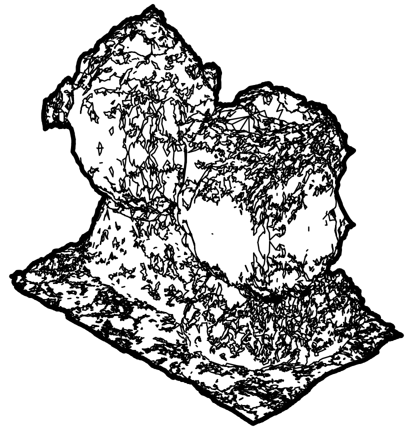


Top of 3D print

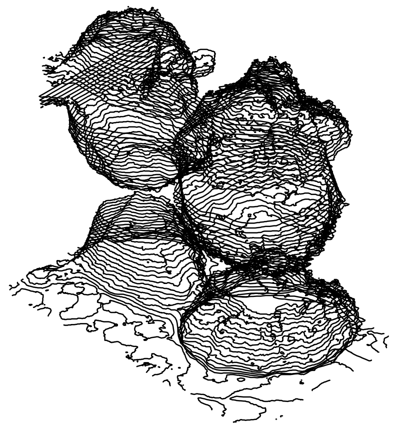


Bottom of 3D print

Experiment 3.1.5



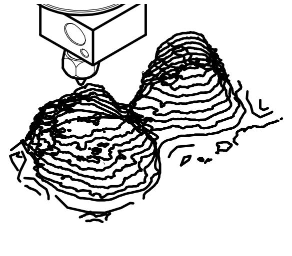
3D modelled geometry



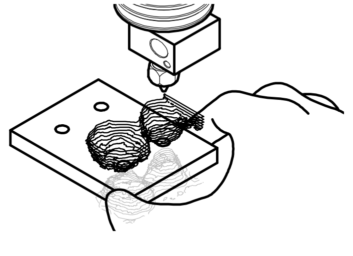
Generated toolpath

Following contouring the 3D modelled geometry, the curves were split into three groups, creating three separate toolpaths. Between each 3D print, wooden blocks are secured in place through filament dripping through the pre-drilled holes. Smaller curves, less than 1cm long, were left in the toolpath which resulted in small diversions of small blobs of filament around the face of the 3D print.

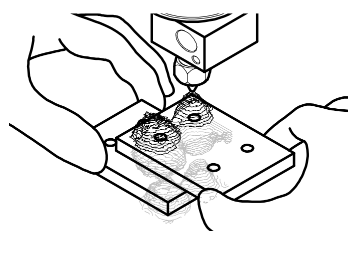
Method



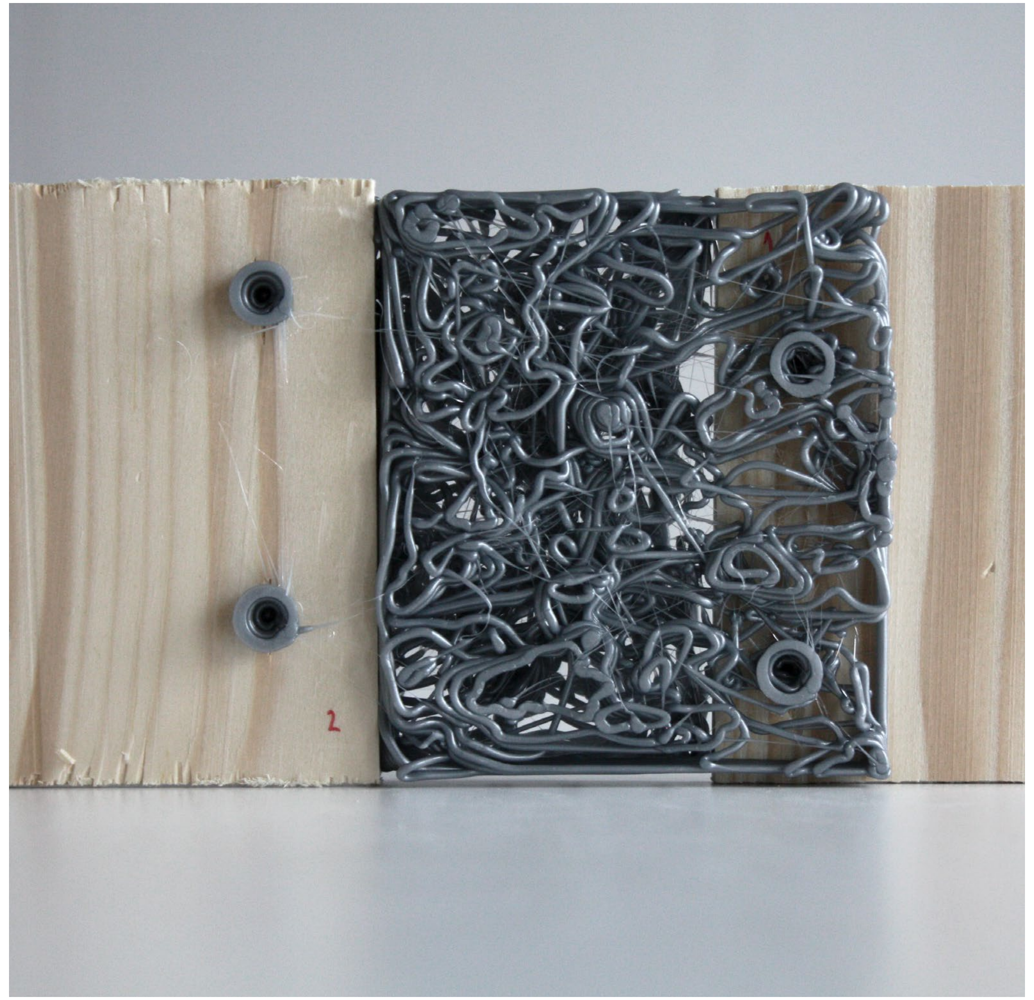
3D print bottom toolpath



Place object over print



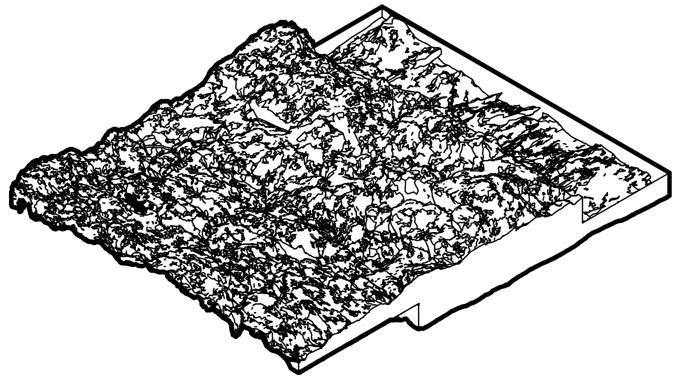
3D print remaining toolpath



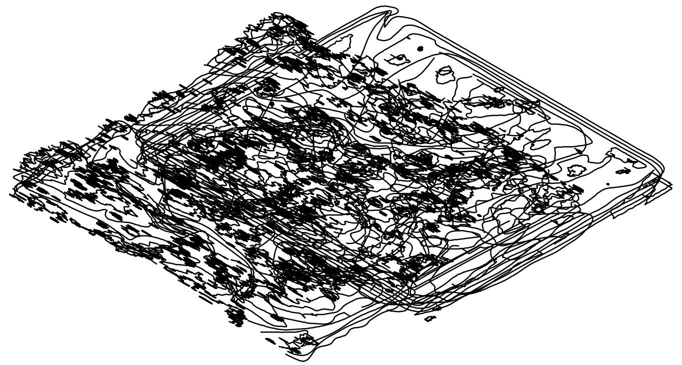
Bottom of 3D print has higher porosity

Single piece of 3D printed geometry is able to hold 2 wooden blocks together

Experiment 3.1.6



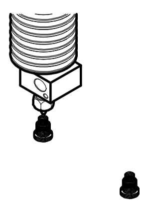
3D modelled geometry



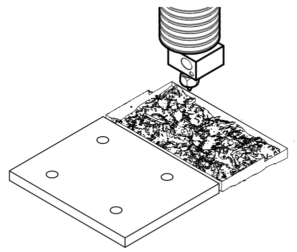
Generated toolpath

A 3D model that was displaced with a highly detailed texture was contoured, resulting in a toolpath largely compromising of small closed curves, resembling the 'blobs' observed in Experiment 3.1.5. A part of the toolpath appears to be floating as a wooden block was placed underneath that was to be fixed to the 3D print. Due to the high amount of small curves, the 3D printer appeared to print in a jittered path. The high speed of the travel path attributes to this, as a majority of the toolpath is compromised of travel movements.

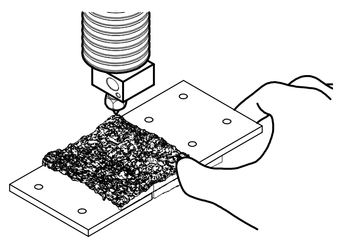
Method



3D print plugs



3D print bottom geometry

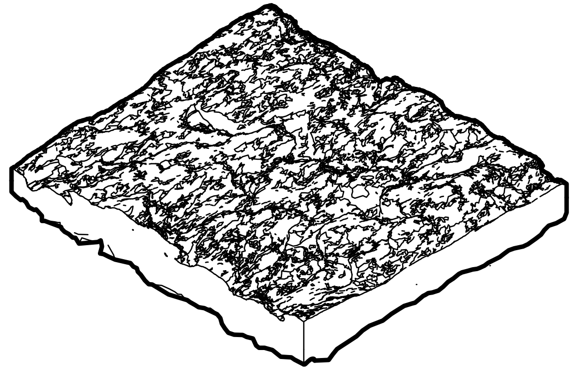


3D print remaining toolpath

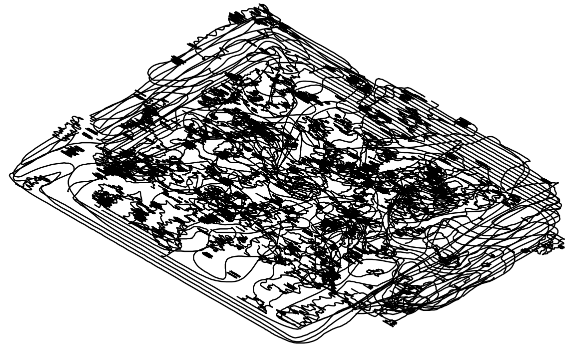
3D printed plugs were left into the concrete block

New filament remelted the 3D printed plugs

Experiment 3.1.7



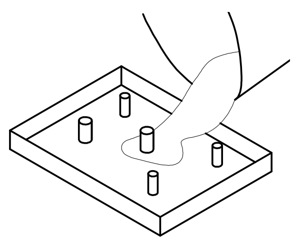
3D modelled geometry



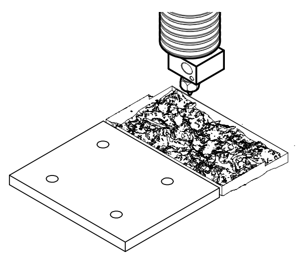
Generated toolpath

A 3D modelled cuboid was displaced and contoured. To avoid straight edges and sharp corners, the curves were rebuilt with less control points, allowing the 3D printer to move less rigidly throughout the print. A part of the curves were trimmed in order to make room for a concrete casted object to fit underneath. Plugs on the 3D printed mold were initially intended to be removed to form holes within the concrete but were left in, where they were remelted and printed over, forming a joinery.

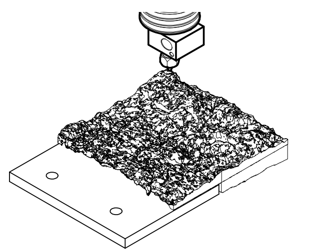
Method



Pour concrete into 3D printed mold



3D print bottom toolpath

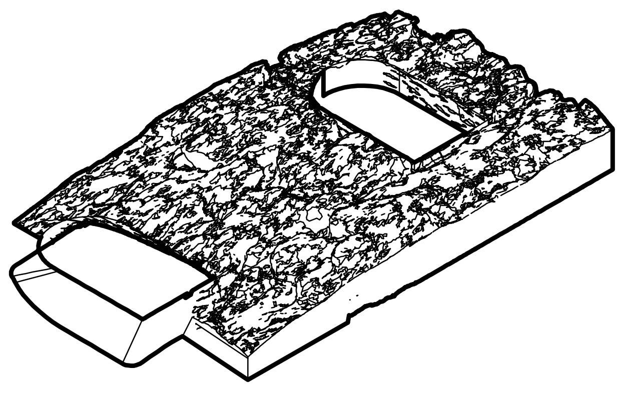


3D print remaining toolpath

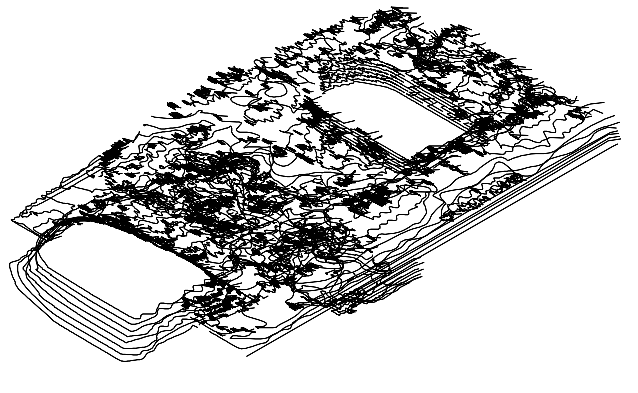
Arches carved into the jittered geometry

3D printed geometry fills in the gap in between concrete blocks

Experiment 3.1.8



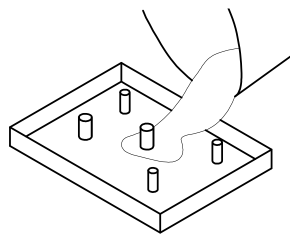
3D modelled geometry



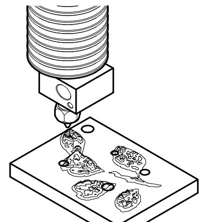
Generated toolpath

Two arches was carved into the 3D modelled cuboid, forming a toolpath that was a mix of deliberate, designed geometry along with jittered, smaller curves. The arch amongst the jittered curves had a more broken up toolpath, resulting in a looser boundary, almost blending into the mess.

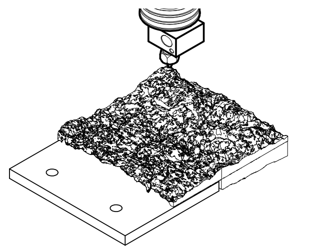
Method



Pour concrete into 3D printed mold



3D print formal toolpath

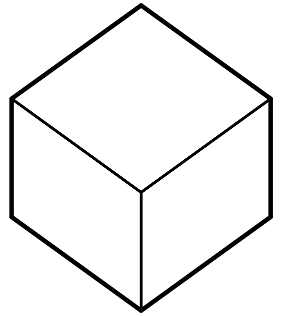


3D print remaining toolpath

Layered pattern

A handcrafted pattern visible from above

Experiment 3.1.9

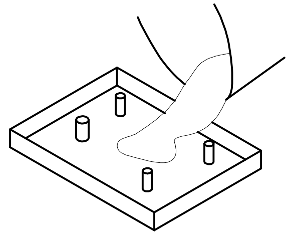


3D modelled geometry

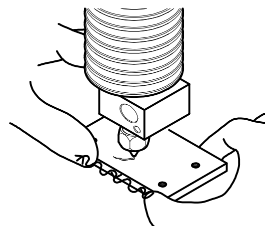
Generated toolpath

No detailed geometry was 3D modelled in this experiment, pursuit to create a toolpath that did not rely on a user designed geometry. The idea was so contour a simple cube where the extruder would pause for a period of time at each point of the contour while extruding filament out, relying on external input to move the object physically to create geometry. To avoid the resulting 3D print to seem too random, the object was moved in a pattern-like manner. The result is a 3D print that appears to be one-of-a-kind, hand crafted by a machine. It should be noted that the result could probably also be achieved by a 3D pen.

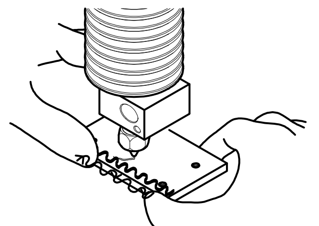
Method



Pour concrete into 3D printed mold

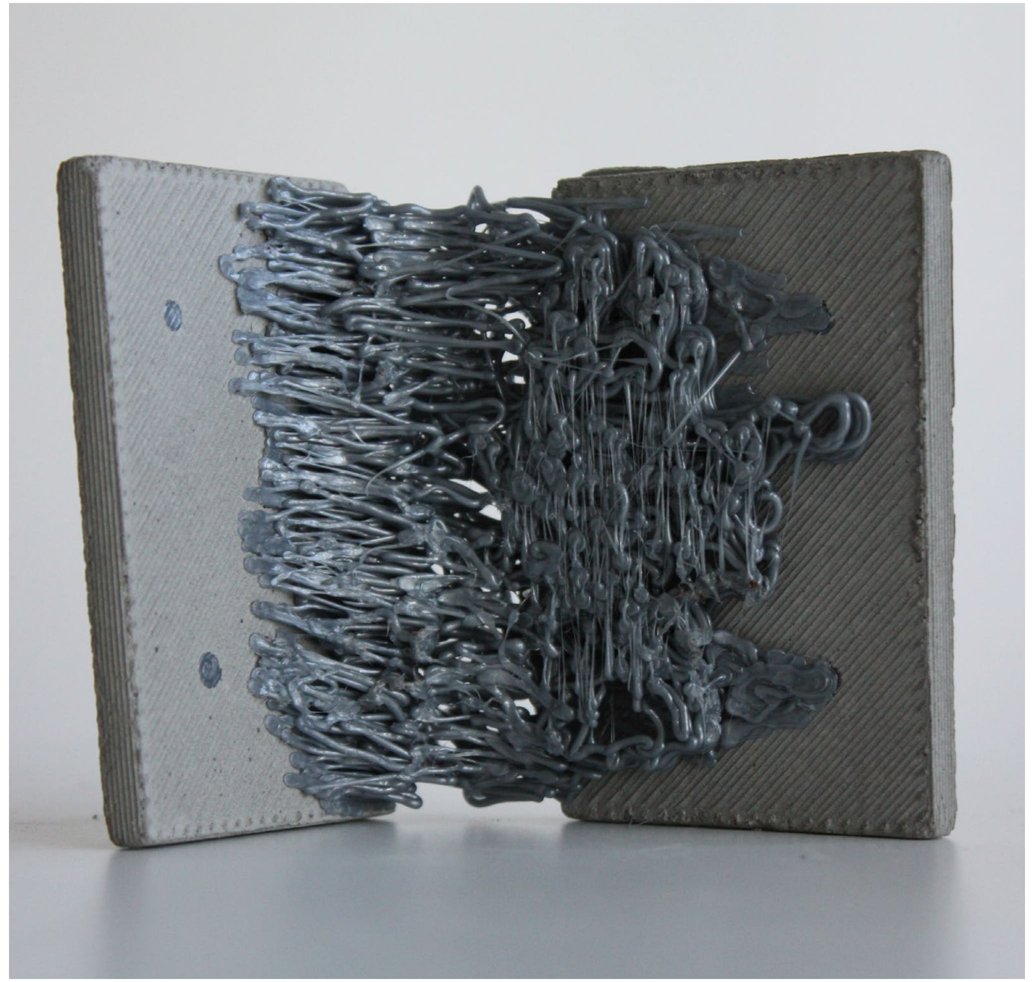


Move object while 3D print releases filament



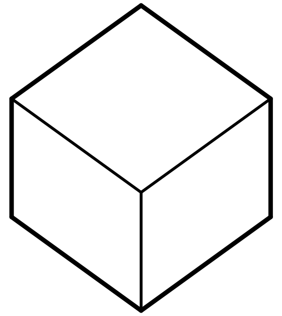
Repeat each layer

3D printed geometry seeps through at the corner

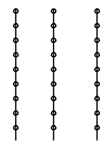


‘Inside’ the corner

Experiment 3.1.10



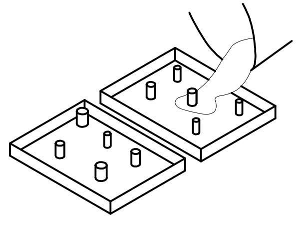
3D modelled geometry



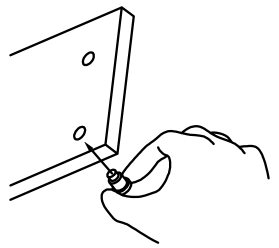
Generated toolpath

Another toolpath was generated, allowing two separate manual movements to control the 3D print. The first two prints involved the object being moved side to side on two concrete blocks, while the third print involved the objects being moved in the shape of a ‘U’, forming a joint at a 90 degree angle to the concrete objects. It was interesting to see the 3D print seep through at the corner of the final piece, while it was only in the ‘inside’ where the joint was visible.

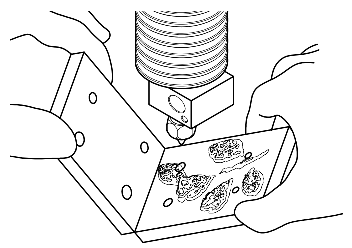
Method



Pour concrete into 3D printed molds



Push 3D printed plugs into holes

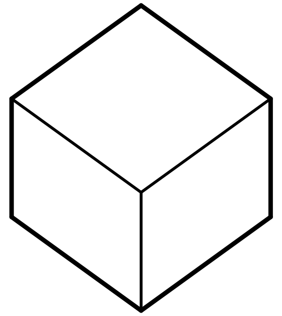


Manually move objects while 3D printer releases filament

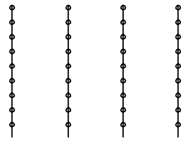
Diversions visible from outside

Concrete blocks held together by imperfect diversions

Experiment 3.1.11



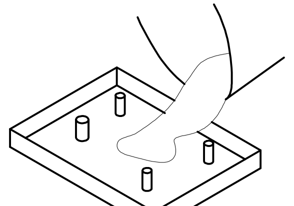
3D modelled geometry



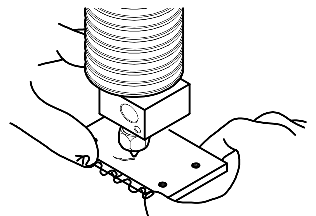
Generated toolpath

Using techniques and methods explored in earlier experiments, an outdoor pavilion was constructed with four concrete blocks with four separate toolpaths. The space that resulted was almost a perfect cube, but did not appear to be at first glance. The 3D printed geometry seems to distract the overall cuboid geometry of the piece with its imperfections and diversions.

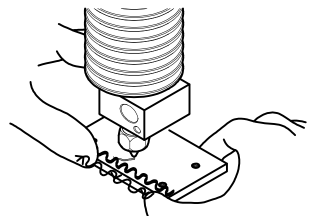
Method



Pour concrete into 3D printed mold



Move object while 3D print releases filament



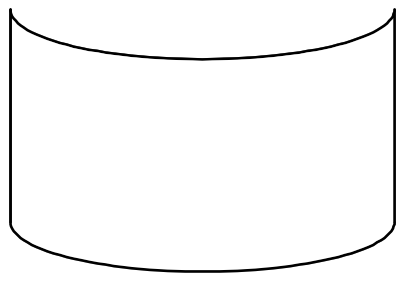
Repeat each layer

3.2 Customised Objects: Toolpath Manipulation

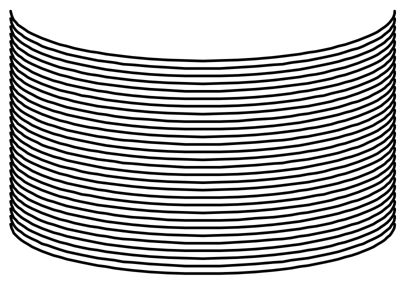
The following experiments explored how the customisation demonstrated in fabrication could be achieved digitally. It considered automation as a means of producing toolpaths, avoiding manual human tasks. This was achieved by working extensively in Grasshopper, minimising the need for 3D modelling.

A 3D modelled surface was broken down into control points that would typically be in a G-code file and given to a 3D printer to instruct movement for the extruder. As working with points is far more efficient than working with curves and surfaces, manipulating control points of a given toolpath were an efficient way to edit the resulting 3D print. The control points were jittered in a chosen direction and distance where it could be fed back into a G-code file for a 3D printer to print. Control points by themselves may not be enough information for a designer to visualise how a 3D print could appear in the end, so NURB curves are generated using the jittered control points and then piped, illustrating an approximation of the resulting 3D print. The resulting Grasshopper script required an input surface that output both G-code and an approximation of the 3D print. The script could be used by designers to 3D print multiple unique surfaces quickly.

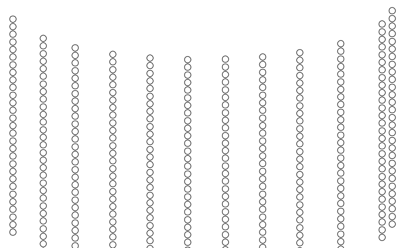
During the development of these experiments, the contours were duplicated and joined together, creating closed curves, rather than one single layered surfaces. This also introduced the possibility of bringing in light from the joint, filtering it out through apertures.



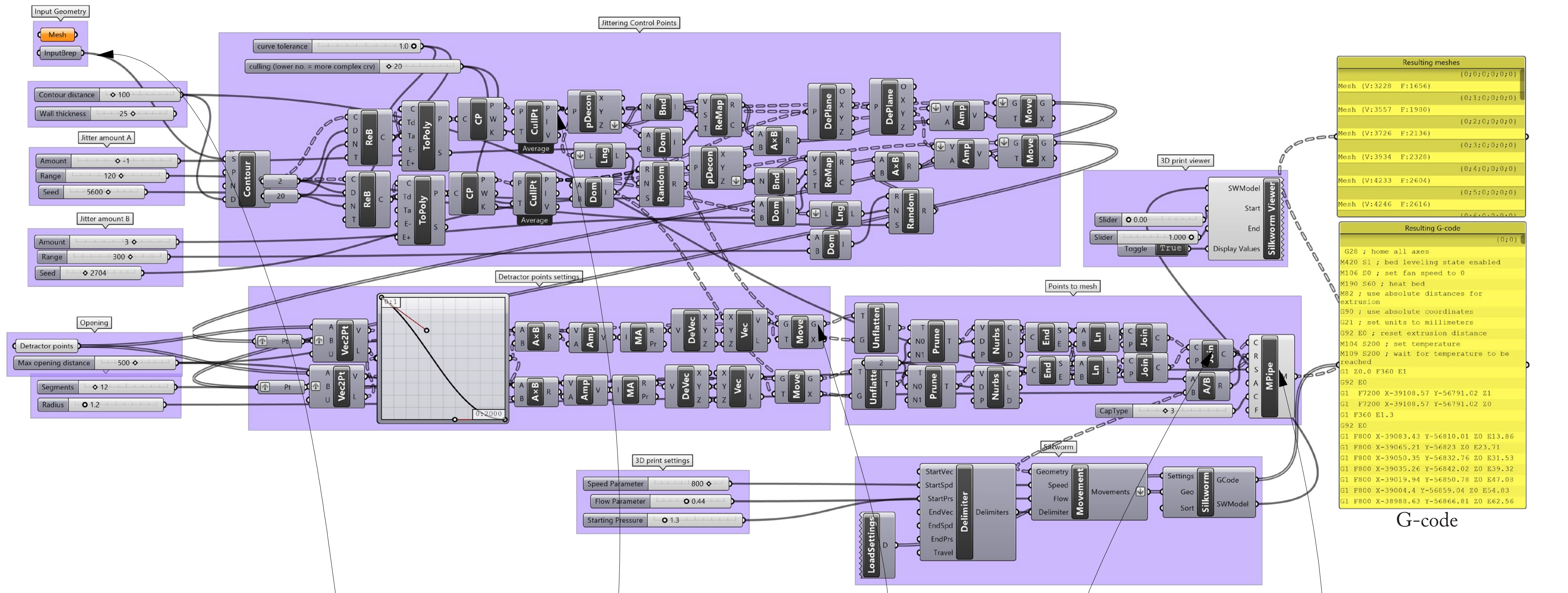
Surface



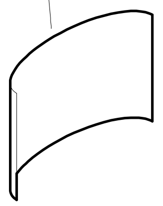
Contoured toolpath



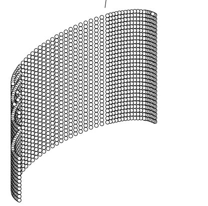
Control points of curves



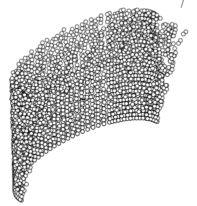
G-code



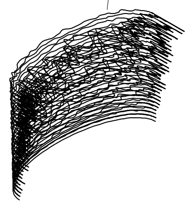
Surface



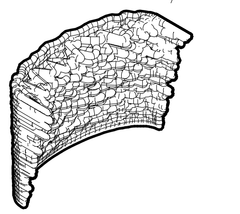
Contoured control points



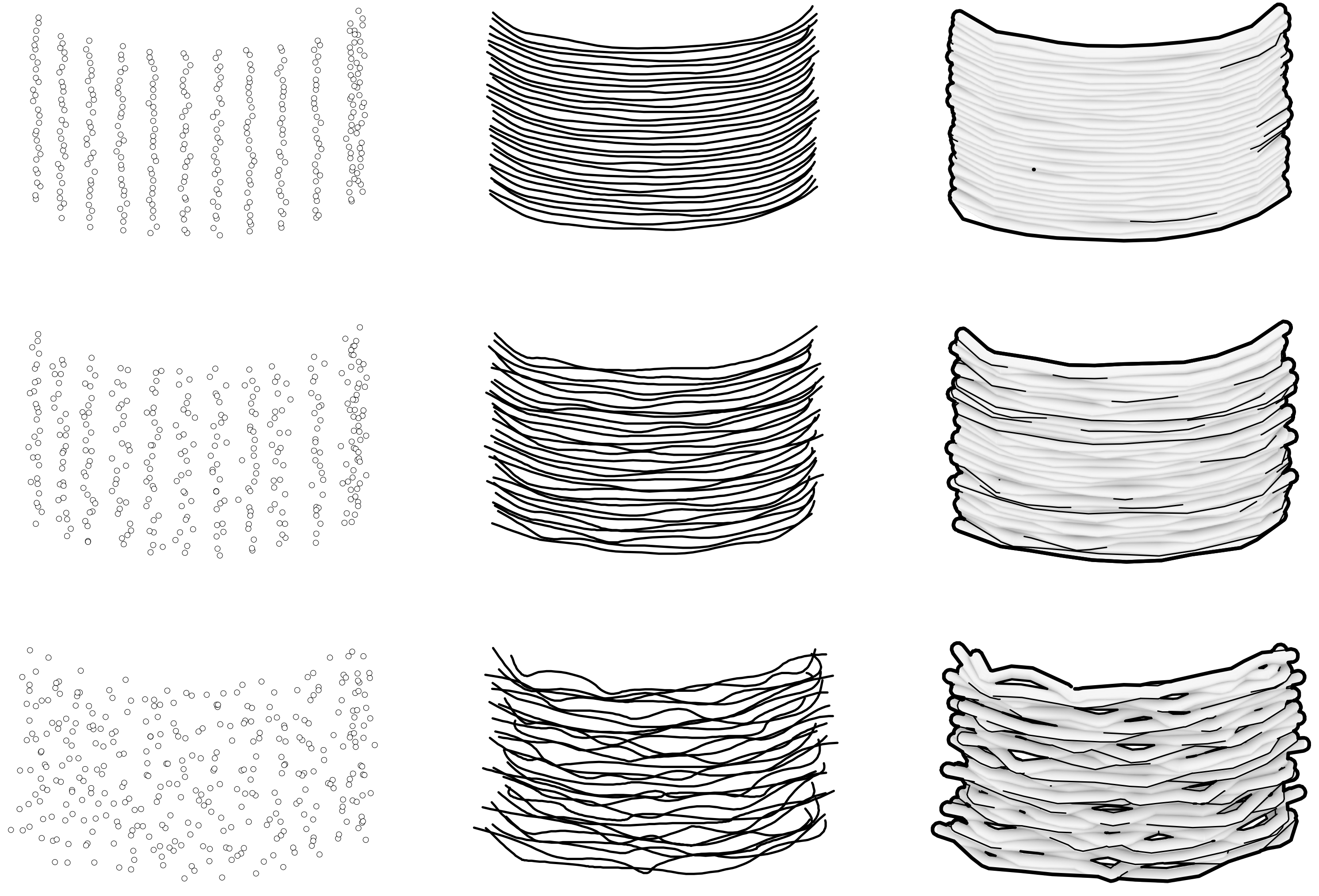
Jittered control points



NURB curves



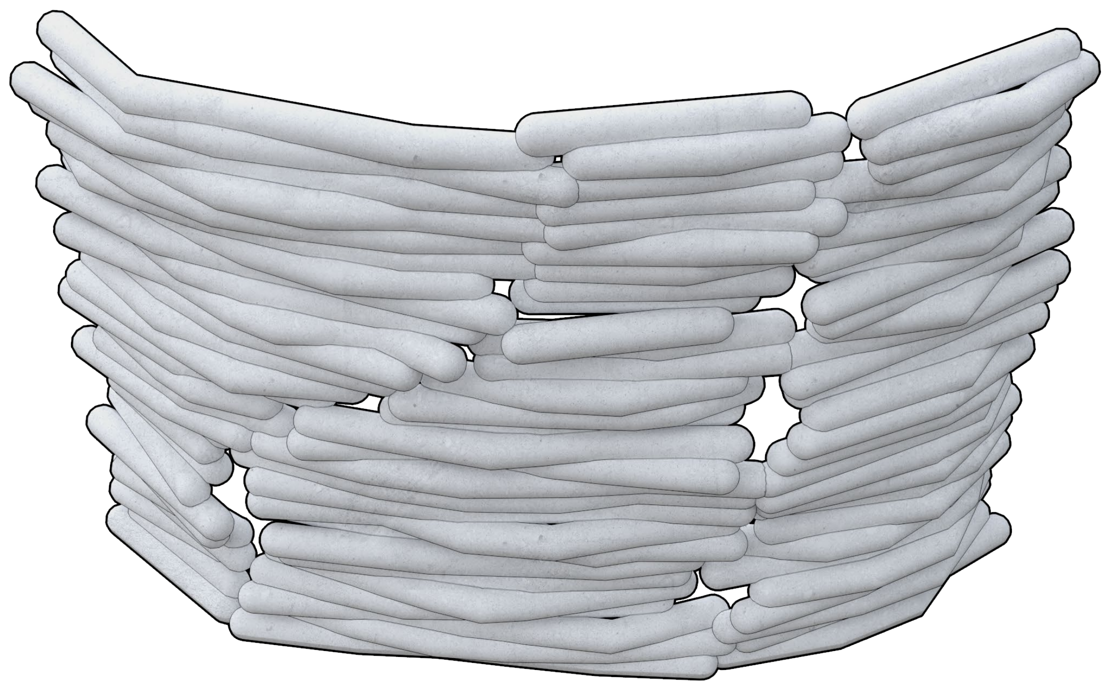
Approximation of print



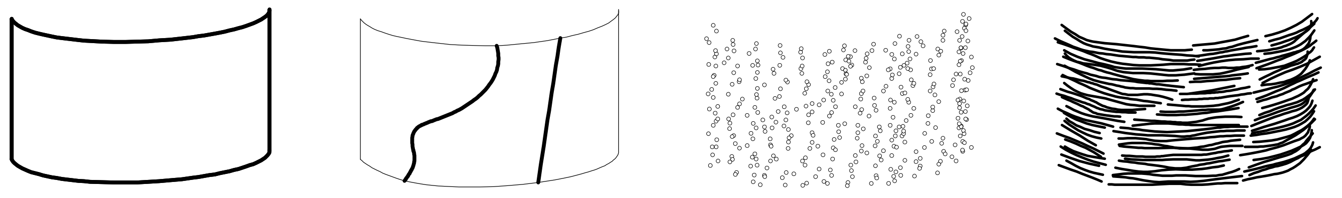
Jittered control points *Generated NURB curves* *Approximation of 3D print*

Experiment 3.2.1

The first experiment involved introducing apertures in the 3D print. The surface was split with input surfaces and then contoured. As control points existed on either side of the split, apertures became present and with control points of the contours jittered, the apertures in the split being more inconsistent, closing off in some areas.



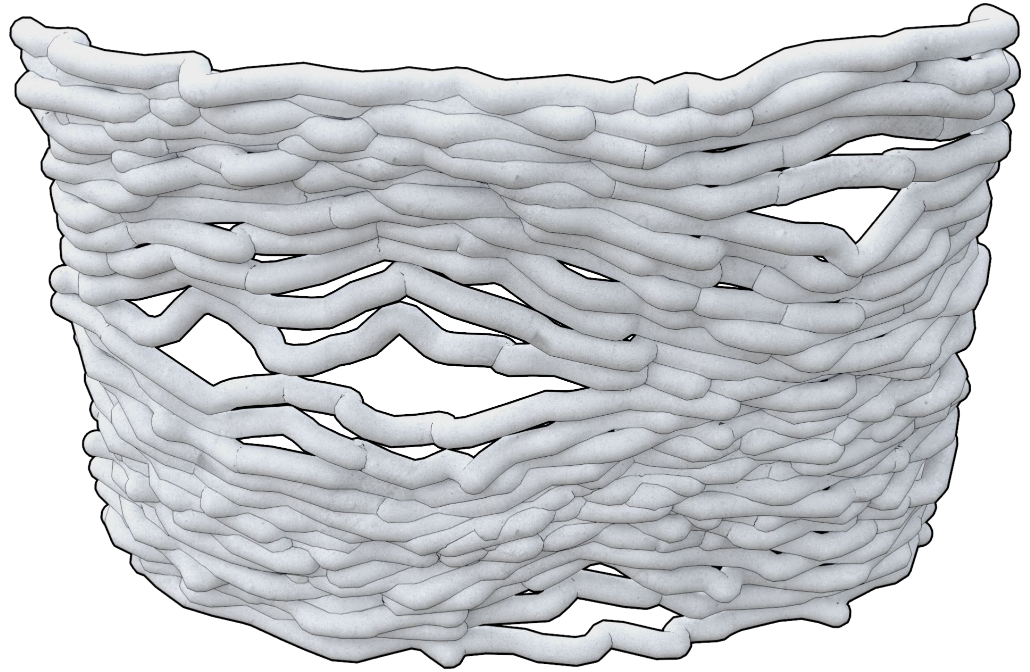
Approximation of 3D print



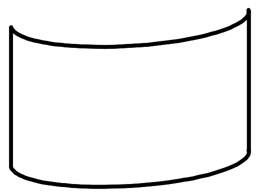
Standardised surface *Split surface* *Jittered contour control points* *Resulting toolpath*

Experiment 3.2.2

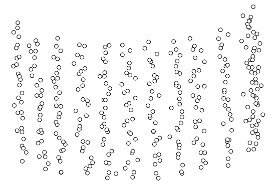
Points were placed along a surface to be used as detractors in the z-direction for the jittered control points. The detractor points effected almost all of the control points, squeezing the layers beneath them and above them together with almost no two control points sharing the same z-coordinate.



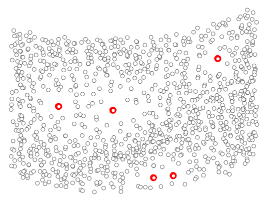
Approximation of 3D print



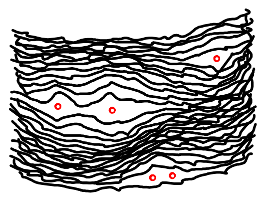
Standardised surface



Jittered contour control points



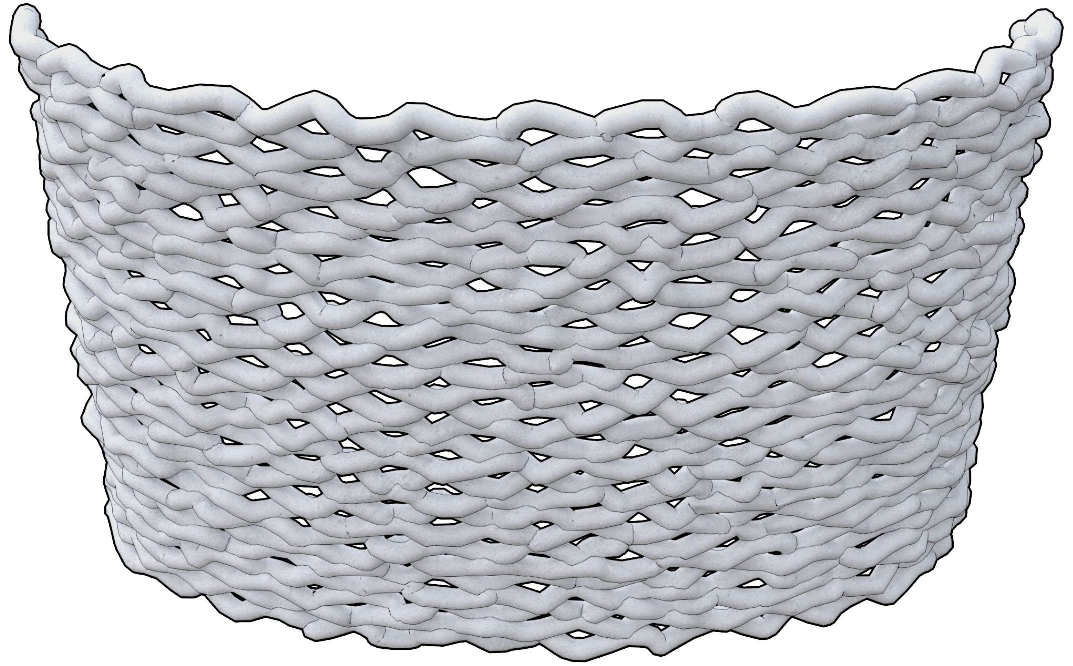
Detractor points



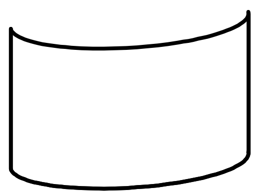
Resulting toolpath

Experiment 3.2.3

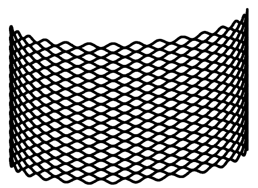
Rather than contouring the surface, a net component was applied to the surface resulting in a wave-like pattern of curves. As the curves are non-planar, the wave height was lowered before jittering the contour points.



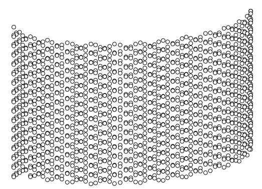
Approximation of 3D print



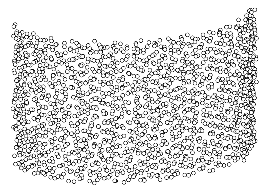
Standardised surface



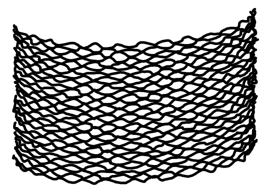
Net contour



Net contour control points



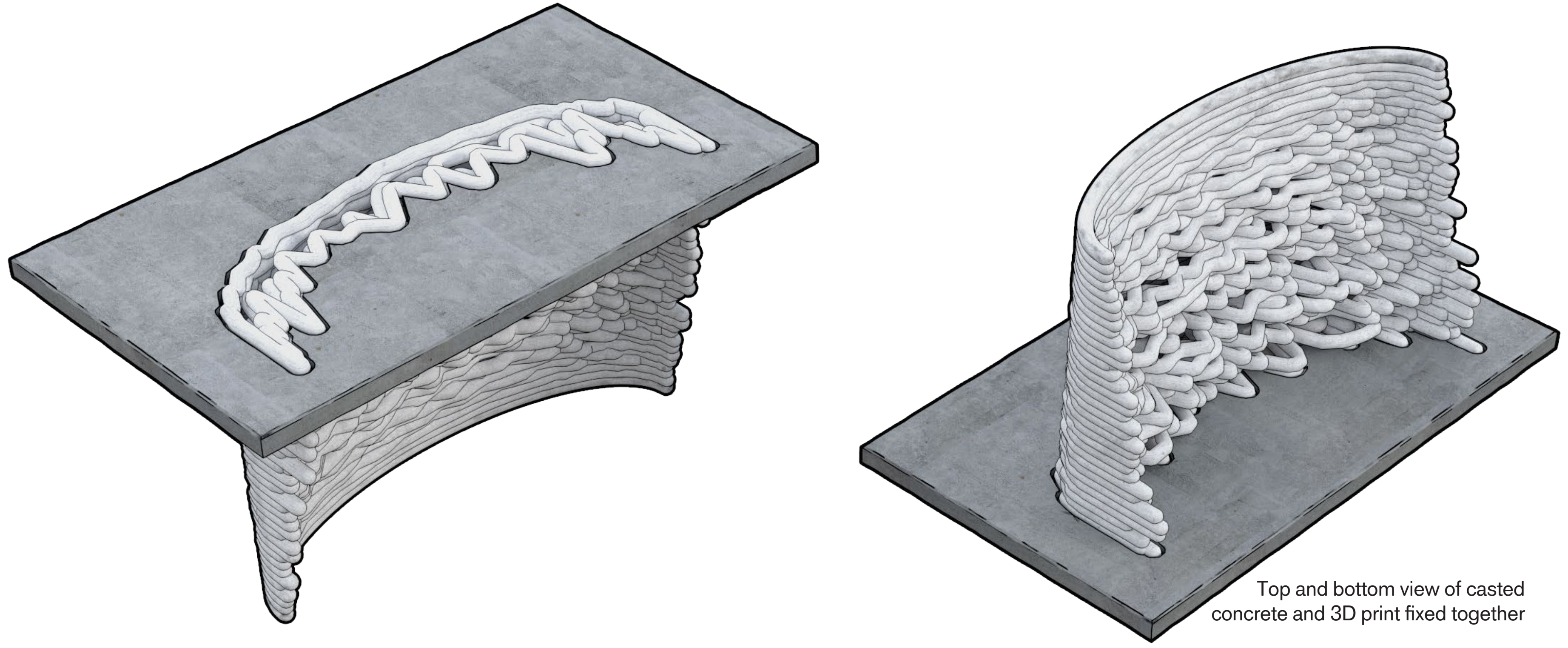
Jittered control points



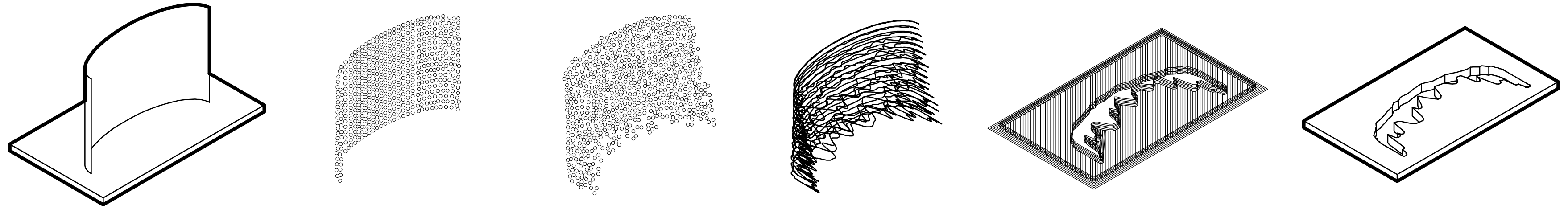
Resulting toolpath

Experiment 3.2.4

A concrete block is introduced to the method that is trimmed with the perimeter of the first layer of the 3D print. The first layer was to be printed for the concrete cast, where the remaining toolpath could be printed on top. Control points are duplicated and joined, forming a light well from the bottom of the print. Intense jittering can allow for light to be filtered out.



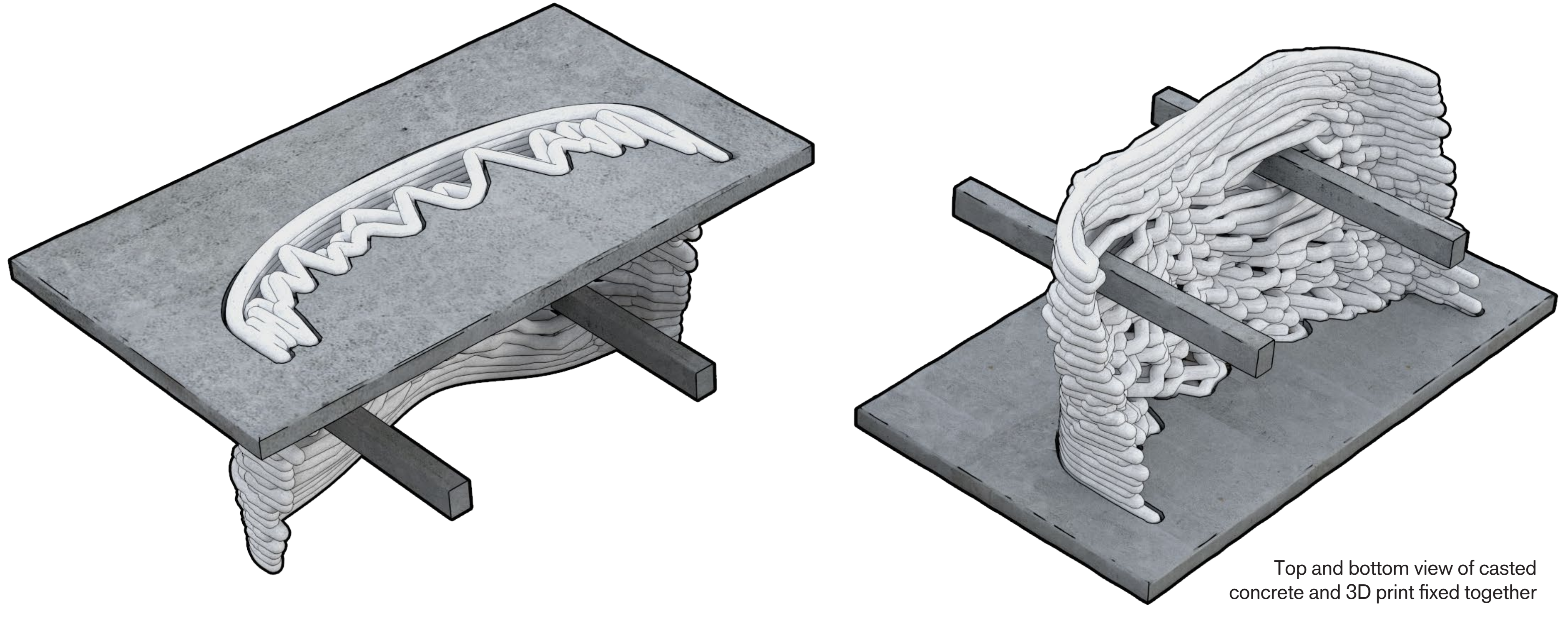
Top and bottom view of casted concrete and 3D print fixed together



Standardised surfaces | *Duplicate control points* | *Jittered control points* | *Resulting toolpath* | *Toolpath for concrete cast* | *Resulting casted concrete*

Experiment 3.2.5

Detractor points were introduced again, allowing space for precast concrete beams to run through the surface. The openings for the beams are exaggerated to let more light out from above.

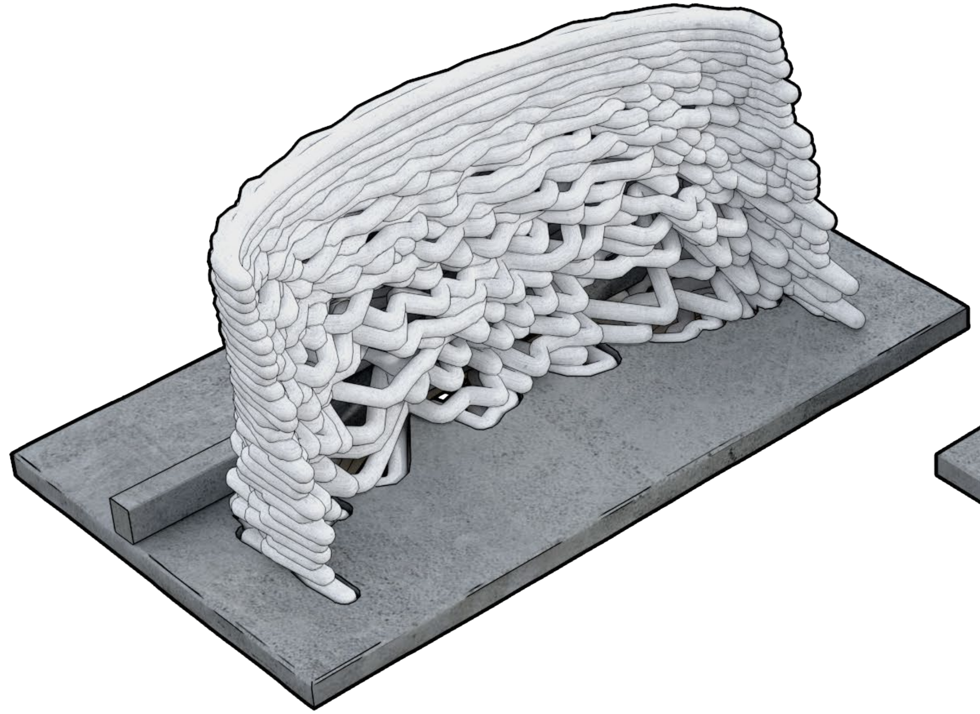


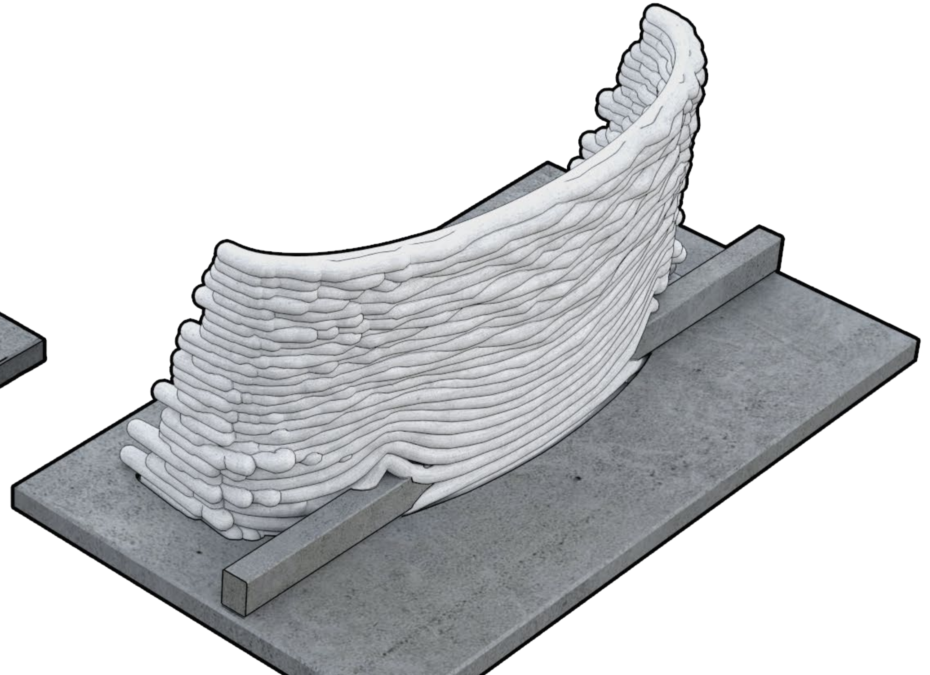
Top and bottom view of casted concrete and 3D print fixed together

Standardised surfaces | *Control and detractor points* | *Resulting toolpath* | *Toolpath for concrete cast* | *Resulting casted concrete*

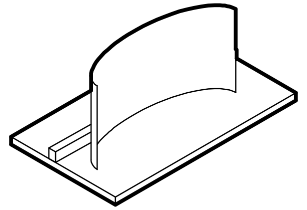
Experiment 3.2.6

In the case that beams run alongside the 3D printed surface, detractor points are placed at the intersections of the beam and surface, creating openings for the beam to run inside the 3D print. Intense jittering allow for apertures where the beam is visible.

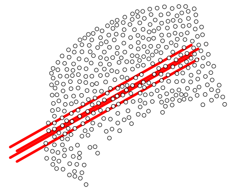




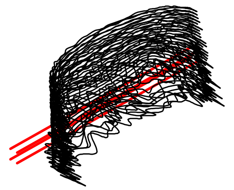
Top and bottom view of casted concrete and 3D print fixed together



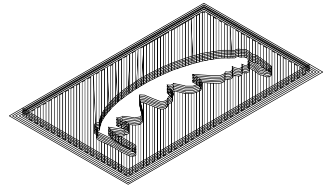
Standardised surface



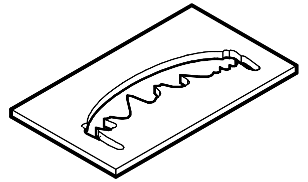
Contour control points



Resulting toolpath



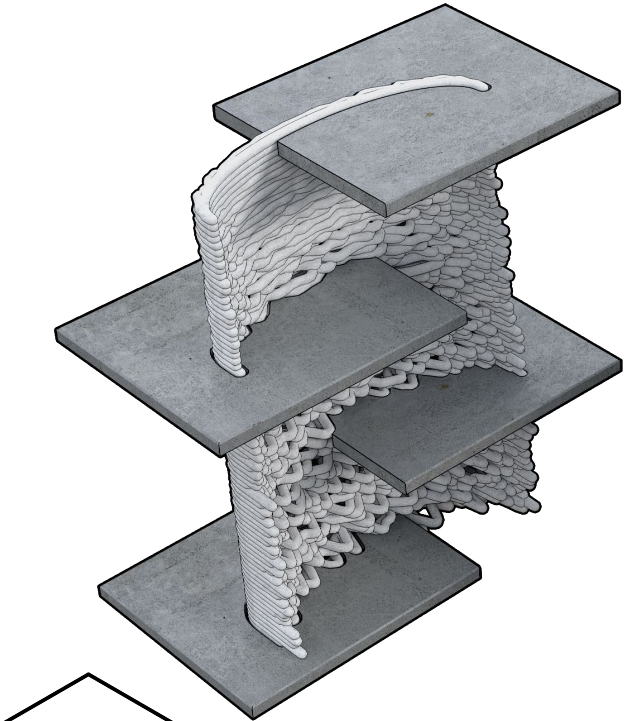
Toolpath for concrete cast

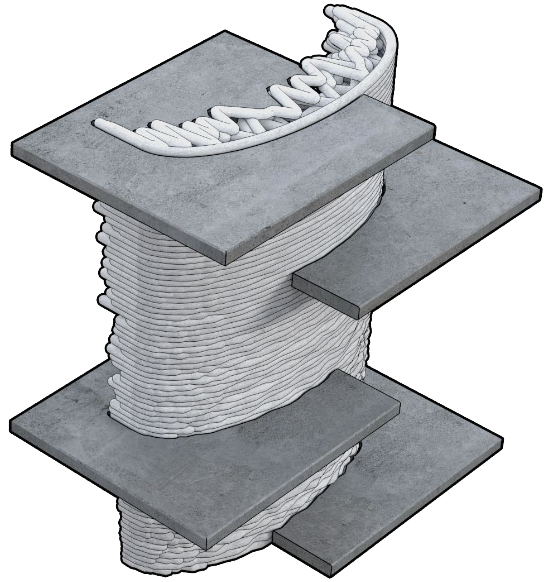


Resulting casted concrete

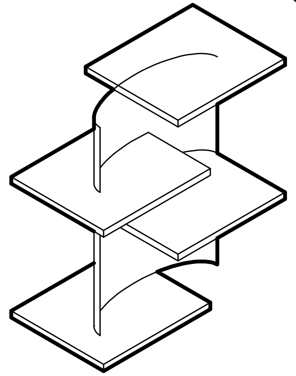
Experiment 3.2.7

Multiple concrete blocks could be joined to a single 3D printed surface. The perimeter of each intersecting layer is 3D printed on the concrete cast to facilitate the joining of each concrete block.

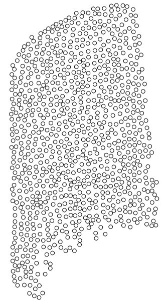




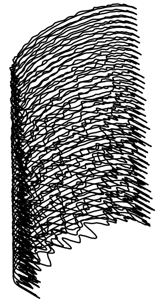
Front and back views of casted concrete and 3D print fixed together



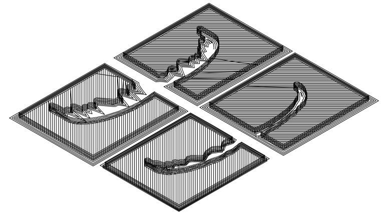
Standardised surfaces



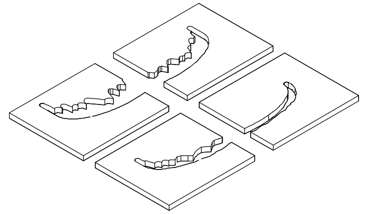
Jittered control points



Resulting toolpath



Toolpath for concrete cast



Resulting casted concrete

Discussion

Overall, the thesis was led largely by intuition and intrigue. This resulted in, at times, a mess (and wealth) of information, ideas and themes, challenging me to critically analyse my short term goals and intentions. I believe this thesis have achieved its goals of exploring spatial possibilities by the means of exploiting the 3D printing method. Due to the complex nature of the experiments and work, it was challenging to communicate ideas in a clear and overarching way.

The experiments introduced 3D printing to mass customisation through various strategies of toolpath manipulation. Achieved by the use of extensive Grasshopper scripting, it proved that many customised objects could be fabricated autonomously, in turn, on a mass scale. 3D print settings such as flow, speed and pressure were reduced down to sliders and wires, challenging Carpo's notion of additive technologies requiring large amounts of data. After all, it is merely the user interface that defines the accessibility of the technology. For example, television remotes today are reduced to just a few buttons despite the complex machines they control: an on/off button, volume control and channel control. Designers of television remotes are able to reduce the hundreds of possible settings of a television down to just a few important parameters that users can and should be able to control. Similiarly, as designers of fabrication and form, we can reduce the complex nature of digital manufacturing to a default setting, with few but important parameters users can control. This 'default setting' in the case of the proposal is a wall that provides light and defines a semi-private space, while the extended parameters are how much light a wall should bring in and the shape and sizes of the spaces. The ability to choose as a user should be designed in the interest of 'a greater good', where interests in resource efficiency and equality can be the foundation of choice.

As the title of this thesis suggests, the work intended to jitter and disrupt how we think about mass production; it is not a critique, nor does it praise mass production, rather, it sees the practical reasoning behind it, but seeks to explore the far reaching arm

mass production has. Today, mass produced buildings and building components are seen everywhere in our cities. Its usage and impact on its users should be just as designed as a handcrafted, one-off home.

This thesis is limited to the use of PLA in 3D printing and does not respond to potential issues arisen at one-to-one scale. The proposal showcased the dynamic spatial qualities that arise when pushing autonomous customisation to the limit, revealing a range of single to triple height floors, various light conditions and different configurations of floor plans. The thesis, overall, aims to provoke questions about 'mass architecture' and its ethical boundaries. It challenges the notion of craft in the modern day, prompting architects and designers to reconsider the conventional role of technology within the design process.

Student Background

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