Space Between Lines:
Diagrammatic Architecture and 3D Printing

by

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Author's Declaration

I hearby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

All forms of communication require a medium to translate abstract thoughts from the mind to an observable and measurable artifact. Whether it is through body movement, vocalization, drawing, making, or multimedia, all ideas rely on some form of medium to leap from the mind and into physical reality.

3D printing is an emerging technology being investigated and developed in many different areas such as medical, aeronautical, as well as in architectural fields. Using 3D printers, digital models can be physically fabricated quickly, giving the maker tactile feedback which can reinform the digital model for further iterations and variations.

In this thesis, an extrusion-based 3D printer is utilized as a sketching tool for the mind. Just as a pen and paper allow the architect to explore conceptual and abstract architecture and space through representations, the 3D printer and its software are used as a medium between ideas and its material reification.

Six interconnected exercises range from establishing an intuitive workflow with the 3D printer to exploring 3D printed diagrammatic architecture.

Acknowledgements

I would like to give my sincere thanks to the following people who have provided insightful knowledge and feedback which guided the thesis:

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A Grasshopper plug-in *Silkworm* has been an invaluable timesaver in the thesis. *Silkworm* takes digital geometry and translate it into g-code, allowing custom controls over a 3D printer. It is a free, open source plug-in initiated by Adam Holloway, Arthur Mamou-Mani, and Karl Kjelstrup-Johnson.

Dedication

To the custodians, the invisible hands which sustain the illusion of infinite stability.

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Introduction

The Medium and the Message

'The medium is the message' - Marshall McLuhan[1]

One of the most significant changes technology has wrought is the way we communicate and transmit information. From a caveman's application of cave walls as the surface to paint imageries, to the invention of language, paper, the printing press and now multimedia, technology expands not only the way we express our thoughts but the thoughts themselves. The variety of mediums available for expression is not simply for the sake of variety. Because of the fracture between the ideas within one's mind and the external reality, each medium's different properties carries out the message differently from the mind. Ideas remain abstract and fuzzy in our mind until they are condensed and consolidated through some mediating construct and translated into representation. Language is a construct that determines a large portion of our thinking processes. However, what cannot be translated cannot be transmitted, and what is not transmitted cannot be expressed[2]. Despite extensive vocabularies in language that break down meanings into nuances, if there is no word that describes one's thought, it cannot be expressed directly but through a combination of words. For example, many foreign vocabularies exist that cannot be directly translated into English. This is one of the reasons for the difficulty of translating poetry where the tightness of the poem is inevitably lost in translation. When certain abstract thoughts are not easily conveyed with words, artful expressions allow one to directly confront the thoughts through a non-standardized medium where one develops own gesture and grammar to translate the thoughts into transmittable forms. The abstract painter Gerhard Richter says: "Talk about painting: there's no point. By conveying a thing through the medium of language, you change it. You construct qualities that can be said, and you leave out the ones that can't be said but are always the most important."[3]

In the episode 'Darmok' of Star Trek, Captain Picard is stranded on a desert planet with an alien species whose language is through conveying metaphors. Rather than using language to deliver precise and clear messages, the alien communicates by describing similar previous events with similar outcomes as a way of relaying relevant information. While such an encounter is one of science-fiction, recent developments in online communication where people express thoughts through the use of Snapchat (images), emoji (pictograms), and memes/gifs(metaphors), show how the modern generation has expanded beyond language to express thoughts more abstractly, expressively, and intuitively.

Technological determinist and media theorist Friedrich Kittler postulates that media develop independently from the body. It is for the users to discover whether they can use media as the extension of the body and mind.[4]

In this thesis, 3D printing is explored - the printer is not simply a copier. It is a means of sketching one's thoughts through objects. Architects already have arsenals of tools to express concepts and ideas, from drawing to model making. A 3D printer, theoretically never-tiring and always-obedient, could expand ways of expressing that extends the desire of the hand and the mind.

increasing of the economy and access to mediums

fig 1.01 Chavet cave paintings, ~30000 BCE

fig 1.02 cuneiform, ~2000BC

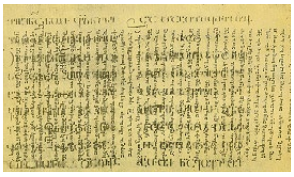


fig 1.03 palimpsest, ~600 CE

fig 1.04 modern pen and paper, ~1800CE

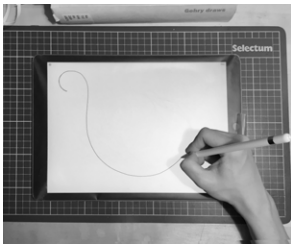


fig 1.05 iPad Pro and Apple Pencil and Concept (app), 2016

fig 1.06 a flow diagram of progression of exercises

Each exercise explores around a theme and the iterations within the exercises are represented by the branches in the diagram. Exercises undergo phases of expansions, where ideas are explored horizontally, and contractions, where the explored ideas are pruned off and only the seminal iterations are kept, which becomes the starting point for the next exercise. While many ideas are dropped off, some are re-integrated into the stream in the later exercises.

This thesis is composed of six series of interconnected exercises. Rather than exploring with an end-goal or pre-established desired outcomes, the exercises employ a heuristic[5] approach to explore things, reflect on the outcome, and expand through iterations and variations *(fig 1.06)*. Just as one would sketch abstract concepts and thoughts on a piece of paper, the exercises are means of bringing out many ideas within the mind together into some sort of physical, observable, and communicable objects that act as bookmarks or reflections that one can engage and reflect on. It is a way of off-loading ideas from the mind, into a physical and material form, an artifact recording one's thoughts, memories, and even ideology.

The exercises are akin to musical études, and the thesis is like an album. Collectively, they form a composition that is potentially 'other' than sum of the individual parts.[6]

While the exercises do not depart with a trajectory in mind, some fundamental values are upheld throughout the entire thesis that guides the journey, such as holism[7] and structuralism[8]. As well, each exercise looks for boundaries, arising from personal limitations to software/hardware limitations, and rather than bypassing the limitations, works to respect and develop within the boundaries. This meant, the early exercises explored boundaries, limitations, and working within to establish a 'path of least resistance' between the mind, the software, and the hardware, to gain an intuitive control over the workflow such that what is produced in the end is as closely as what the mind intended to.

The exercises are sketches, and while there is no goal for the thesis, the ultimate search and hope of the thesis is to explore the idea of "what you think is what you get". By creating a dialogue between the mind, the software, and the hardware, the desire is for the explorations to take a life of their own.

1 https://en.wikipedia.org/wiki/The_medium_is_the_message

2 Author's variation on Mario Carpo's "What cannot be recorded will not be transmitted, and what is neither recorded nor transmitted cannot be imitated." from 'Alphabet and the Algorithm', pg 12.

3 https://www.gerhard-richter.com/en/quotes/mediums-3/painting-15

4 'Technologies of Writing: Interview with Friedrich A. Kittler', pg 738.

5 "A heuristic technique is any approach to problem solving, learning, or discovery that employs a practical method not guaranteed to be optimal or perfect, but sufficient for the immediate goals. Where finding an optimal solution is impossible or impractical, heuristic methods can be used to speed up the process of finding a satisfactory solution. Heuristics can be mental shortcuts that ease the cognitive load of making a decision. Examples of this method include using a rule of thumb, an educated guess, an intuitive judgment, stereotyping, profiling, or common sense." https://en.wikipedia.org/wiki/Heuristic

6 The phrase by Gestalt psychologist Kurt Koffka, "The whole is other than the sum of the parts". https://en.wikipedia.org/wiki/Gestalt_psychology

7 "Holism is the idea that systems (physical, biological, chemical, social, economic, mental, linguistic, etc.) and their properties should be viewed as wholes, not as collections of parts. This often includes the view that systems function as wholes and that their functioning cannot be fully understood solely in terms of their component parts." https://en.wikipedia.org/wiki/Holism

8 "Structuralism is the belief that phenomena of human life are not intelligible except through their interrelations. These relations constitute a structure, and behind local variations in the surface phenomena there are constant laws of abstract culture." https://en.wikipedia.org/wiki/Structuralism

A Quick Primer on 3D Printing

fig 1.07 metal node, Arup

fig 1.08 Digital Grotesque, Dillenberger and Hansmeyer

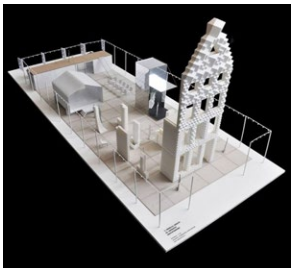


fig 1.09 Canel House, DUS Architects

fig 1.10 prototype house, WinSun

fig 1.11 print detail, WinSun

fig 1.12 'Between Shit and Architecture', Anish Kapoor

The concept of 3D printing is quite simple and not new. A 2D printer prints out two-dimensional information, a 3D printer prints out three-dimensional information. The use of mechanisms to reproduce 3D objects can be traced back to Benjamin Cheverton's reducing machine in 1820's[1], while 2D printing goes back further with the printing press in 1440[2].

However, a critical difference is that, while two-dimensional information can be easily quantized[3] into pixels or bits of information which can be printed on a blank paper, three-dimensional information is much more difficult when translating from virtual to physical. Not only is there infinitely more information along the third axis, but also, the physical constraints of the reality does not exist in the virtual. For example, digital models are commonly represented by zero-thickness grey boundary surfaces while hollow inside. As well, materials are difficult to quantize as the relationship happens at microscopic or even atomic level.

In theory, a molecular printer which can assemble individual atoms and molecules can work very much like a 2D printer with CMYK pigments. In fact, all living beings are a like molecular printer that self-replicates itself, consuming the necessary molecular components and assembling them at the molecular level. However, with our current technology, both the software and hardware are as yet incapable of such tasks.

The current 3D printing technology is mostly limited to manipulating materials at the macro level using a select few methods that are affordable and controllable, often working with one material at a time.

Different technology is used to manipulate different materials. For example, the stereolithography method uses photosensitive resin to selectively cure it using lasers. The laser sintering method uses powder materials that are heated using a laser to bind the powders together. Some printers are 'inkjet' based, which laminates many small microdots of materials like an inkjet printer.

Automation is one of the most appealing aspects of 3D printing in architecture, allowing designers and makers to push the boundaries of fabrication, such as the customization and reduction of human labour. For example, Arup engineers designed and printed a metal building component that distributes its structure according to the forces acting on the component (fig 1.07).[4] For project Digital Grotesque, Benjamin Dillenburger and Michael Hansmeyer, uses a powder based printer, generating a model with a complex form that pushes the limit of details to microscopic levels (fig 1.08).[5] DUS architects are building a plastic house on-site in Amsterdam using a portable 3D printer[6] (fig 1.09), while WinSun group built a house-like structure in 24 hours using a cement based printer (fig 1.10).[7]

Outside of architecture, 3D printing is used in industrial design for rapid prototyping, medical field for custom prosthetics and anatomic visualizations, 3D printed artworks by artists such as Anish Kapoor, and by many makers and hobbyist for personal explorations.

fig 1.13 Deltamaker

fig 1.14 1kg white PLA filament spool

The printer used in the thesis, a *Deltamaker*, is an FFF[8] printer that extrudes a thin line of plastic such as ABS (used in Lego) or PLA (corn-based and biodegradable) through a heated nozzle. Out of all available 3D printers, FFF is one of the most affordable and simplest in mechanism. While other 3D printers use high-tech solutions such as lasers, FFF printers simply require a material to be squeezed through a nozzle and moved along a path using any type of industry standard armatures. Its popularity amongst hobbyist and 'garage inventors' is due to the abundance of existing affordable off-the-shelf components that can be put together without requiring specialist knowledge, and readily available cheap and shelf-stable plastic materials. Some disadvantages of FFF printers are, a lower fidelity for small and detailed objects compared to other printing methods, and materials limited mostly to plastic based filaments for desktop printers. Some custom FFF printers have explored clay, ceramics, cement, or glass as materials. One of the biggest disadvantage of FFF (though not exclusive to FFF) is that objects with cantilevering or steep outward slopes require support structures that act as a scaffolding. Otherwise, the cantilevering layer will not have any surface to be laid upon while hardening and will droop down. For desktop printers, support structures can be automatically generated by the printer's software, which identifies areas requiring the supports, and prints breakaway or dissolvable structures that can be removed after the print finishes.

Deltamaker's maximum print size is a cylinder of 240mm diameter and 260mm in height. It can print lines at a speed of 5mm-80mm per second depending on the complexity of the model. The lines are 0.35mm in width and 0.1mm - 0.2mm in thickness. Small objects can be printed in minutes, while larger and complex models at slow speed can take well over 24 hours.

White PLA filaments are used extensively throughout the exercises. The filaments are extruded at a temperature of 195 Celsius and are slightly translucent when objects are printed in single-line thickness. The white plastic, which does not have dominant characteristics, is treated as a 'meta-material' in the exercises as an abstract 'placeholder' material for immaterial digital models.

1 https://www.ago.net/idea-lab-benjamin-cheverton

2 https://en.wikipedia.org/wiki/Printing_press

3 Quantization: "the procedure of constraining something from a continuous set of values to a relatively small discrete set." https://en.wikipedia.org/wiki/Quantization

4 http://www.arup.com/News/2014_06_June/05_June_Construction_steelwork_makes_3D_printing_premiere.aspx

5 http://www.digital-grotesque.com

6 http://www.3dprintcanalhouse.com/

7 http://www.ibtimes.co.uk/china-recycled-concrete-houses-3d-printed-24-hours-1445981

8 FFF, or Fused Filament Fabrication, is a term describing the additive method used by the printer. More commonly known as FDM, or Fused Deposition Modeling, the term FDM is trademarked by Stratasys where as FFF is legally unconstrained. https://en.wikipedia.org/wiki/Fused_deposition_modeling

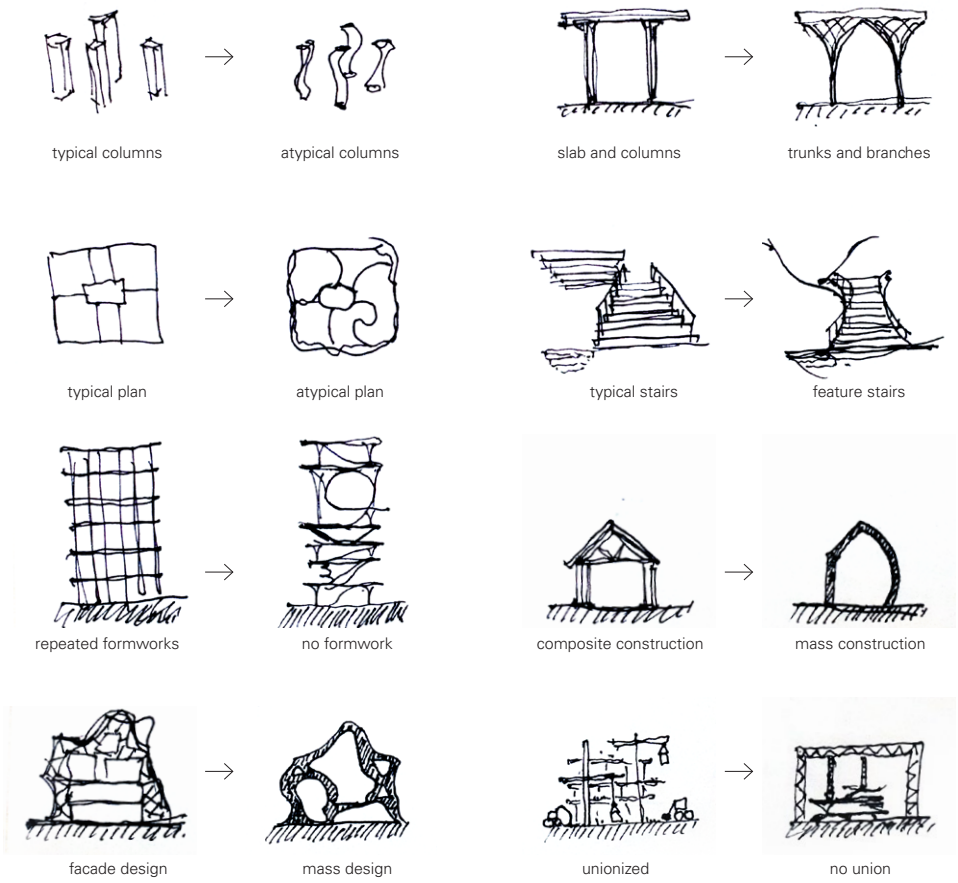


fig 1.15 initial speculation of how digital additive fabrication can challenge 'standards' in architectural design

X I

Introduction

fig 2.01 Modo

fig 2.02 Rhinoceros

fig 2.03 Grasshopper

fig 2.04 Processing

The first exercise explores limitations: the software limitations, the hardware limitations, and the personal technical limitations. Four different types of modeling software were used for modeling, from user-friendly software Modo, to mathematical and precision oriented Rhinoceros, parametric modeling plug-in (for Rhino) Grasshopper, and code/script based Processing. Using these software, many varieties of objects were made, from abstract sculptural forms, toys, to functional objects to determine what I am capable of making. Each object began with an image/idea of the object/form/function in mind, modeled in software as imagined, and printed for observation and reflection.

One limitation imposed in this exercise is to avoid support structures. While automatically (or manually) generated support structures greatly expand the possibilities of printable objects, the key aspect in this thesis is to work within the bounds of what each component (the mind, the software, the hardware) is capable of and to work within these limitations to help guide the exploration. Support structures not only require extra time and material but also leave defects behind when they are removed.

Objects modeled in Modo

The following models were generated using Modo. Modo is a surface modeling tool that allows artists to create smooth, organic shapes with ease. Modo has a very user-friendly interface that is simple and intuitive. Forms are initially modeled using primitive geometries such as a cube or a cylinder and manipulated by pushing and pulling the surfaces to sculpt and modify the surfaces. The ease and fluidity of manually forming objects come at the expense of precise controls.

fig 2.05 calla lily inspired form
One of the first objects modeled and printed, inspired by the gracious form of a calla lily.

fig 2.06 soap holder #1
Needing a soap holder in the bathroom, this form is designed to drain away the remaining water from the soap. The shape is a variation of the calla lily print. The steepness of the cantilevering slope caused improper adhesion of the layers, resulting in small defects on the underside.

fig 2.07 a 'rook' chess piece
A re-imagining of a rook chess piece inspired by the movement (direction and distance) as the game progresses. Similar to the soap holder, the cantilever with steep slopes resulted in print defects.

fig 2.08 spaceship toy
Individual elements coming together.

fig 2.09 sculptural figure #1
Using the array tool in Modo, a single bone-like column was modeled, polar arrayed and joined at the top. An improper printer setting resulted in the formation of webs of plastic between the six thin pieces joining at the top.

fig 2.10 sculptural figure #2
A variation of the *sculptural figure #1*.

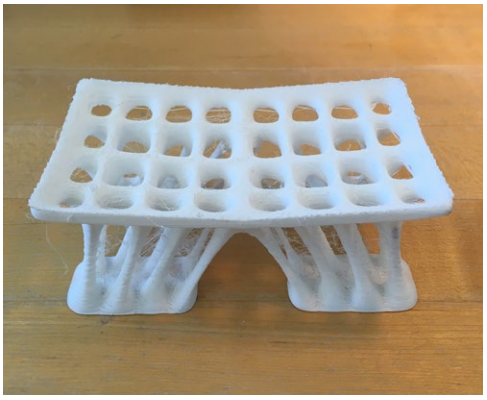


fig 2.11 soap holder #2
Using a similar workflow of the sculptural figure #1 and #2, the drainage function of the soap holder was reimagined. The many thin and small columns also resulted in the stringing of the plastic.

fig 2.12 asymmetrical sculptural figure #3

Moving away from the symmetrical forms of the previous sculptural figures, this figure is a conceptual image of a futuristic tower with sky gardens.

Objects modeled in Rhinoceros

Rhinoceros is a CAD software based on NURBS (Non-uniform rational B-spline) and mathematically driven curves, allowing precision and accuracy even when creating complex forms. It is used in fields requiring engineering-level precision, from industrial design, to jewelry, and architecture. However, this comes at the expense of a less intuitive and complex workflow as the model becomes complex and harder to modify and control.

fig 2.13 modular toy
Inspired by Lego, these are modular arch toy blocks with interlocking pegs. After each printing, the interlocking mechanism is modified for better performance.

fig 2.14 custom spool holder
This is a modified attachment to my 3D printer, a spool holder. The original spool holder that came with the printer was not compatible with some of the spools of filaments. After measuring the dimension of the original spool holder, adjustments were modeled and printed to replace the original. Though the adjustments are very minor, with a slightly slender and longer rod portion, the advantage of digital fabrication is that variation and customization can be honed to imperceptible increments quickly and easily. An interesting concept of a 3D printer is a self-replicating machine that could improve its own parts as well as replicating its own parts to reproduce.

fig 2.15 the original spool holder

Objects modeled in Grasshopper

Grasshopper is a plugin for Rhinoceros and extends the capabilities of Rhinoceros by allowing procedural and parametric workflow where the process is graphically visualized. However, unlike Modo or Rhinoceros, one does not 'draw' with Grasshopper. Rather, one designs the process and parameters, then Grasshopper generates forms based on the parameters. One cannot directly control the model. However, by carefully laying out the parameters, complex and precise models can be generated.

fig 2.16 Koch vase
Starting with a lower order Koch fractal pattern, the pattern undergoes further recursive iteration as it extends outwards. As the model is a continuous single wall, the printer can easily trace the outer perimeter in one continuous motion with minimized chances of defects.

fig 2.17 parametrically generated twisting torus

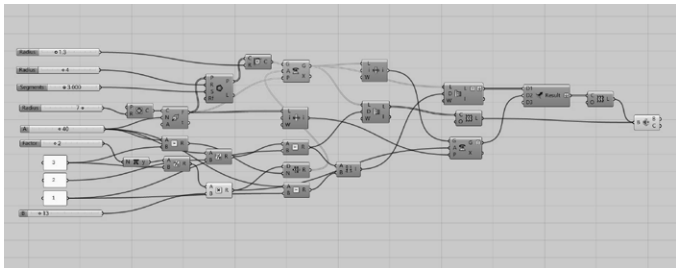


fig 2.18 the grasshopper script of the twisting torus

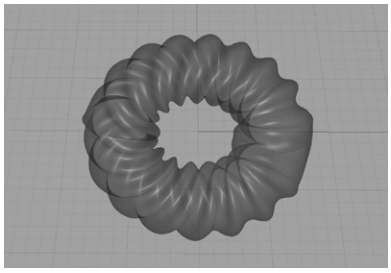


fig 2.19 the digital model of twisting torus

Objects modeled in Processing

Processing is a programming language that has been simplified to be more accessible to those in the creative field. Starting from scratch, forms are scripted and simulated through a series of operations rather than formed using pre-written commands. Unlike the previous software used, where users execute pre-established functions written into the software, in Processing one must first write the functions in code. While not as user-friendly as the other software, coding/scripting is one of the most powerful methods of modeling as it allows the user to write codes for specific tasks. However, the user has very little control over the result once the code is executed, which often makes the final results hard to predict.

```
class Node {
  ArrayList circles;
  PVector center;
  PVector velocity;
  float diameter;
  float speed;

  Node (PVector _center, float _diameter, ArrayList _circles) {
    center = _center;
    diameter = _diameter;
    speed = 1;
    circles = _circles;

    float angle = random(TWO_PI);
    float vx, vy;
    vx = cos(angle) * speed;
    vy = sin(angle) * speed;
    velocity = new PVector(vx, vy);

  }

  void update() {
    center.add(velocity);

    for (int i = 0; i < circles.size(); i++) {
      Node two = (Node) circles.get(i);
      if (two != this) {
        float d = dist(two.center.x, two.center.y, center.x, center.y);
        if (d < ((diameter + two.diameter) / 2)) {
          float ang = atan2(center.y - two.center.y, center.x - two.center.x);
          float vx = cos(ang) * speed;
          float vy = sin(ang) * speed;
          velocity = new PVector(vx, vy);
        }
```

fig 2.21 a screenshot of the code in Processing

fig 2.20 extrusion of 2d circle collisions

A simple code was written where 25 circles on a plane move at different speeds and directions, colliding and bouncing off each other. This movement is extruded upwards to create a form. *The print defects visible between the tubes are due to an improper printer setting as well as many individual parts that are close to each other.*

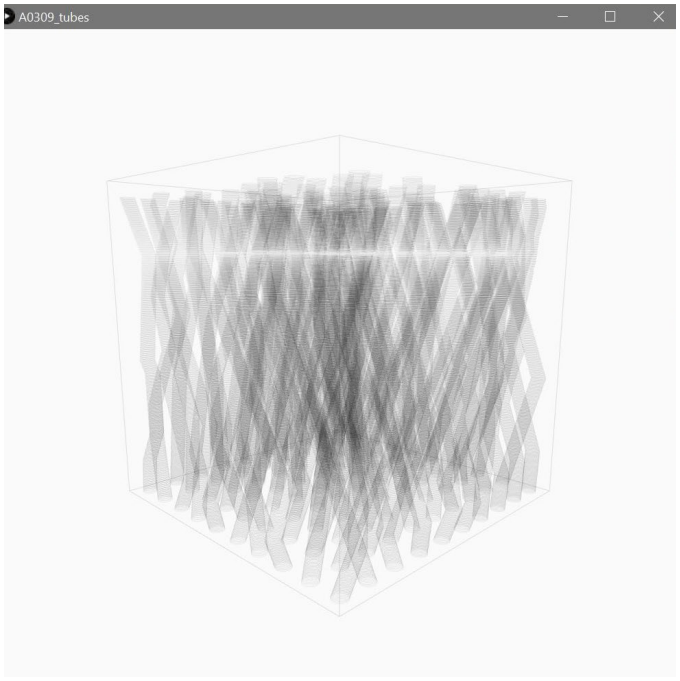


fig 2.22 a screenshot of the simulation in process

fig 2.23 'queen', chess piece

fig 2.24 'queen', plan view

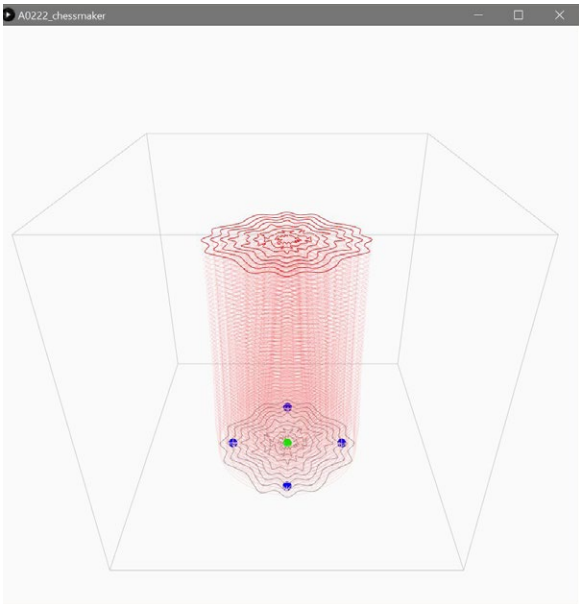


fig 2.25 a screenshot of the 'rook' simulation in process

For this iteration, a script was written where a series of concentric circles with spring-like behaviors are deformed through attractors. The attractors are positioned to reflect the directional restriction of the chess pieces, creating an internal grain pattern that embodies its own movement. Each run of the simulation generates unique grain patterns.

Failed prints

fig 2.26 Turing reaction-diffusion form
This was an attempt to script and generate forms using a variation of Alan Turing's reaction-diffusion reaction. This code quickly became quite challenging, requiring the integration of many pre-written code resources available online. Ultimately, this exercise was stopped due to the complexity of coding and my inability to make use of the function in an intended way.

fig 2.27 medusa column
This print failed before completing as some of the many thin pieces broke off during the print.

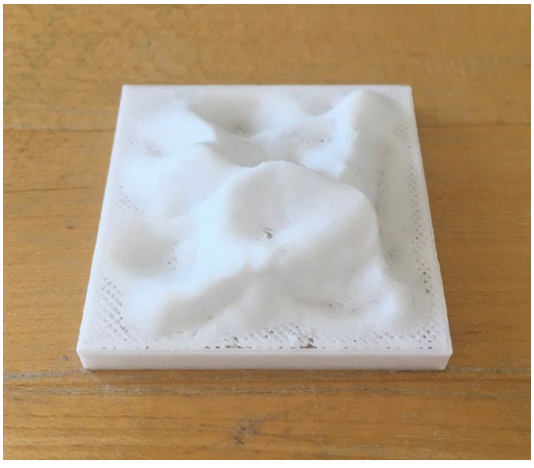


fig 2.28 topography model
In this print, a landscape-like topology was modeled. Because one does not prescribe how the object is to be printed during modeling, and although the contours of the topology were well executed by the printer, the flat areas were printed using a criss-cross pattern by the printer rather than continuing the contour pattern.

X1 Reflection

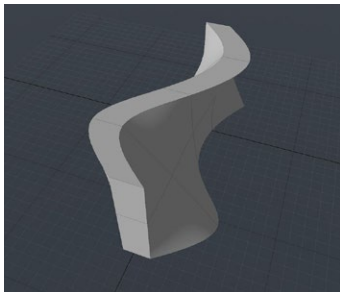
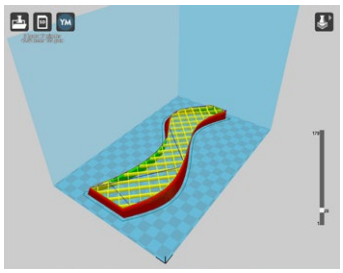
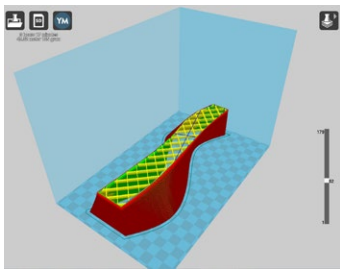


fig 2.29 an example shape modeled in Modo





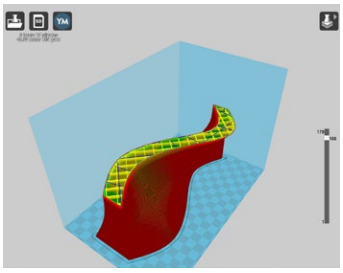


fig 2.30 the model being sliced and translated into g-code in Cura

In terms of the printer limitations, without support structures, objects cannot cantilever an angle over roughly 45 degrees, and generally, singular and monolithic forms print better than a model with multiple small individual parts.

The modeling software does not natively account for the process of printing, and there is no way of inputting additional printer information within the model. Because the software and the 3D printer operate under a different language, the models created in software must be exported into a generic file (STL) which is then imported into an intermediary software that translates the model into the printer language, g-code. In this exercise, a free program called Cura was used as the intermediary software. Cura takes a model, slices it into thin layers according to the specification of the printer, then generates a toolpath for the printer to follow. Cura also automatically generates a generic grid-like internal support structure to fill any internal voids. Because this translation process is automatic, there are very few, if at all, ways of prescribing the toolpath.

This disconnect between the software and their hardware means the print is always a representation of the digital model rather than a facsimile.

However, there is a common thread, a lowest common denominator, that flows amongst the mind, the software, and the hardware: the line. Not only are lines a familiar tool in architecture and CAD software, the printer's line-drawing method prints models generated using lines (e.g. the Kock vase) to be part to part identical to its digital version.

Some of the models generated in Processing tried to address this by generating models through extrusion of lines. By extruding lines, the printer can simply trace each line per layer and the printed model becomes a physical render of the digital model.

By designing with an understanding of how the machine operates, the translation gap can be minimized. Extrusion is a familiar process in our daily lives, from toothpaste, extruded metals, woodwind musical instruments, and even defecation, and of course, drawing lines. Since lines can be easily transposed into a series of coordinates, lines drawn in software can be faithfully translated into g-codes without losing the cohesion of information.

fig 2.31 Fiore Musicale, toolpath plan drawing

This was one of my first sketches of a 3D printed building, a spiralling music performance pavilion 'Fiore Musicale', using toolpath as a design language. Each wall is made up of a single line that folds in on itself. There are three lines that make up the walls, each line representing treble, mid, and bass respectively, to create a surface pattern and thickness. The floor pattern is a blending of the two adjacent wall patterns. The drawing explores the lines and walls embodying symbolic meanings.

fig 2.32 Fiore Musicale, wall pattern

fig 2.33 Fiore Musicale, floor pattern

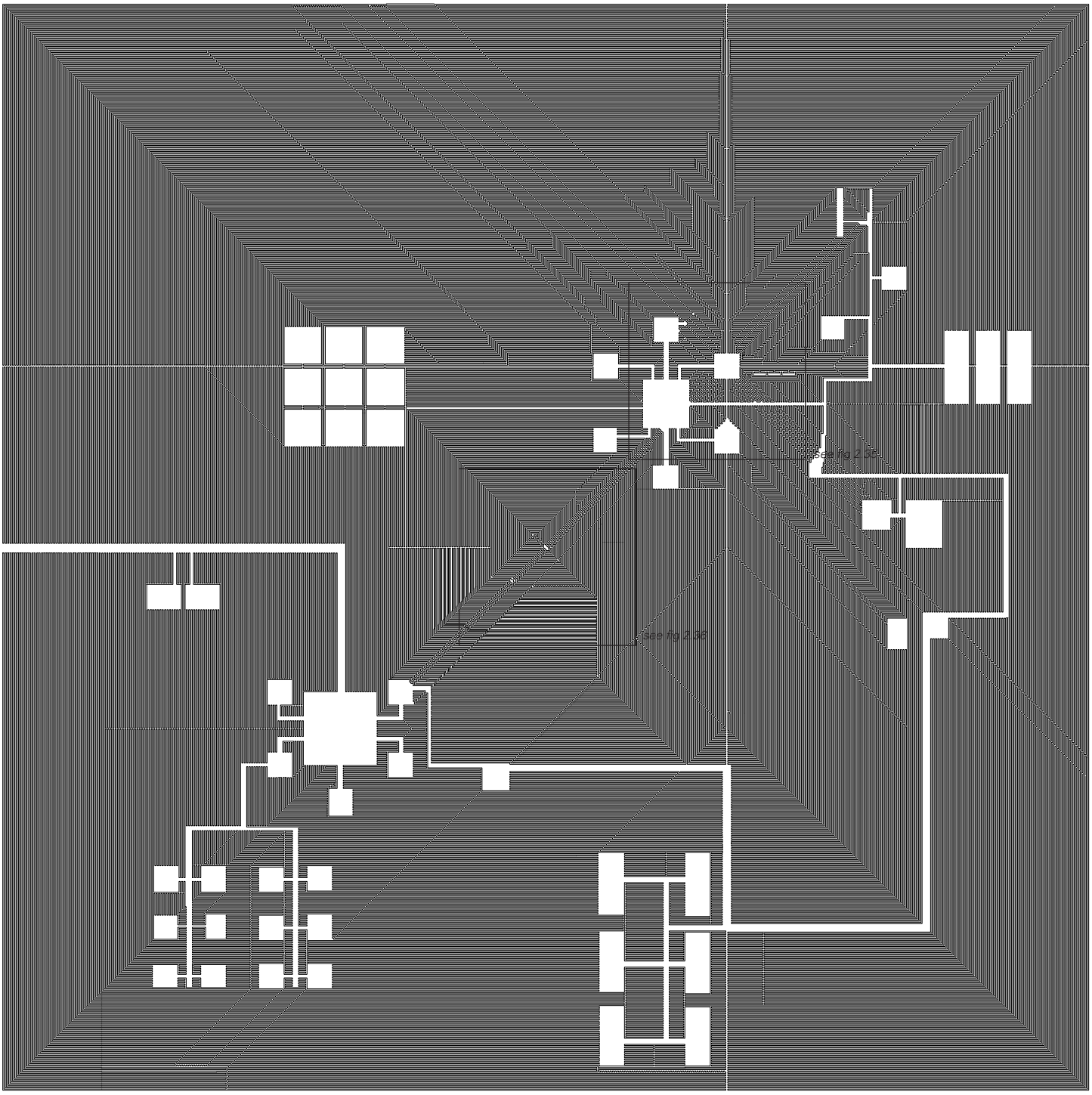


fig 2.34 The Two Focii

This is a sectional plan of a hypothetical pyramid, 3D printed in lines. The internal chambers and passages are maze-like with many dead ends to confuse intruders. Without labels, it is difficult to know where the Pharaoh's chamber is. However, the pyramid is drawn such that all lines lead back to one room (fig. 2.35). Four continuous lines, starting from the pharaoh's chamber, emanate outwards to fill in the solid portion of the pyramid. The lines generally follow the contours of a geometric pyramid. However, the geometric center of the pyramid is interrupted by the symbolic center of the pharaoh's chamber where the four lines start from, creating ripples in the contour that spreads across the pyramid. Here, the symbolic center imposes its order over the geometric center.

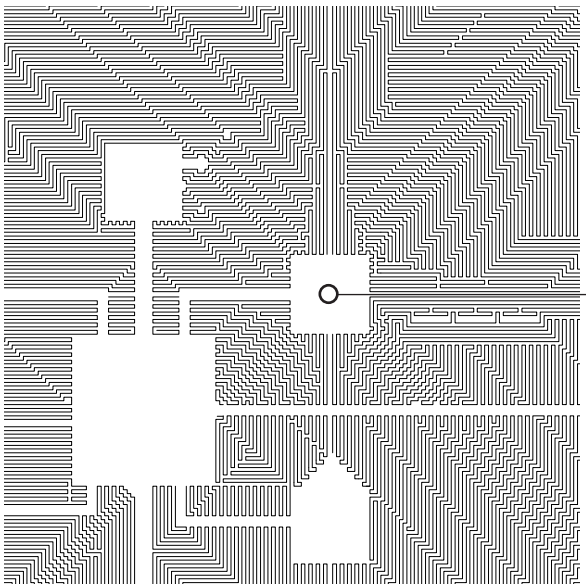


fig 2.35 detail, symbolic center

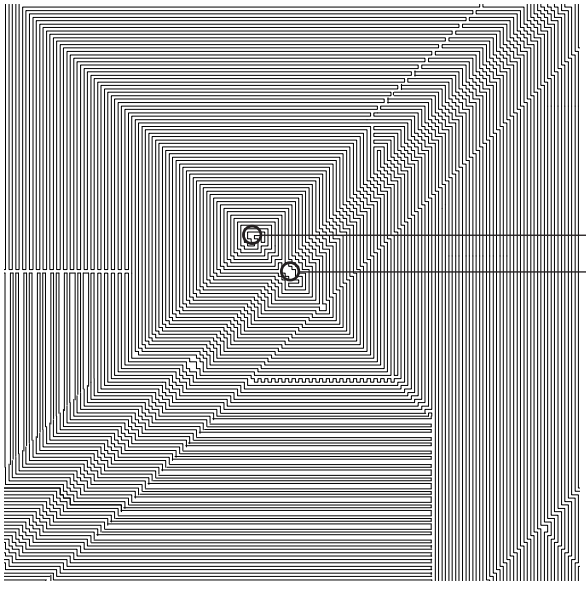


fig 2.36 detail, geometric center

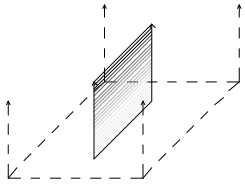


fig 3.01 lofting of two identical lines

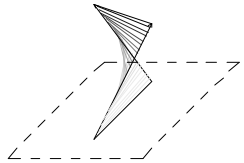


fig 3.02 lofting of two identical but shifted lines

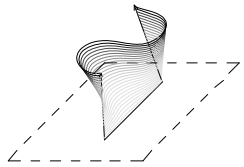


fig 3.03 lofting of two different lines

fig 3.04 lines drawn and lofted in Rhinoceros

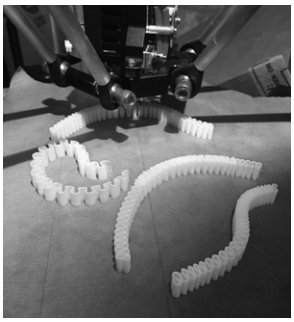


fig 3.05 lines traced by the 3D printer

X 2

Introduction

"The translation that runs between drawing and building remains to a large extent an enigma." Robin Evans[1]

The end of X1 established that lines are the means by which the models are to be generated. When a line-generated model is sliced into layers, the resulting sections are lines which can be directly translated into g-code by transposing the lines into series of cartesian coordinates. There is no additional process, such as exporting or importing the model from one software to another which alters the original.

Lines are drawn and lofted in Rhinoceros and then sliced into hundreds of thin sections. A plug-in called Silkworm takes the lines and transpose them into g-code. When this g-code is executed by the 3D printer, the printed model is an identical 'render' of the lofted digital model and the reification of the mental image of the model.

Lofting is a technique whereby sectional curves are drawn to be interpolated into a surface by tweening between the curves. It creates a smooth transition from one curve to the next. Initially used in aircraft and boat design, CAD software have popularized the technique by allowing one to quickly generate forms through drawing critical sections which the computer then fills in the blanks between the curves.[2]

The lofting technique is similar to drawing an animation. Lines are imagined to be 'moving' or 'transitioning' from initial state to another state. Critical moments/movements are drawn at intervals and lofted to create a smooth transition from one movement to another. The models generated in this exercises are like stacking a series of 'frames' of movements on top of each other (fig 3.06). They are then lofted to interpolate between the frames. A line is first drawn in its initial state, copied vertically, and then modified. Each subsequent line is a modified version of the previous line. The final model is, then, a visualization of two-dimensional lines moving through time displaced vertically across space.

X2 begins with models generated from simple lines, and as the workflow matures and evolves, more complex ideas and movements are introduced.

1 'Translations from Drawing to Building and Other Essays', pg 160

2 https://en.wikipedia.org/wiki/Lofting

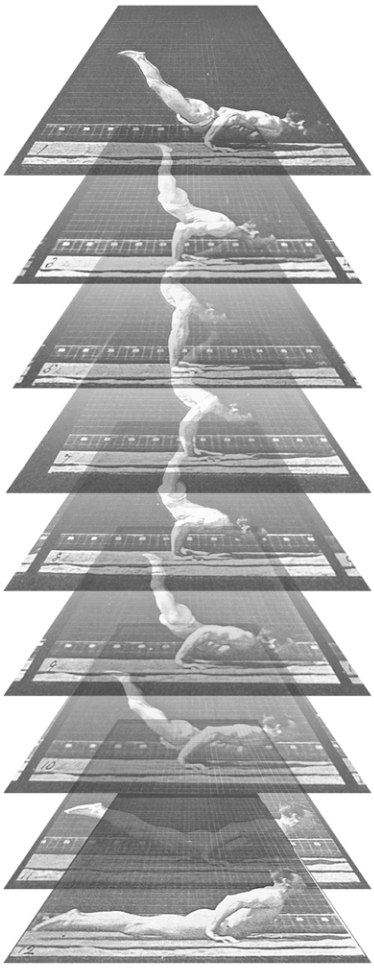


fig 3.06 Muybridge frames stacked on top

drawn sections = *sections drawn as described in the X2 introduction and fig 3.06*

critical sections = *moments within the drawn sections where the inflections of the movement is significant*

lines lofted = *a model generated by lofting the sections*

sliced into layers = *the lofted model is sliced at 0.2mm increments*

printed model = *the 3D printed model made from depositions of a thin line along the paths of the sliced model*

#1 expanding/contracting

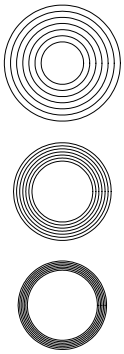


fig 3.07 #1 drawn sections

fig 3.08 #1 printed model

#2 expanding at different rates

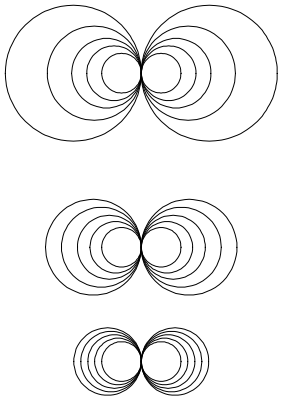


fig 3.09 #2 drawn sections

fig 3.10 #2 printed model

#3 expanding at different speeds

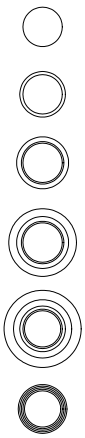


fig 3.11 #3 drawn sections

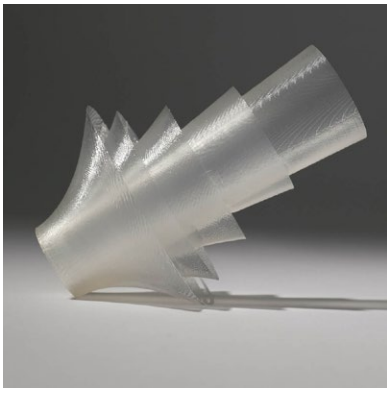


fig 3.12 #3 printed model

#4 convex

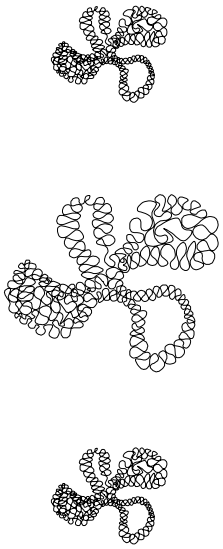


fig 3.13 #4 drawn sections

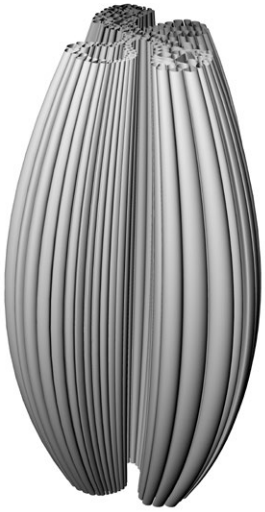


fig 3.14 #4 lines lofted

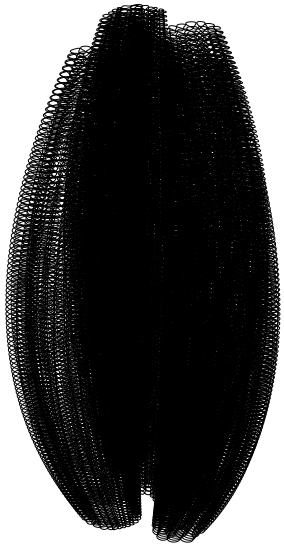


fig 3.15 #4 sliced into layers

fig 3.16 #4 printed model

From a folded line emerges a folded plane which becomes a 'solid' object.

The relationship between the inner form of the model and the outer form are congruent.

fig 3.17 #4 bottom of the model

#5 concave

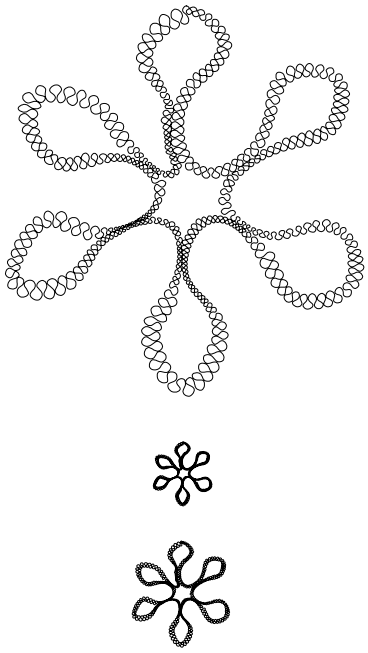


fig 3.18 #5 drawn sections

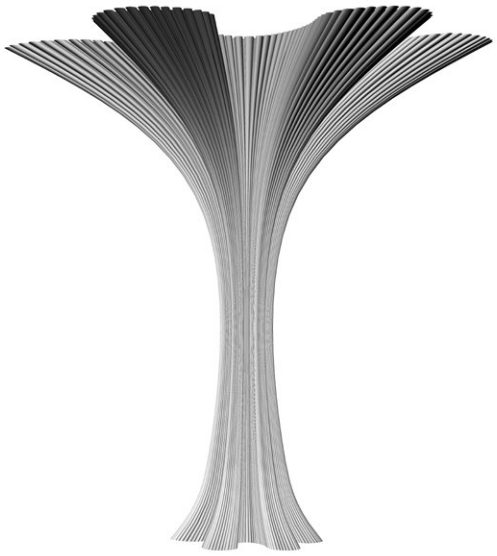


fig 3.19 #5 lines lofted

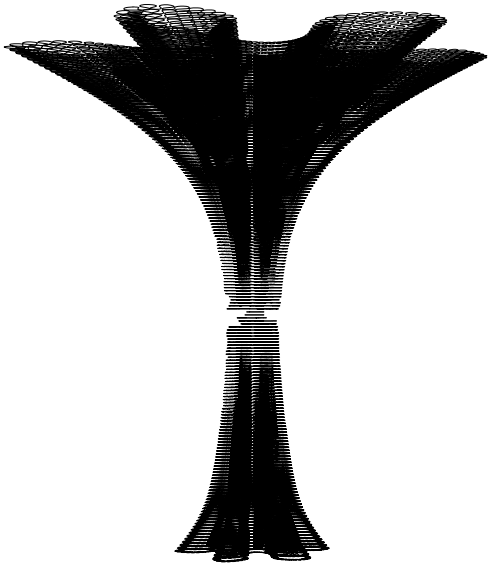


fig 3.20 #5 lofted model sliced into layers

fig 3.21 #5 printed model

#6 inversion

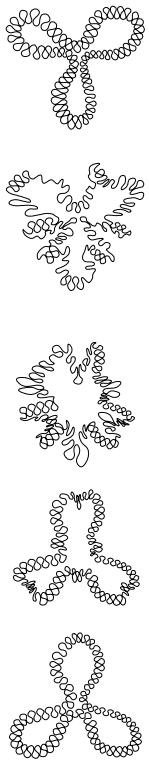


fig 3.22 #6 critical sections

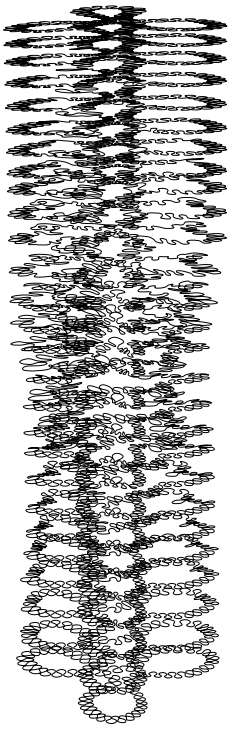


fig 3.23 #6 drawn sections

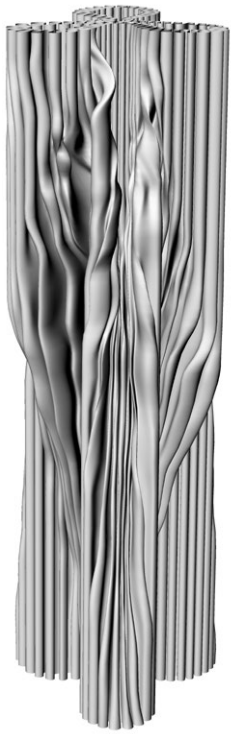


fig 3.24 #6 lines lofted

```
G21        ;metric values
G90        ;absolute positioning
M107       ;start with the fan off
G28        ;move to endstops
G92 E0     ;zero the extruded length

G1  F7200 X2660.58 Y27.65 Z5
G1  F450 X2660.58 Y27.65 Z0
G1  F9000 E5

G92 E0

G1 F1800 X2660.48 Y27.65 Z0 E0
G1 F1800 X2660.35 Y27.68 Z0 E0.01
G1 F1800 X2660.3 Y27.7 Z0 E0.01
G1 F1800 X2660.25 Y27.73 Z0 E0.01
G1 F1800 X2660.19 Y27.76 Z0 E0.02
G1 F1800 X2660.15 Y27.79 Z0 E0.02
G1 F1800 X2660.1 Y27.83 Z0 E0.02
G1 F1800 X2660.05 Y27.87 Z0 E0.02
G1 F1800 X2660 Y27.91 Z0 E0.03
G1 F1800 X2659.96 Y27.96 Z0 E0.03
G1 F1800 X2659.92 Y28.01 Z0 E0.03
G1 F1800 X2659.88 Y28.06 Z0 E0.03
G1 F1800 X2659.84 Y28.12 Z0 E0.04
G1 F1800 X2659.81 Y28.17 Z0 E0.04
G1 F1800 X2659.78 Y28.23 Z0 E0.04
G1 F1800 X2659.75 Y28.29 Z0 E0.04
G1 F1800 X2659.72 Y28.36 Z0 E0.05
G1 F1800 X2659.7 Y28.42 Z0 E0.05
G1 F1800 X2659.67 Y28.52 Z0 E0.05
G1 F1800 X2659.65 Y28.64 Z0 E0.06
G1 F1800 X2659.64 Y28.77 Z0 E0.06
G1 F1800 X2659.64 Y28.82 Z0 E0.07
G1 F1800 X2659.64 Y28.93 Z0 E0.07
G1 F1800 X2659.65 Y29.04 Z0 E0.07
G1 F1800 X2659.66 Y29.15 Z0 E0.08
G1 F1800 X2659.74 Y29.8 Z0 E0.11
G1 F1800 X2659.75 Y29.9 Z0 E0.11
G1 F1800 X2659.75 Y30 Z0 E0.11
G1 F1800 X2659.76 Y30.1 Z0 E0.12
G1 F1800 X2659.75 Y30.2 Z0 E0.12
G1 F1800 X2659.74 Y30.29 Z0 E0.13
G1 F1800 X2659.72 Y30.38 Z0 E0.13
G1 F1800 X2659.69 Y30.48 Z0 E0.13
G1 F1800 X2659.65 Y30.57 Z0 E0.14
G1 F1800 X2659.58 Y30.68 Z0 E0.14
G1 F1800 X2659.54 Y30.74 Z0 E0.15
G1 F1800 X2659.49 Y30.8 Z0 E0.15
G1 F1800 X2659.44 Y30.85 Z0 E0.15
G1 F1800 X2659.39 Y30.91 Z0 E0.15
G1 F1800 X2659.33 Y30.95 Z0 E0.16
G1 F1800 X2659.27 Y31 Z0 E0.16
G1 F1800 X2659.21 Y31.04 Z0 E0.16
G1 F1800 X2659.15 Y31.08 Z0 E0.17
G1 F1800 X2659.08 Y31.12 Z0 E0.17
G1 F1800 X2659.02 Y31.15 Z0 E0.17
G1 F1800 X2658.95 Y31.18 Z0 E0.17
G1 F1800 X2658.89 Y31.21 Z0 E0.18
G1 F1800 X2658.83 Y31.24 Z0 E0.18
G1 F1800 X2658.76 Y31.26 Z0 E0.18
G1 F1800 X2658.7 Y31.28 Z0 E0.19
G1 F1800 X2658.6 Y31.31 Z0 E0.19
G1 F1800 X2658.6 Y31.31 Z0 E0.19
```

fig 3.25 #6 g-code

fig 3.26 #6 printed model

#7 thickening

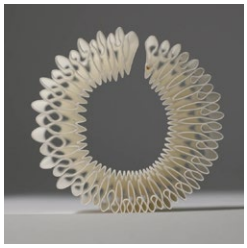


fig 3.27 #7 top view

fig 3.28 #7 bottom view

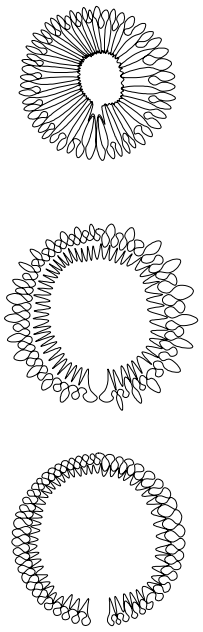


fig 3.29 #7 critical sections

fig 3.30 #7 printed model

#8 stretched

fig 3.31 #8 bottom view

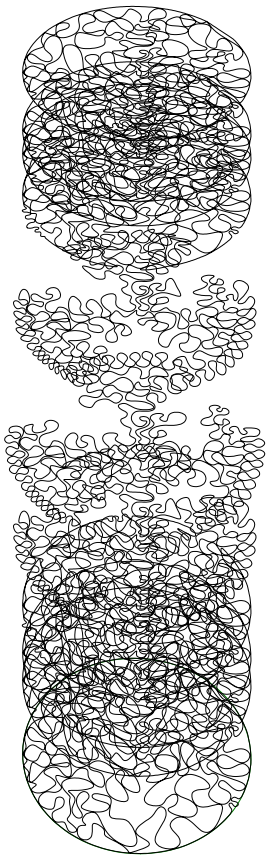


fig 3.32 #8 drawn sections

fig 3.33 #8 printed model

#9 compacting

fig 3.34 #9 initial sketch

fig 3.35 #10 critical sections

#10 zipper``

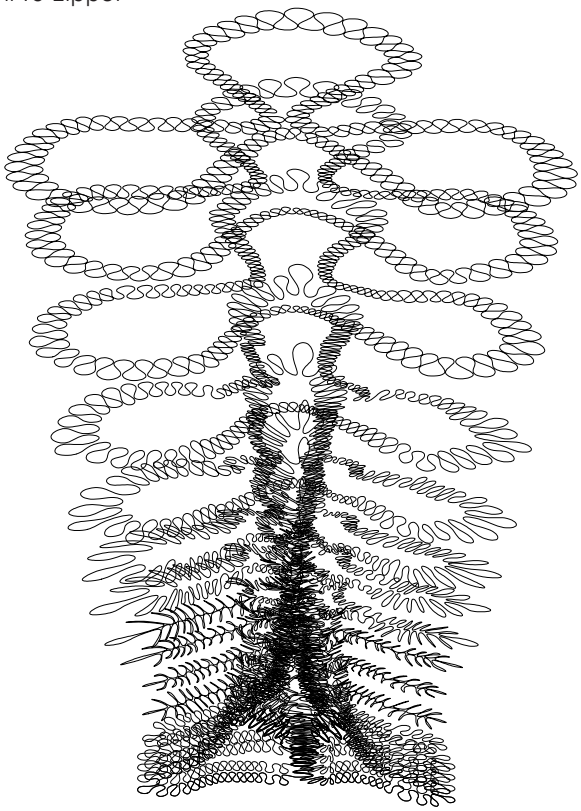


fig 3.37 #11 drawn sections

fig 3.36 #10 printed model

fig 3.38 #11 printed model

#11 bifurcation

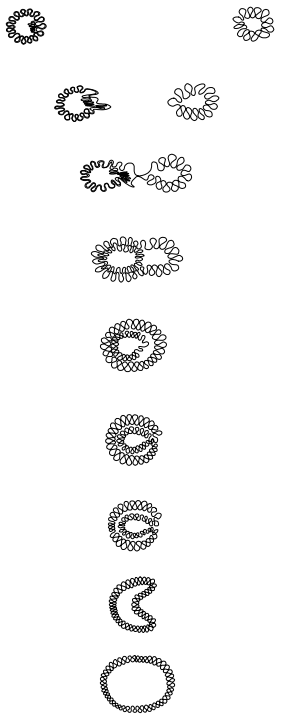


fig 3.39 #11 drawn sections

fig 3.40 #11 printed model

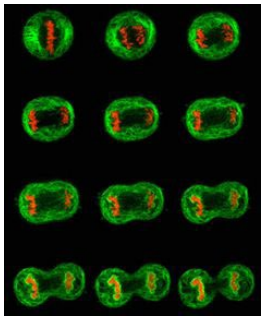


fig 3.41 image of cell mitosis

Inspired by cell mitosis, a single loop line is imagined how it could split into two loops.

fig 3.42 Loie Fuller's 'Serpentine Dance'

fig 3.43 #12 drawn sections

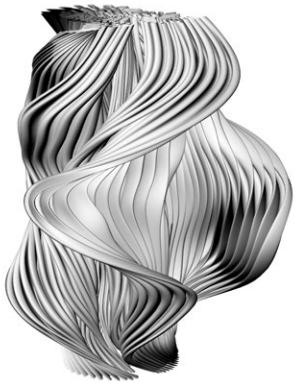


fig 3.44 #12 lines lofted

fig 3.45 #12 lofted model sliced into layers

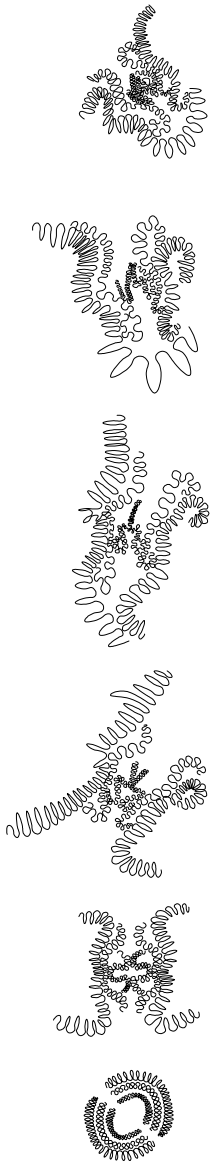


fig 3.46 #12 critical sections

#12 serpentine

fig 3.47 #12 printed model

Inspired by the *Serpentine Dance*, the flowing movement of the fabric is imagined and deconstructed in the mind and using lines, drawn to achieve a visually similar form.

#13 pinched

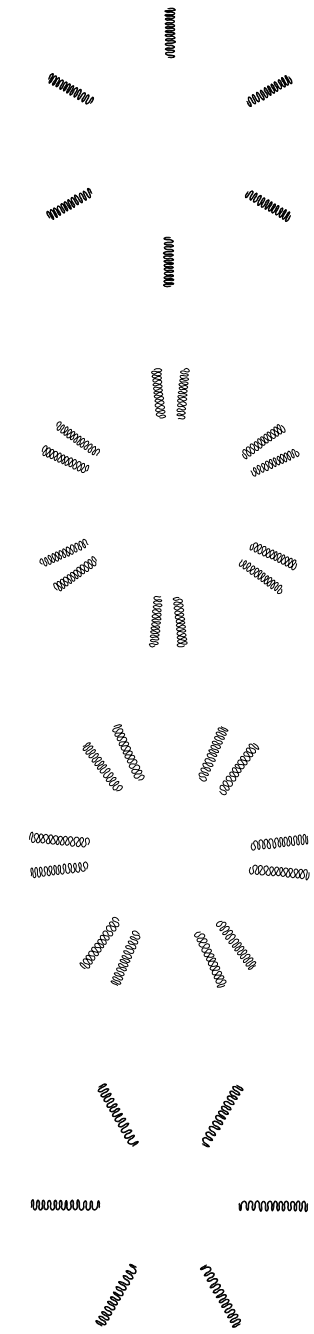


fig 3.48 #13 critical sections

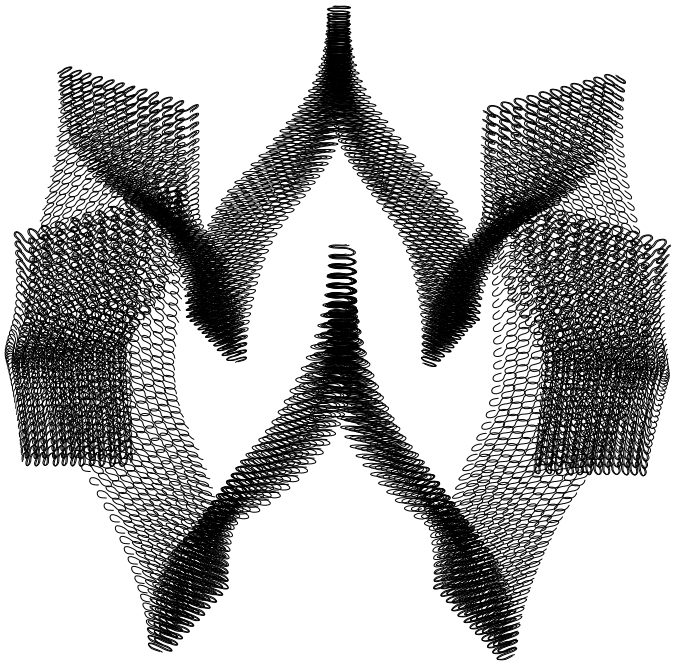


fig 3.49 #13 sliced into layers

fig 3.50 #13 printed model

In starting to think about spatial models, multiple lines are pinched together to frame ‘negative spaces’.

tree/house #1

fig 3.51 first draft form study of tree/house #1

The ‘tree/house’ Series

To start exploring forms with spatial quality and functions, a ‘treehouse’ motif was used for the next three iterations. A treehouse is normally an object, ‘house’, added onto the subject, ‘tree’. However, if one were to 3D print a ‘treehouse’, one could conceive the subject and the object a singular being. The next three iterations are titled ‘tree/house’, with the slash acting as the ambiguity that suggests it either one or the other and both at the same time.

fig 3.52 tree/house #1 printed model

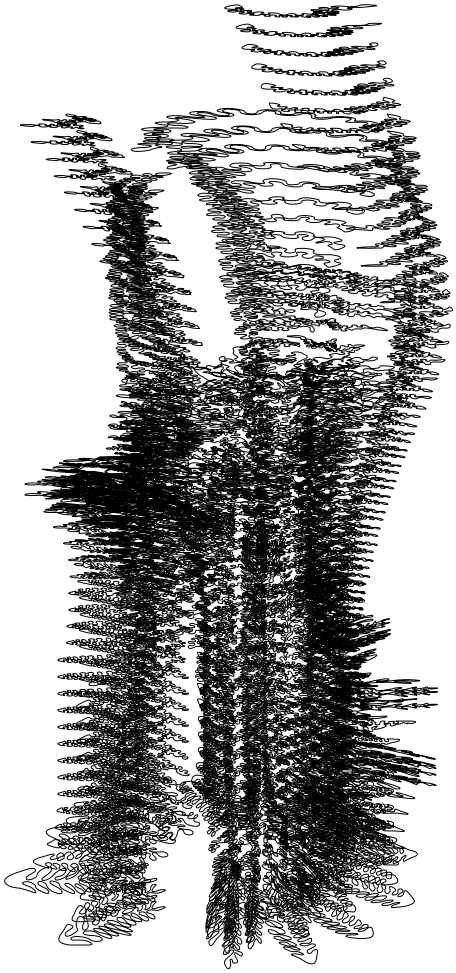


fig 3.53 tree/house #1 drawn sections

Tree/house #1 combines multiple concepts explored from previous iterations. Multiple trunk-like structures transform from columns to steps, floors, and canopies to form an enclosure. An observation deck can also be found at the top level.

tree/house #2

fig 3.54 tree/house #2 printed model

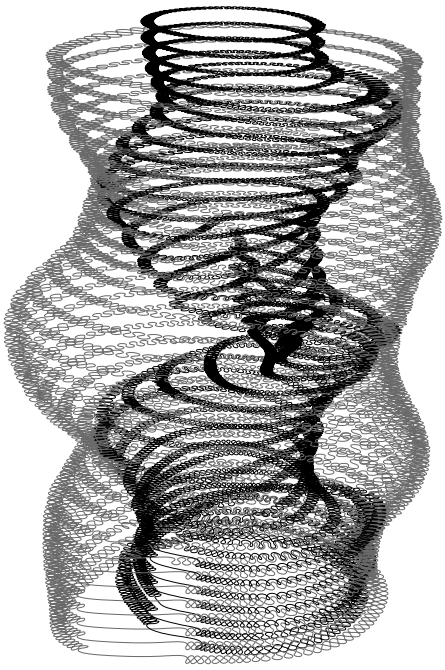


fig 3.55 tree/house #2 drawn sections

While the previous tree/house was made up of a complex network of individual parts, tree/house #2 aims to use as few parts as possible. Here, a smaller structure spirals within the larger envelope. The spiralling interior gently slopes up to provide a ramp that connects the bottom to the top of the structure.

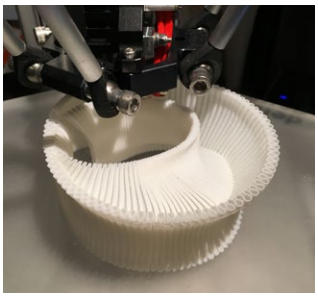


fig 3.56 view of the interior during 3d printing

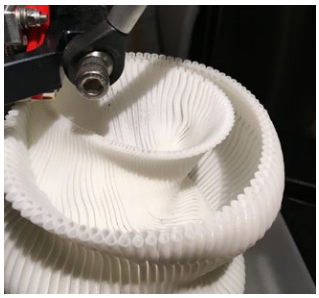


fig 3.57 view of the interior during 3d printing

tree/house #3

fig 3.58 tree/house #3 printed model

Tree/house #3 further simplifies the previous iteration by applying only one function to the wall instead of having it act as steps and floors. In this iteration, the floors are simple plates inserted in between the walls, while the vertical circulation is imagined to be achieved through other means such as ladders, ropes, or elevators.

fig 3.59 a view of the interior looking down from top level

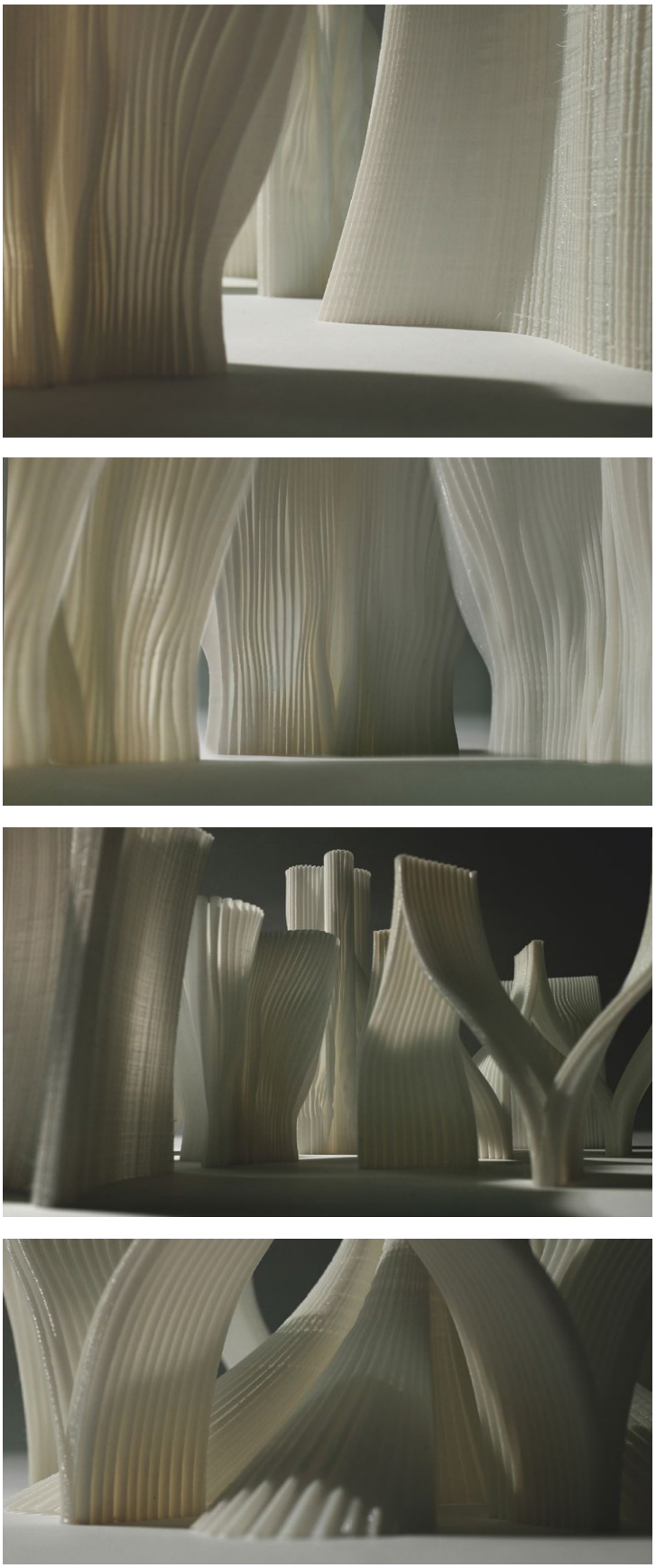


fig 3.60 a series of photographs of the printed models arranged to frame spaces, taken at a lovv angle to view the spaces different than typical 'birds eye' observations of the models.

X2 Reflection

Throughout the iterations of modeling and printing, a robust workflow was developed that allowed me to imagine, draw, and print a form.

While working through the treehouse series, which starts to explore spatial forms, I wondered what the forms would look like in relation to each other.

The printed forms were placed together and photographed to create an abstract spatial composition. The similar 'language' of folding lines create a sense of unity between the objects.

The sculptor Constantin Brâncuși considered the relationship of the placement of his sculptures just as significant as the works itself. In his later years, he stopped sculpting completely and focused solely on their relationship between each other within his studio.[1] Whereas classical sculptures were defined by the pedestal or base which physically elevated and isolated the work from others, Brâncuși explored variations of the base where sometimes the base was more significant than the sculpture, such as the 'Cock', while others such as the 'Endless Column' was all base. Brâncuși's studio, therefore, acts as another kind of base, a framing device which then allows free placement of his works, where the works themselves are also the base for other works.

Photography is a vital tool for documentation. As physical objects take up space, storage becomes an issue as more iterations are made. This is a common problem in sculpture where unlike paintings which can often be rolled up, sculptures need to be stored or be thrown out or recycled. Photographing is one method of preserving the works even if partially.

Beyond documentation of the works, photography also allows a different way to engage the models than directly observing the models through the act of framing. Framing removes external distractions while condensing information through the composition. As well, a camera can be positioned at places where the head cannot reach, and can explore the composition from a different perspective/angle.

1 https://www.centrepompidou.fr/en/Collections/Brancusi-s-Studio

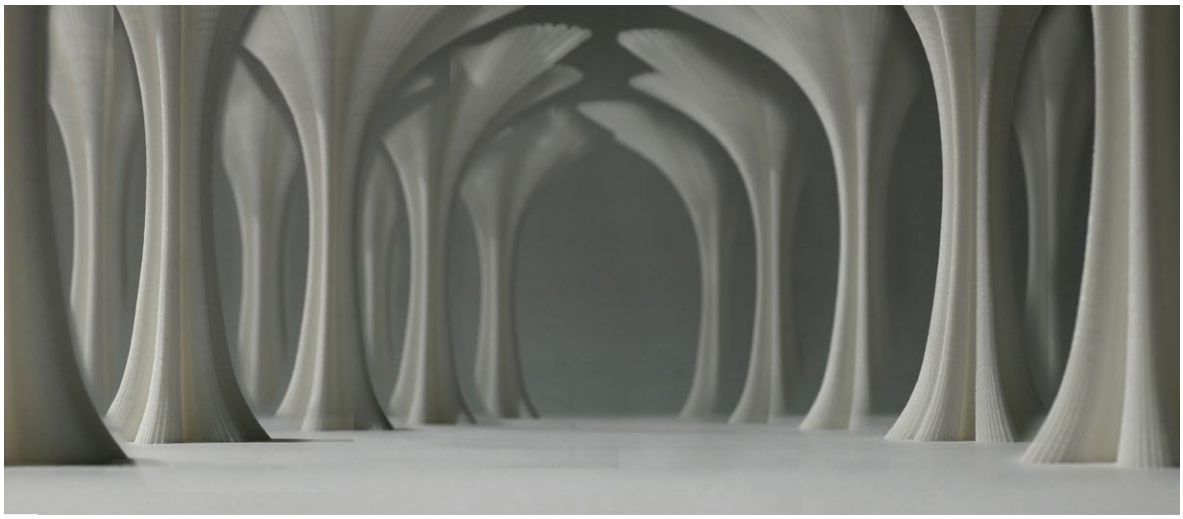


fig 3.61 an array of model #5 to create a forest-like spatial experience

fig 3.62 an array of model #13 to create a cave-like spatial experience

X 3

Introduction

"Without borders nothing can exist, or at least we cannot know of it. At the border, something ends and something else begins. Or can begin. A difference thus exists the moment we become aware of a border. Border creates order." Roemer van Toorn and Ole Bouman[1]

Whereas the previous exercise generated forms from lines independently, this exercise explores the composition of lines, and the space between lines, on an infinite plane.

The infinite plane represents infinite possibilities. By drawing lines, the infinite continuous space is divided and space is intervalized, reducing from the infinite possibilities/potentials to finite sets of possibilities/potentials. Lines frame spaces and thereby give it cohesion in which entropy can be contained. Therefore, framing the infinite space is not to introduce/activate possible events, but by excluding certain possibilities, allows the rest of the potentials to occur without being interfered by undesired events.

The infinite plane as the site of a composition is interesting because infinity is the site of the mind. Rather than exploring architecture on geographical, political, economical, or ecological site, the infinite plane is a psychological site. The complete emptiness of the site is a challenge in itself, as there are no external cues to guide one through the design process.

The lines divide the space into rhythms and sequences. What kind of spatial rhythm would one design in an infinite space?

As one cannot draw an infinite amount of lines on the infinite space, in the exercises, only a portion of the space is represented. However, by looking at one segment of the spatial field, one could imagine it extending to the infinity.

In Brâncuși's 'Endless Column', he achieves the effect of a column rising to the infinity by leaving the top and the base of the sculpture incomplete, suggesting they continue on forever. There is no beginning or end, but an endless repetition of the base. Normally, the base is a visual and physical cue that elevates the sculpture to identify it as a sculpture. In 'Endless Column', the base is the sculpture.

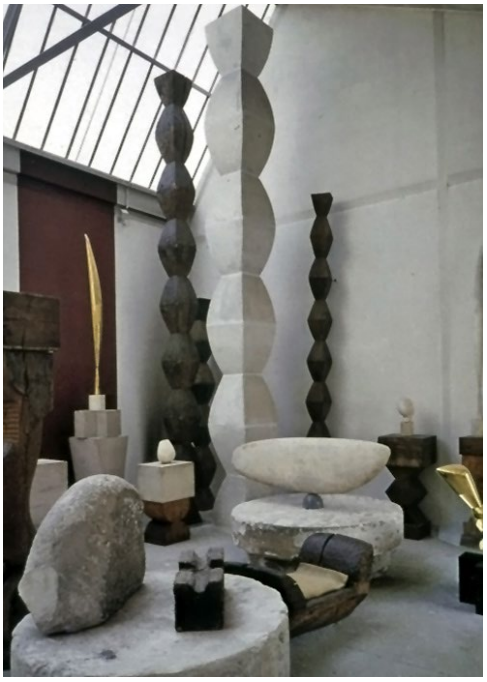


fig 4.01 Brâncuși's Studio

A replica of Brâncuși's studio at the Centre Pompidou, and the exact repositioning of the sculptures as it was left by Brâncuși. Brâncuși left his entire collection to the state of France at the request the works and the studio to be displayed just as it was at his death. Seen in the background are some of the Endless Column iterations among his other sculptures which he referred them as 'mobile groups'.

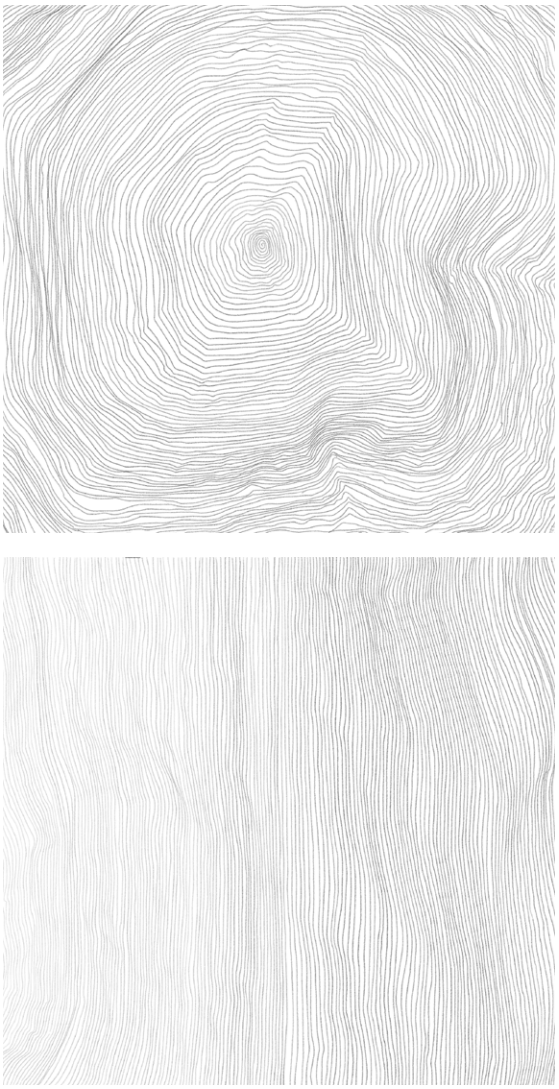


fig 4.02 line drawings exploring infinite relationships

On an infinite white plane, the lines not only form architectural spaces, but with the lack of 'site', the architecture is also the landscape. Inside and outside are simply subjective perception from one's reference point.

Onto these drawings, one can project/imagine how a human would behave and interact within the lines of the boundaries drawn.

"The map is not the territory." Alfred Korzybski[2]

One way to read the compositions is, rather than reading it like a literal plan, it is to be read as a map of spatial rhythm, like reading a sheet music. Another way is to read them as hypothetical rat maze for humans, and projecting how a person would act and react within the composition as they traverse through the plane.

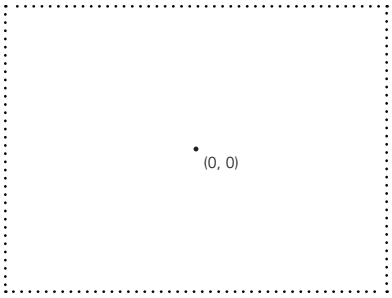
1 'Invisible in Architecture', pg 150

2 https://en.wikipedia.org/wiki/Map-territory_relation

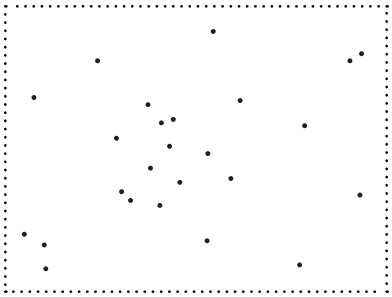
fig 4.03 a brief introduction to infinity

1. In an infinite white space, there is no center, yet, everywhere can be a center.

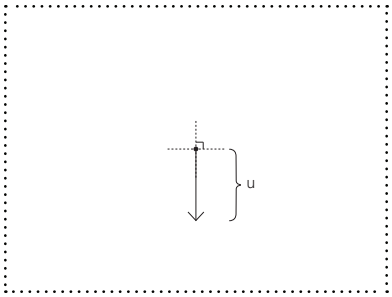
2. We can draw a point, and this point becomes a reference point, somewhere we all can point to and agree on: a (0,0) reference point.



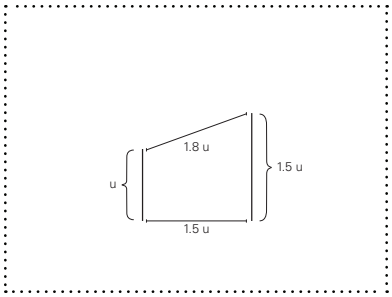
3. However, a point does not have any relationship but only with itself, as it only contains information about itself.



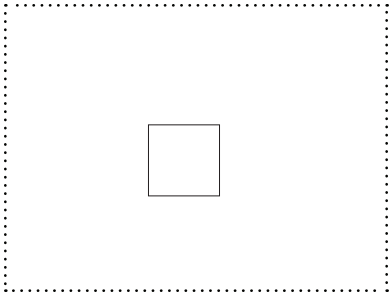
4. Clusters of points create a semblance of relationships, but the points do not have inherent cohesion with others. The duration-less aspect of points make them inherently resist relationships.



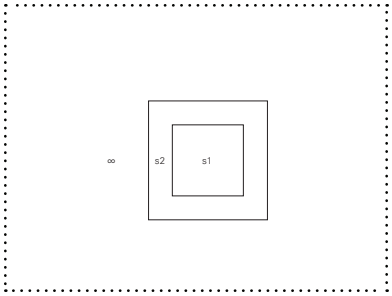
5. When we move a point, we have a line. A line gives us a reference unit, 'u', and a reference direction.



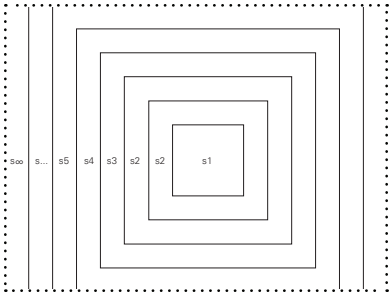
6. Drawing a second line allows us to compare, and this comparison is the act of recognizing relationships. A space is recognition of relationships. Space is relationships.



7. We can connect the ends to create an enclosure, an 'inside'. However, there is no recognizable relationship between the inside and the outside as one is finite while the ohter is infinite.



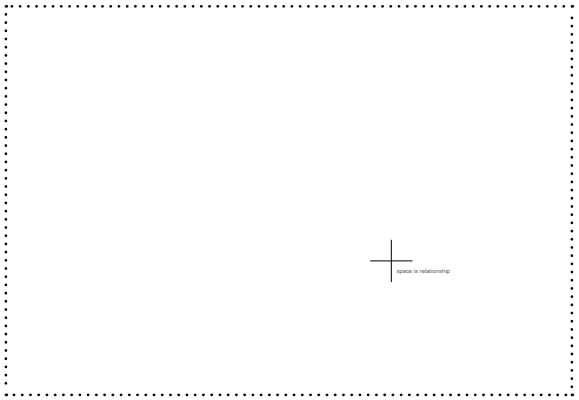
8. We can create a second boundary to contain the first space. However, the second boundary face the same problem as before.



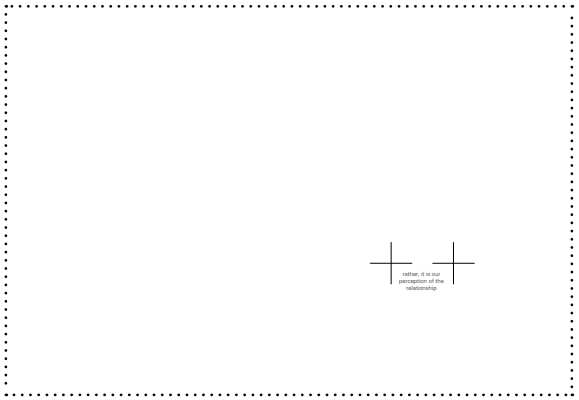
9. Jorge Luis Borges subsumes this paradox with a literary ease. He can simply say that there are an infinite amount of rooms. Therefore, we can create a relationship with the infinity by creating infinite relations.

In Borge's Library of Babel, the story takes place in a universe made up of an infinite array of hexagonal rooms. Each hexagonal room contains one of the infinite variations of all possible combination of alphabets that could occur on a 410 paged book. Just as modernism has shown the folly of gridded spaces, Borge's story is one of declining humanity, where the incomprehensible relationship between the infinite hexagonal rooms to each other and the books within which lead people into either holy fanaticism or existential crisis.

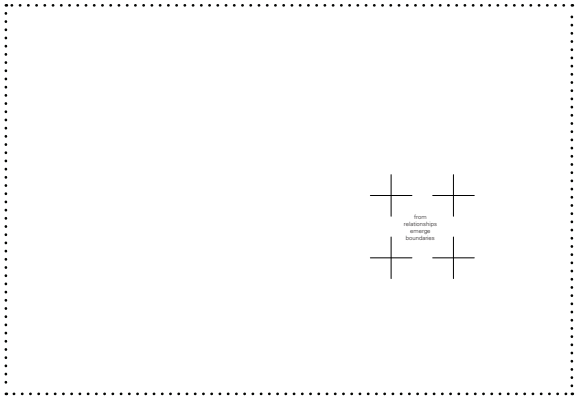
fig 4.04 Space is Relationship



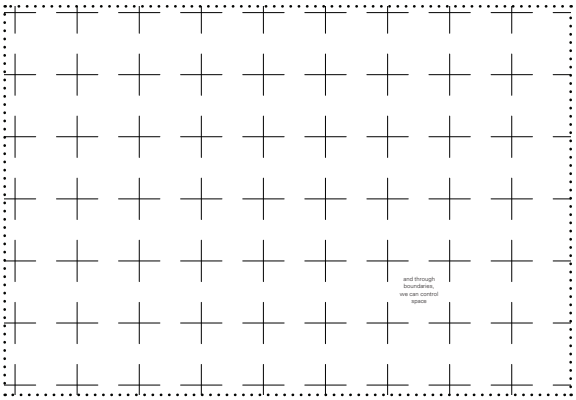
1. ‘space is relationship’



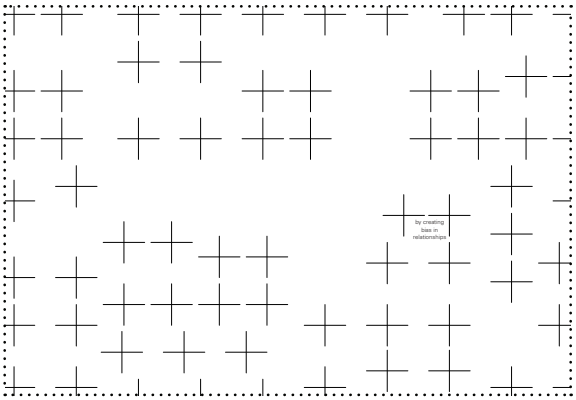
2. ‘rather, it is our perception of the relationship’



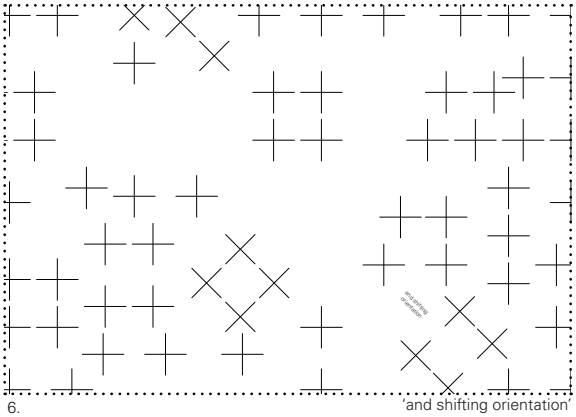
3. ‘from relationships emerge boundaries’



4. ‘and through boundaries, we can control space’



5. ‘by creating bias in relationships’



6. ‘and shifting orientation’

Pattern by Rotation

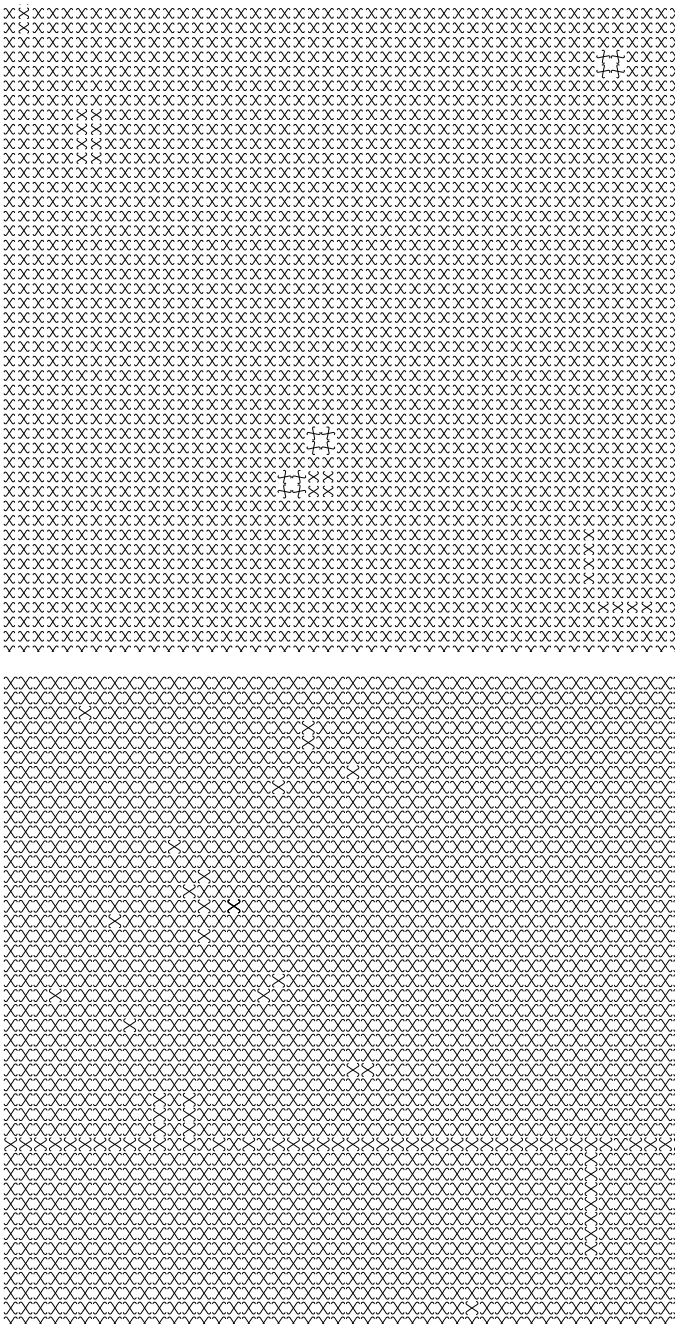


fig 4.05 pattern by rotation

Imagine being in a maze where within the never ending repeating room, one is asked to search an incongruent room. While from a plan view, finding an anomaly in a perfectly symmetrical and heterogeneous pattern is easy, within the maze, it is an absurdity.

Pattern by Subtraction

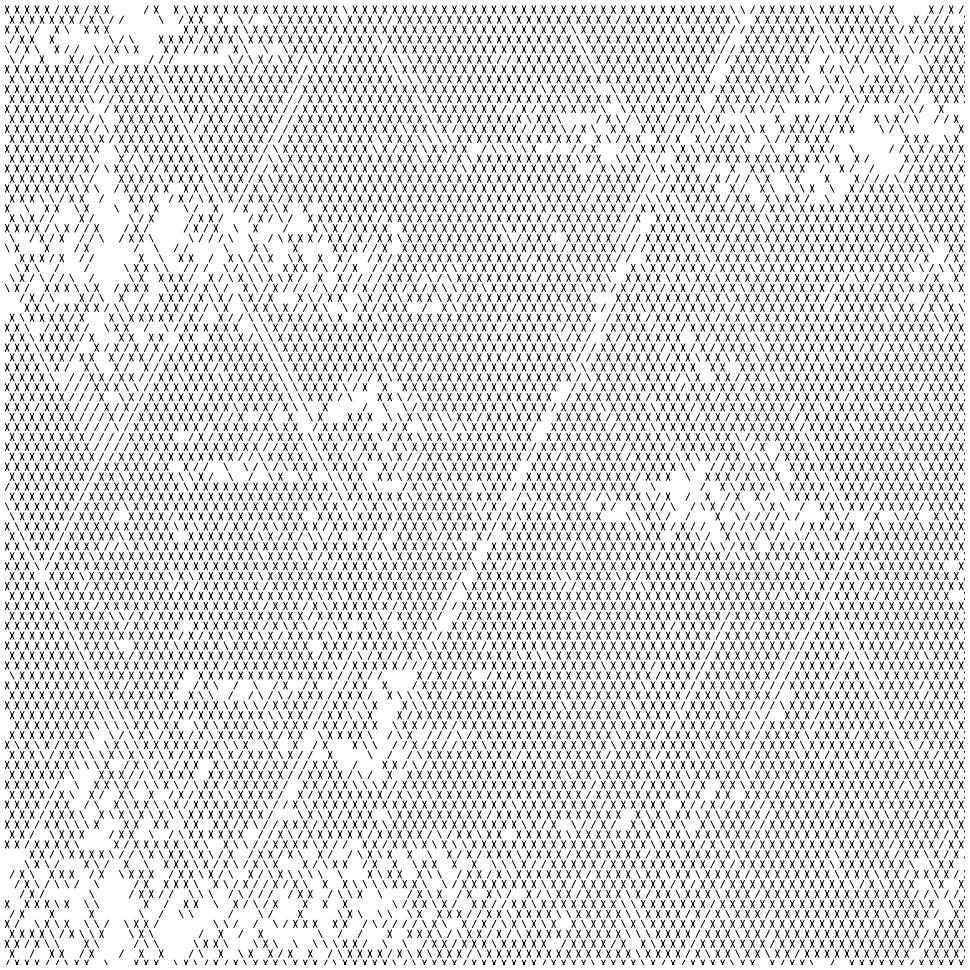


fig 4.06 pattern by subtraction

The Infinite Temple

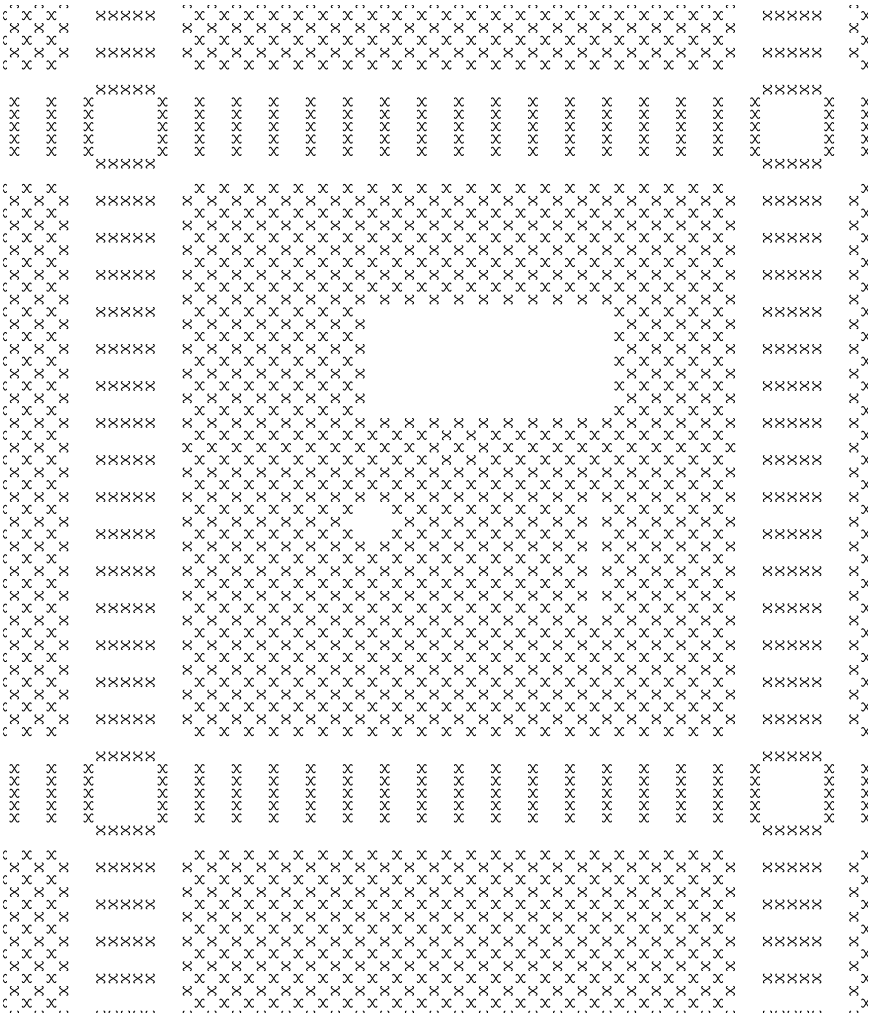


fig 4.07 Infinite Temple

A cosmic grid act as a ‘time signature’ onto which micro and macro interval rhythms are composed.

Camp

fig 4.08 Camp

Each pattern has a local grid that shifts in orientation from each other, creating a field-like composition

Cave

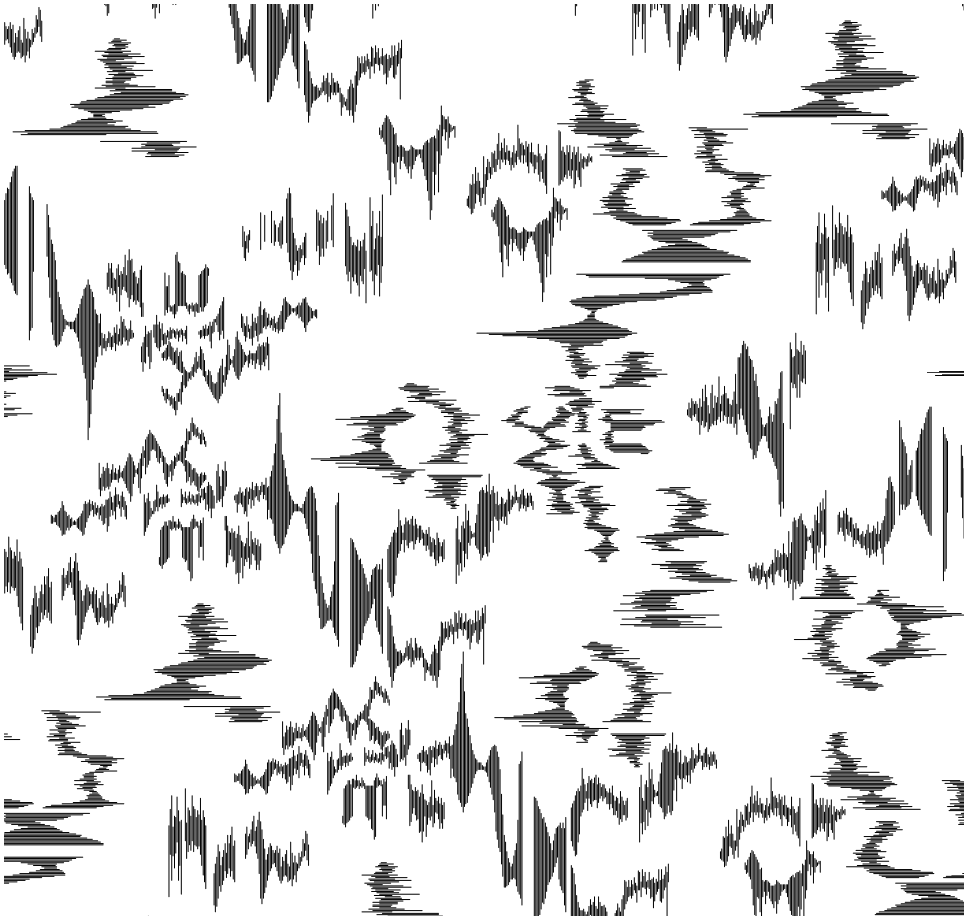


fig 4.09 Cave

A noisy field is drawn while lines are restricted to a bi-directional grid.

Nest

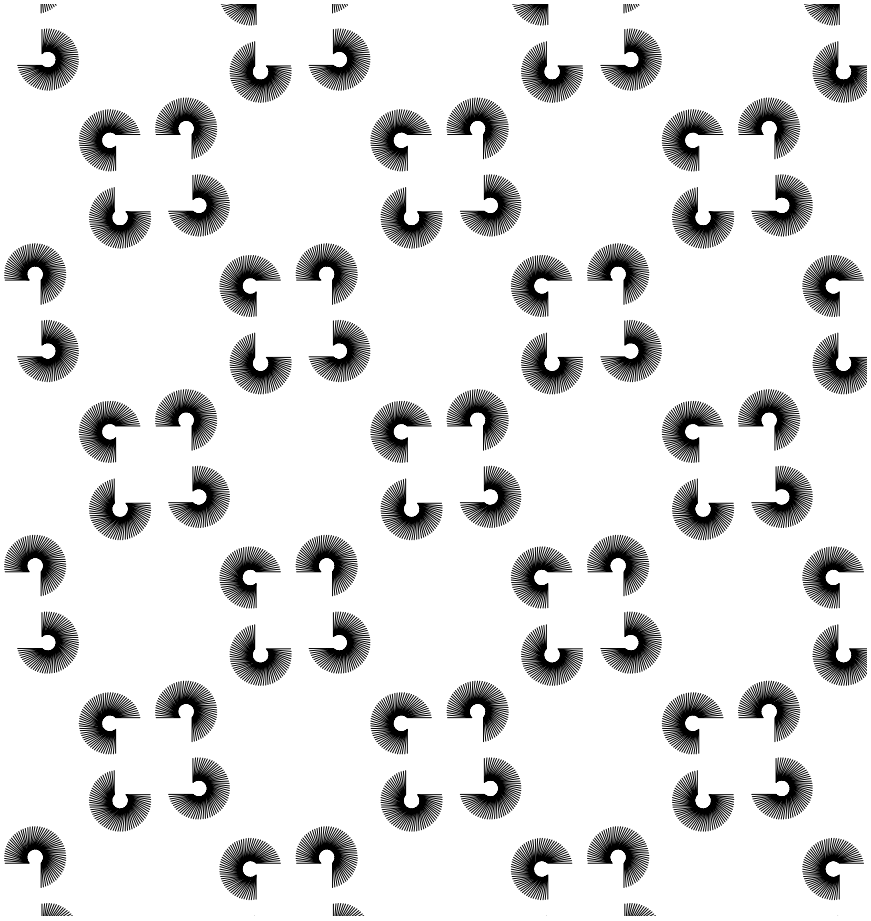


fig 4.10 Nest

There is no square, only the reification of form through perception

Flow

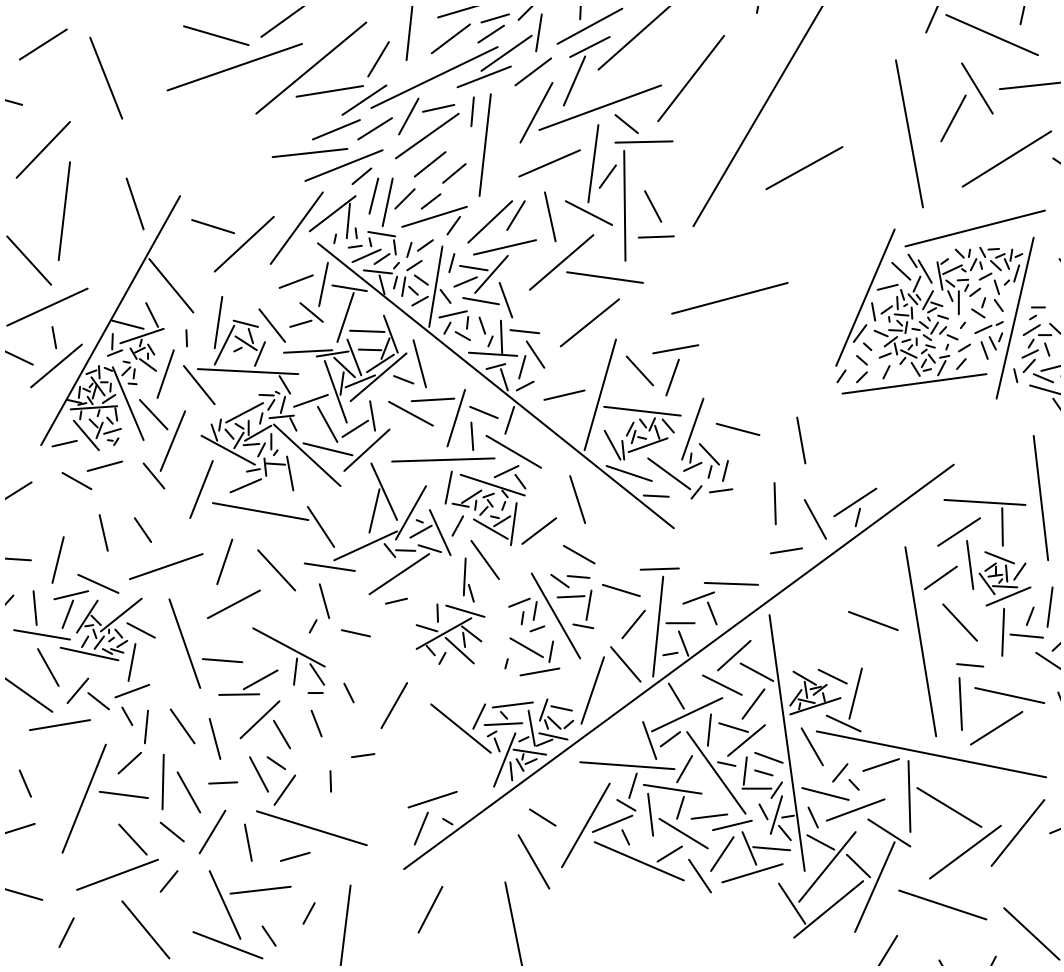


fig 4.11 Flow

In this drawing, a field is generated procedurally. Long lines are drawn first, dividing the spaces into smaller intervals, and a series of smaller lines continue to subdivide the space. The process is like dropping sprinkles of reducing lengths. Different vector tendencies of the lines produce different spatial flow/movement from one space to another. A field of parallel vectors creates spaces of continuous interval, while perpendicular vectors create staccato intervals.

Stop

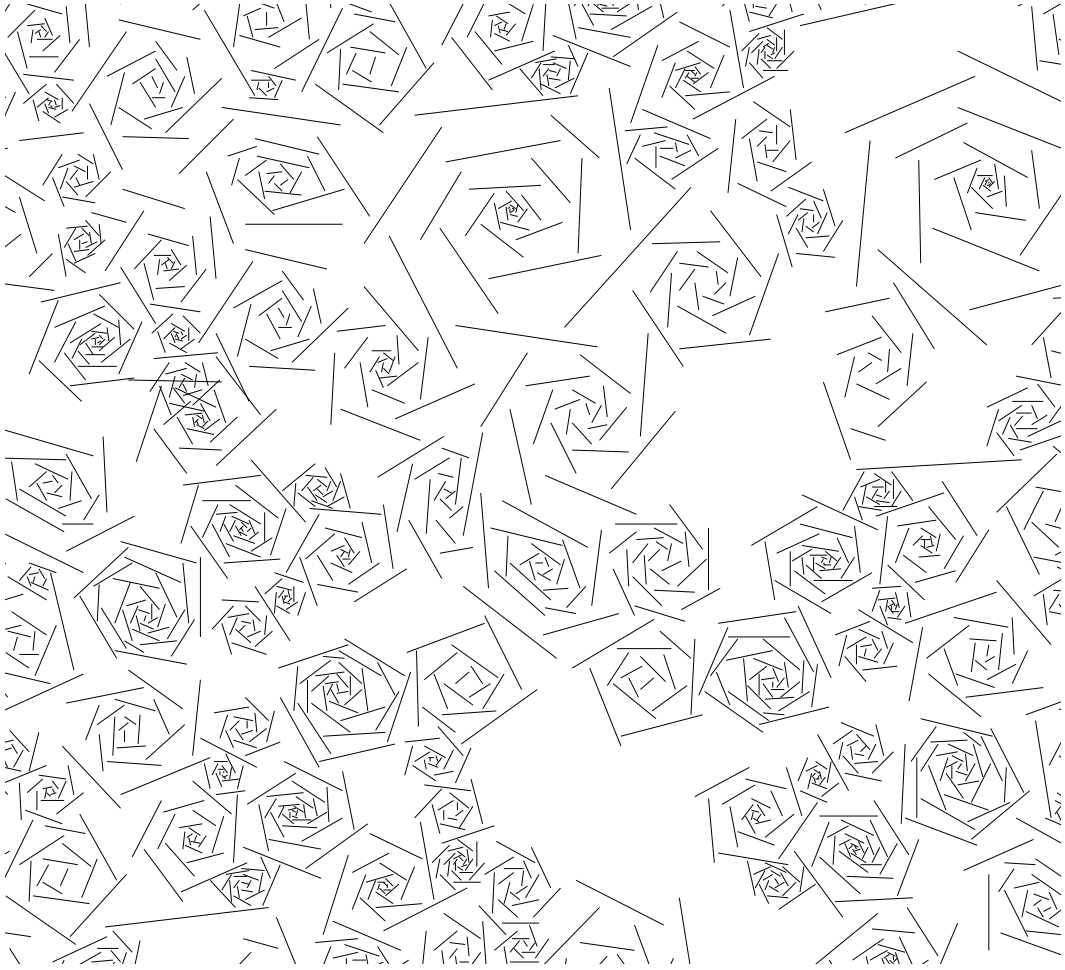


fig 4.12 Stop

Similar to the previous drawing, lines of reducing lengths are drawn, but restricted to oblique perpendicular vector to the previous lines, generating a spiral like enclosures.

Maze

fig 4.13 procedurally generated drawing through scripting

Scripted through Processing, this is a simple procedurally generated field. First, 'forbidden zones' (the empty white spaces) are manually designated, then the script fills outside the boundaries with spiralling lines. The spiral is randomly generated and grows outward until it either comes in contact with the boundary of the forbidden zones or another spiral. As the script goes on, the gaps between spirals are continually filled with smaller and smaller spirals until no more can be drawn.

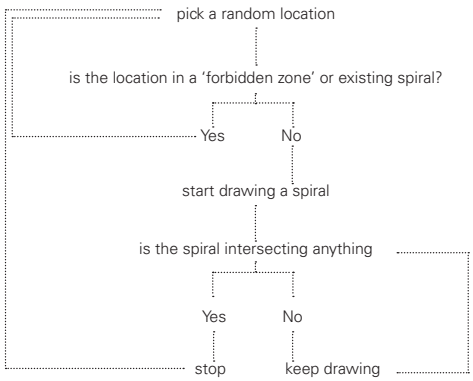


fig 4.14 Diagram of the procedural logic structure

Labyrinth

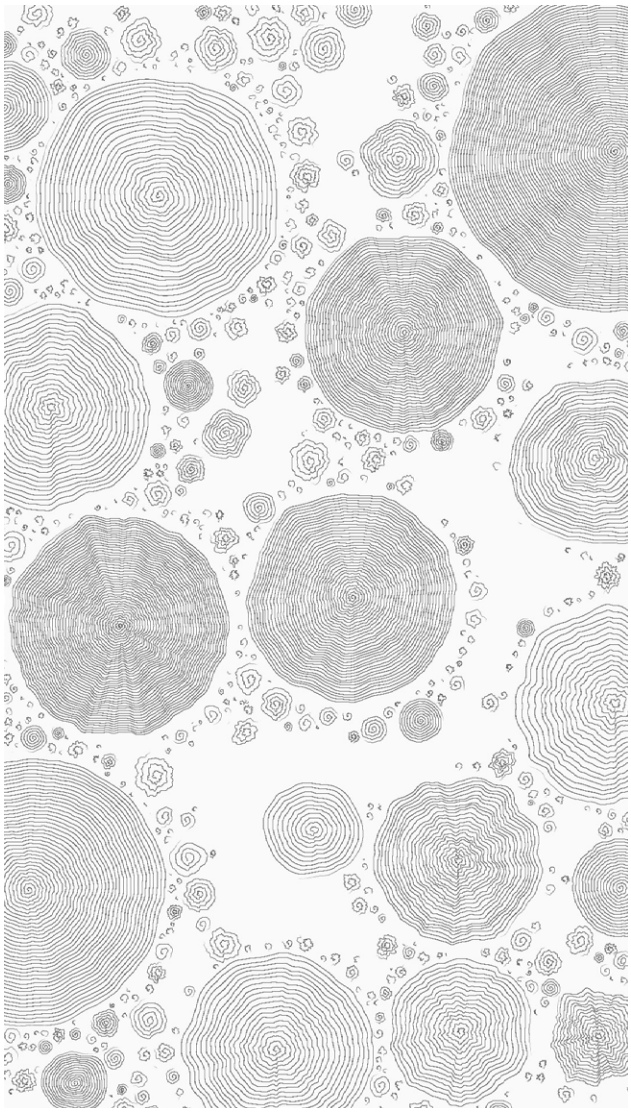


fig 4.15 procedurally generated drawing through agent-based scripting

In this iteration, the placement of the spiral is influenced by invisible agents with behaviours that interact with the spirals as they are drawn and dynamically shape the field.

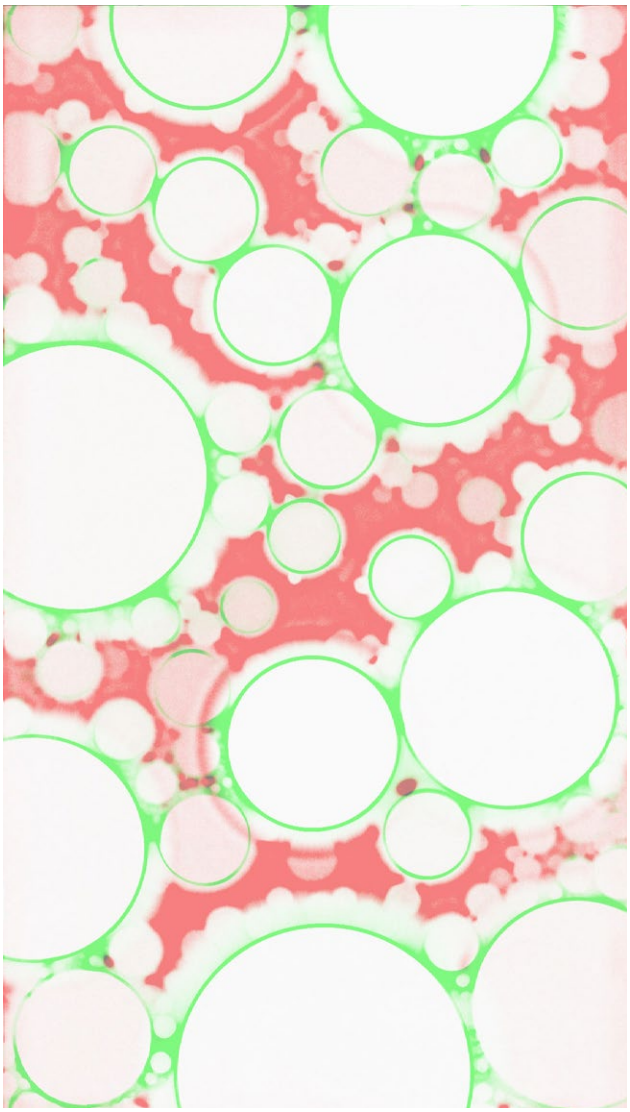


fig 4.16 visualization of the invisible agents (The composition does not match fig. 4.15 as each simulation produces different results)

Corridor City

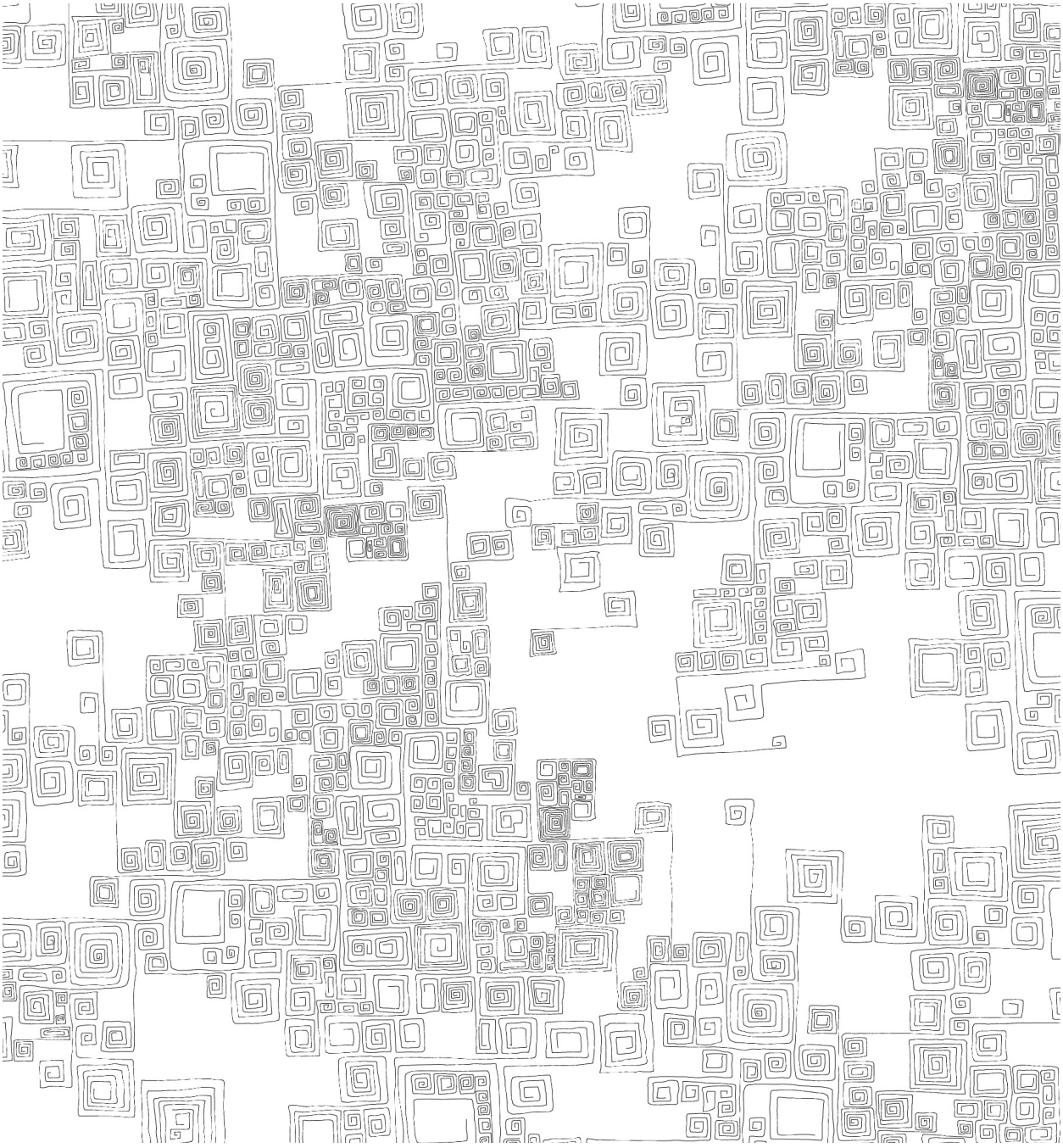


fig 4.17 Corridor City

This drawing is an expression the spatial experience of living in a city. Living in a city, a daily spatial rhythm can be imagined as series of expanding and contracting rectangular and linear spaces. We wake up in a rectangular room, walk through rectangular corridors, make 90-degree turns, take an elevator, walk on straight sidewalks, drive on straight highways, etc...

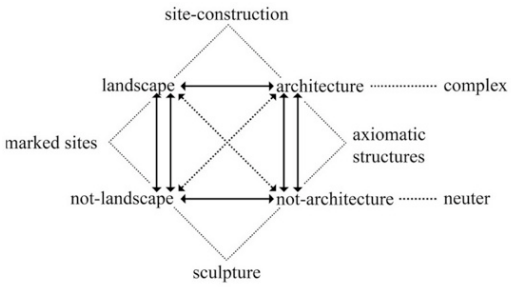


fig 4.18 Rosalind Kruass' Greimas square, from "Sculpture in the Expanded Field"

X3 Reflection

On an infinite plane, lines simultaneously act as both architecture (bounding of space) and landscape (context of the space). By procedurally generating fields, a part-to-whole relationship can occur by appending what it has already generated. Through this, the field has a self-referential like development.

In Rosalind Krauss' Greimas square, she describes sculpture as something bound within what is 'not-landscape' and 'not-architecture'. She describes labyrinth and maze as being both 'landscape' and 'architecture'.[1]

Borges uses the labyrinth as a metaphor for living. In 'The Garden of Forking Paths', a labyrinth is used to explain the infinite bifurcating, diverging, intersecting, web of time, embracing every possibility.

An infinite labyrinth on an infinite plane represents the diverging and converging relationship between spaces, each space an environment in which something happens. The connection between spaces is a rhythm, a rhythm of volume, a rhythm of time, a rhythm of events, a rhythm of certainty/ uncertainty, a rhythm of memory.

The affinity towards a labyrinth is a reaction against the infrastructure-based matrix of spaces that capitalism and consumerism necessitates. The democratic and universal access given to all spaces, through networking each space with corridors, means each space loses its characteristic by the way of losing any meaningful relationship between adjacent spaces. In an apartment, despite hundreds of units side by side, one rarely encounters another, and if at all, in the corridor which is designed for transient and efficient traversing. With the democratic and universal access corridors allow, require locked doors to prevent unwanted intruders.

A labyrinth-like architecture is a place where maps do not help. Gregory Bateson says that on maps, it is the differences that get on the map. In a labyrinth, where everything is different, a map is nothing more than a noise.

A labyrinth is a place that creates placeness not through uniqueness, but through differences. The longer one is within a labyrinth, the more it becomes familiar, and the place becomes yours. In a labyrinth, a place is not yours through monetary purchasing, but through one's ownership of the knowledge of the space, and the relationship with one's neighbours.

1 'Sculpture in the Expanded Field', pg 38

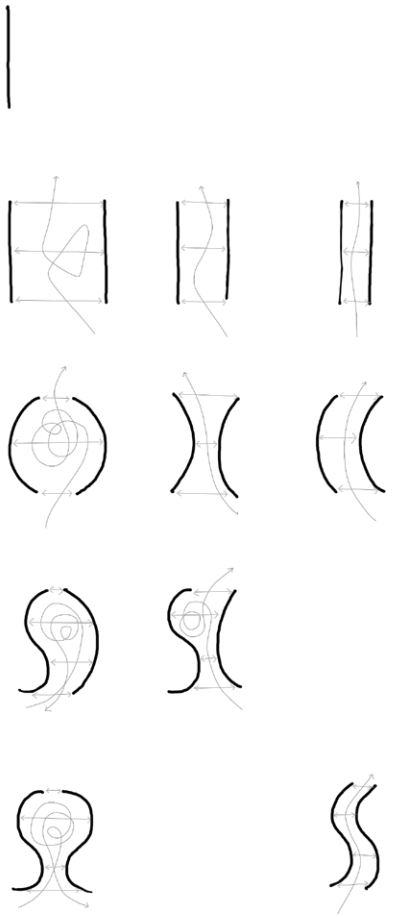


fig 5.01 space between lines

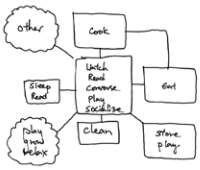
A line is a continuous relationship of points. One way to approach lines is to imagine them as a tracing a point in the movement.

The duration of the movement of a point determines the length of the lines, while the change in the direction gives the lines inflections at its local minima and maxima.

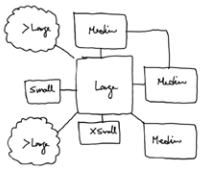
These local minima and maxima start to create spatial relationships along the line itself, as well as nearby lines.

Depending on the combination of the inflections, one can give characters to the spaces, from creating a simple enclosure to one that engender or prohibit access and movement to and within the space.

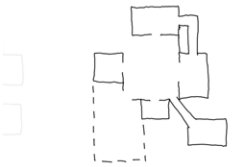
a text diagram of a suburban house



labels are replaced with events



events are replaced with sizes



sizes are visually represented

fig 5.02 diagrams of the spatial relationships of a suburban home

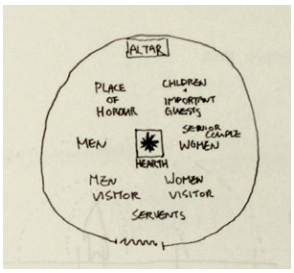


fig 5.03 a diagram of a Mongolian Yurt and the spatial distribution of the occupants

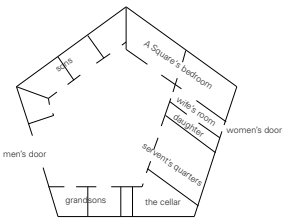


fig 5.04 'square's house' from Flatland expresising social heirchy through spatial arrangements

X4

Introduction

"If anything is described by an architectural plan, it is the nature of human relationships." Robin Evans[1]

In this exercise, a heterogeneous field is procedurally generated on an infinite plane. Starting by establishing a basic grammar, a field is composed through a series of simple rules that compound to create a more complex system.

"Heterogeneous space in architecture is neither difference produced by form within an overall uniformity (modern space) nor a collage of distinct formal elements (Post-Modern space). Instead, the proposition of a heterogeneous space would produce and permit differentiation and discontinuity of both quality and organisation across multiple conditions within an overall coherency." Michael Hensel[2]

The first iteration in this exercise begins with framing the "I", the self, the consciousness. Because we perceive the universe through our senses, we gaze outwardly starting from the center, the consciousness that constitutes the self, to infinity. Everyone perceives the reality from the subjective center, and therefore, for each person the center of the universe is one's own mind.

The lines and space between the lines are drawn as diagrammatic.

"A diagram is ... not a thing in itself but a description of potential relationships among elements, not only an abstract model of the way things behave in the world but a map of possible world." Stan Allen[3]

1 'Figures, Doors and Passages', pg 73

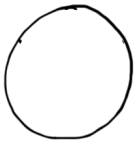
2 'Space Reader', pg 16

3 'Diagram Matters', pg 17

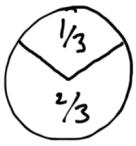
house I

"Can there be anything like an "everyday architecture," similar to the notion of "everyday life"? One must first ask, what is everyday life? How does it manifest itself? Does everyday life have a form or is it formless?"[1]

"Habitations are actually places for long habits, places where habits may be inscribed in a space that awaits them."[2] *Georges Teyssot*

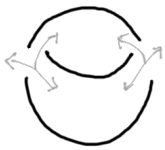


framing of a space

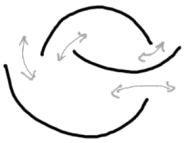


creating biased division between the waking space and the sleeping space

openings to connect the two spaces inside



openings to connect the two spaces with the outside



shifting to create bias in the opening sizes

fig 5.05 diagram of deriving house I

House I imagines a space for a self on an infinite flat plane. The infinite plane represents a total symbolic destitution, with no external influences or pre-narratives that ground a design. Without any framework to base space with, designing in the infinite plane requires the space to look towards itself for reference.

What is a space for one person?

The lowest common denominator of all human beings is sleeping. All human beings go through a daily cycle of being in the sleeping state and the waking state. We spend a third of our lives in the sleeping state.

This cycle of 8 sleep hours per every 24 hours is the basis of the rhythm of one's life.[3] It affects everything from business hours to what constitutes our daily routine. It is proposed that, at a minimum, a self requires two separate spaces, a sleeping space, and a waking space.

The spatial separation of the two states is to provide a framework for this daily cycle that must be maintained. As well, the spatial requirement and expectation for the two states are very different, where the waking state involves around conscious acts, while during the sleeping state our body is in a catatonic state as we phase in and out of our dream world. A small space that provides both physical and mental protection during our state of involuntary disembodiment becomes a frame that is constant, the sure expectation that when one returns to the waking world, the world will remain the same as it was left.

"What we experience in dreams, provided we experience it often, pertains at last just as much to the general belongings of our soul as anything "actually" experienced; by virtue thereof we are richer or poorer, we have a requirement more or less, and finally, in broad daylight, and even in the brightest moments of our waking life, we are ruled to some extent by the nature of our dreams." - Nietzsche, from 'Beyond Good and Evil'[4]

The bedroom is the point of departure and return, the nexus between our sleeping state and waking state. The sleeping space is connected to the waking space, the first spatial transition after the return. It provides one with a choice. Rhythm, or back-and-forth movement between one state to another, is a way of intervalizing the constants, shifting from one constant to another, helps to prevent the stillness.

The waking space then connects to the outer reality. This transition from a small and private space, to a medium living space, to a larger outer space, becomes the rhythmic constant that helps one to establish a placeness in our daily cycle.

The distance of the openings between two lines determines the function of the opening, with small openings that visually connects to the outside but not large enough to be an entrance, and large openings that both visually and physically connect spaces.

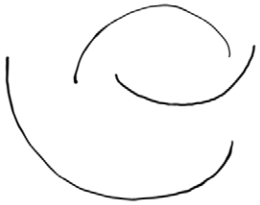


fig 5.06 an example of house I

Rules for house I:

Two spaces, one for sleeping, one for waking, and

the sleeping space connects to the waking space, and

the waking space connects to the outside, and

the overall form must be chiral[5].

1 'Boredom and Bedroom', pg 45

2 'Boredom and Bedroom', pg 53

3 The space station experience 15 dawns in a 24 hour cycle. Despite the concept of day and night does not exist, astronauts still maintain equal intervals of 8 hour per 24 hour cycle.
"Human beings have been conditioned by millions of years of evolution to a 24-hour daily cycle, and so-called circadian rhythms of waking and sleeping are hard-wired into our brains and bodies. So astronauts work and sleep to fixed schedules that match these ancient rhythms. Any other arrangement would soon have crews living in a state of permanent jet lag." http://www.esa.int/Our_Activities/Human_Spaceflight/Astronauts/Daily_life

4 https://www.marxists.org/reference/archive/nietzsche/1886/beyond-good-evil/ch05.htm

5 Chiral: A chiral form is where the mirror image of a form do not align when they are superimposed. It is a property of asymmetry and frequently found in chemistry where chiral molecules, despite being a mirror identical to each other, interact vastly different with other molecules. From the Greek word for hand, "kheir", hands are another example of chirality. Even though the left hand is part to part identical to the right hand, we develop a preference of one hand over the other, forming habits and routines. Chirality influence the habits and designs of the everyday life. For example, a notebook is often bound for right-handedness and right hands alway shake hands with another right hands. Chirality is a way of creating a duality simply through asymmetry.

house II

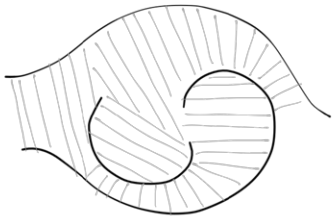


fig 5.07 an example of house II, gray lines drawn to show different zones/intervals

House II is a space for two people in union. Expanding from house I, a space for two should not simply be doubling the spaces, but providing more subtle intervals between the spatial gradients from one space to another. For example, a space for two could have an inner courtyard that creates multiplicity in how one chooses to transition from one space to another, providing variations within the space for two people to be in separate spaces, but not total isolations. How we move from one space to another is a form of expression, often unconscious. We can choose to avoid seeing a person, or sneak behind them, meet them head on, or ignore them. The introduction of a 'third' interval between the waking and the sleeping space is an expression of the complex human relationship.

Rules for house II:

Same as house I, and

an addition of a semi-private internal space.

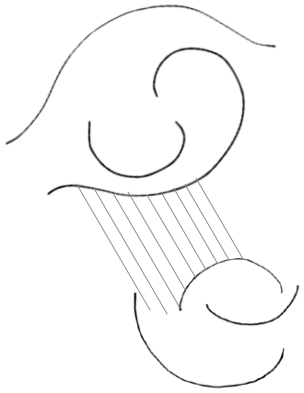


fig 5.08 space between spaces

When house II is placed next to house I, interstitial space is framed between the two houses.

house III

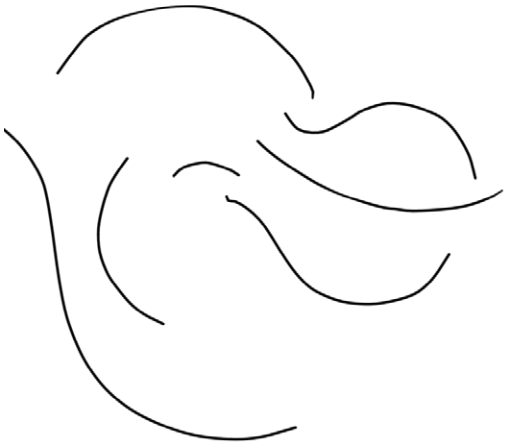


fig 5.09 an example of house III

A house for three people, for example, parents and a child, would further extend the themes of space I and space II by incorporating a semi-private courtyard which introduces another interval between the spatial gradients of public and private spaces. The chirality of the overall form unconsciously helps to create a routine, such as the flow of movement between inside and outside, which helps to instill a sense of place through repetition.

Rules for house III:

Same as house II, and

bedrooms are conjoined, and

an addition of a courtyard

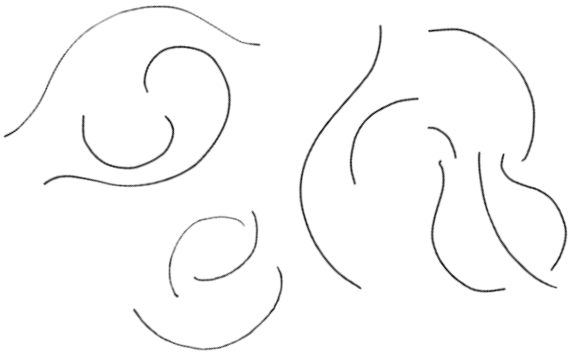


fig 5.10 interstitial spaces

As the different houses are drawn together, the interstitial space becomes more defined and behave as intervals extending from the interior spaces.

house V, house VIII

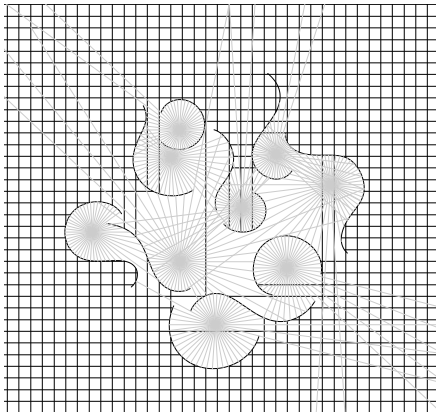


fig 5.11 an example of house V

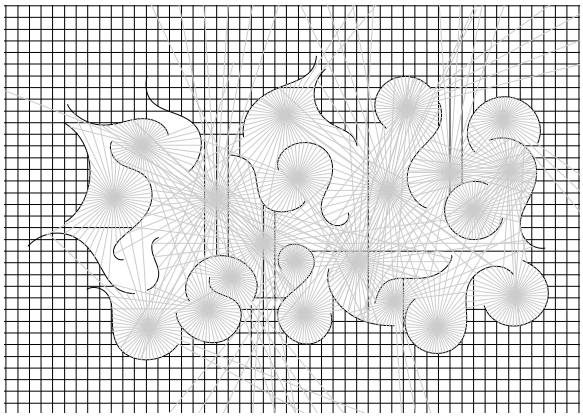


fig 5.12 an example of house VIII

As the number of occupants increase, the internal spatial dialogue demands further intervals within the gradient of public/private spaces while maintaining a flow between each space. The overall space for five is a labyrinth of interconnecting small, medium, and large spaces.

In figure 5.11 and 5.12, sightlines are projected from each space to visually represent the level of privacy where more intersecting lines mean less private.

Rules for house V and VIII:

Same as house III, and

finer internal spatial gradient, while

maintaining aspects of privacy.

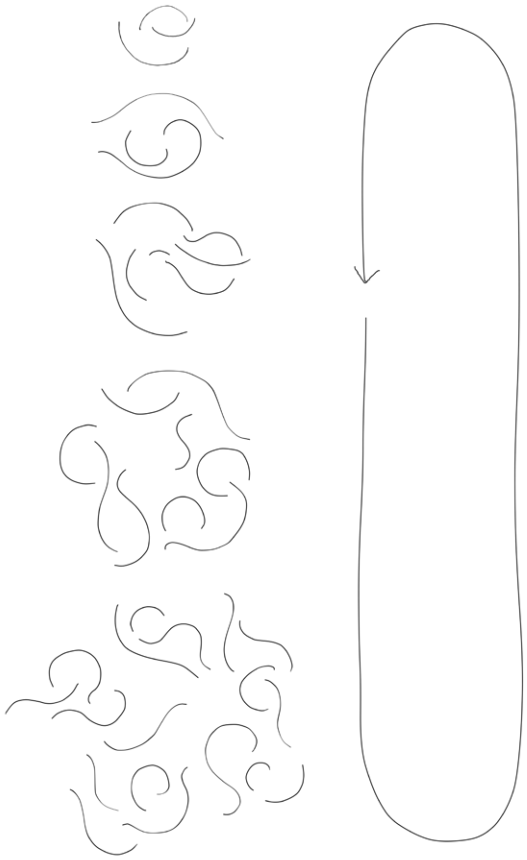


fig 5.13 life cycle expressed as spatial realms

Houses I through VIII can be seen as a spatial representation of a 'life cycle' as one moves from place to place throughout their lives. Each house we move into demarcates a new chapter in our lives, a new cycle.

This cycle imagines a baby being born in a young relationship (house III), who moves to bigger and bigger houses as the family grows (house V and VIII), the departure of the children who moves into his or her own place (house I), and starting a relationship and moving in together (house II)

Each house tries to engender the necessary spatial condition critical at each stage of life:

house I - independence

house II - relationship

house III - birth

house V - growth

house VIII - family

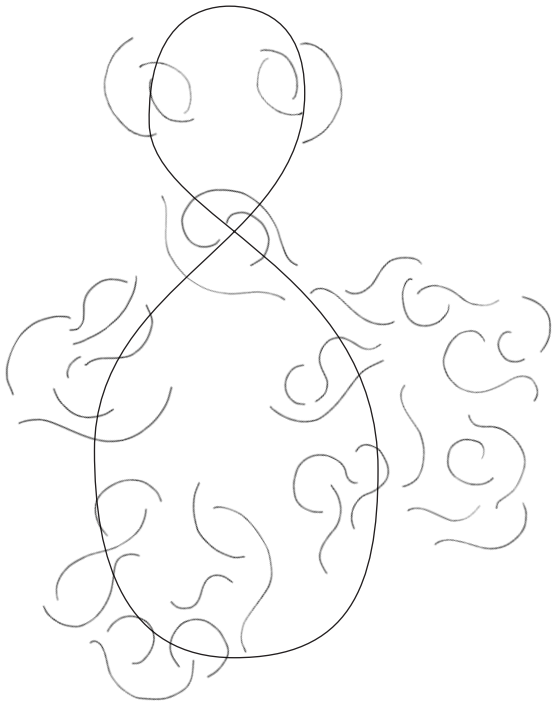


fig 5.14 distributing houses along a figure-8

The houses are distributed along a figure-8 path. The smaller houses, representing adulthood/ independence, are gathered together around the smaller loop, while the larger houses, representing family/children, are gathered around the larger loop. The houses along the figure collectively frame local courtyards to be shared among the neighbours.

House II is placed along the intersection between the small loop containing two house I's, and the larger loop, containing house III, V, and VIII. House II gaze towards both the present, the smaller loop, and the past/future, the larger loop.

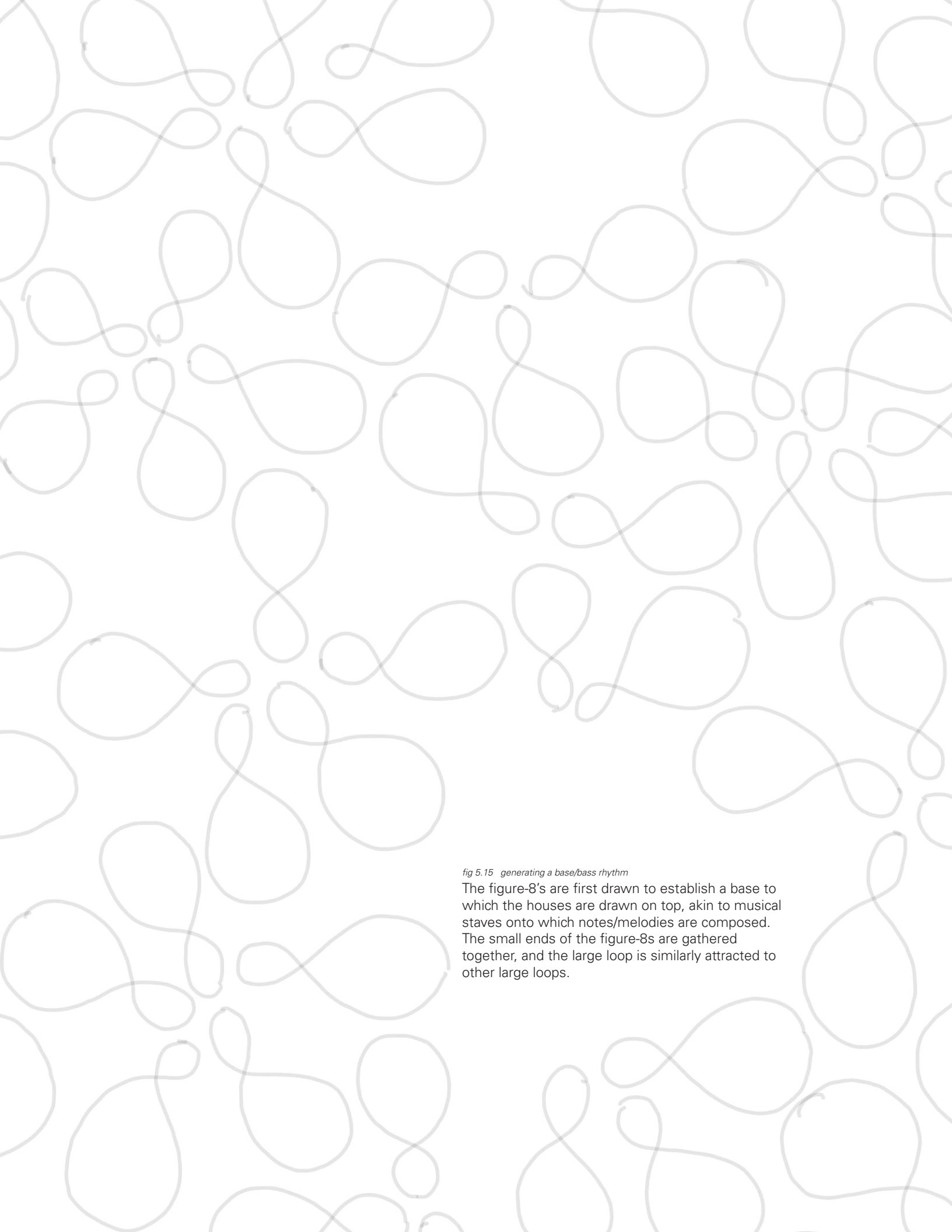


fig 5.15 generating a base/bass rhythm

The figure-8's are first drawn to establish a base to which the houses are drawn on top, akin to musical staves onto which notes/melodies are composed. The small ends of the figure-8s are gathered together, and the large loop is similarly attracted to other large loops.

fig 5.16 Amor Fati

Starting from any location, houses are drawn along the figure-8 base (which is removed after). Each subsequent houses are drawn in relation to its neighbours. The figure-8 base ensures overall uniformity of the of the composition. Yet, the simple rules established in the previous exercises allow quick freehand generation of houses and no houses are identical.

As one expand the 'mental gaze' out from a space within a house, the universe is seen as a labyrinth within a labyrinth within a labyrinth. While homogeneous in the overall texture, the individual spaces and houses remain unique and singular within the local context, maintaining the placeness not through distinctive forms but through its distinctive connections to neighbouring contiguous spaces. This heterogeneous field creates individual distinctions that become more and more familiar to the inhabitants and the experiences become part of their daily spatial rhythms that are unique to each person.

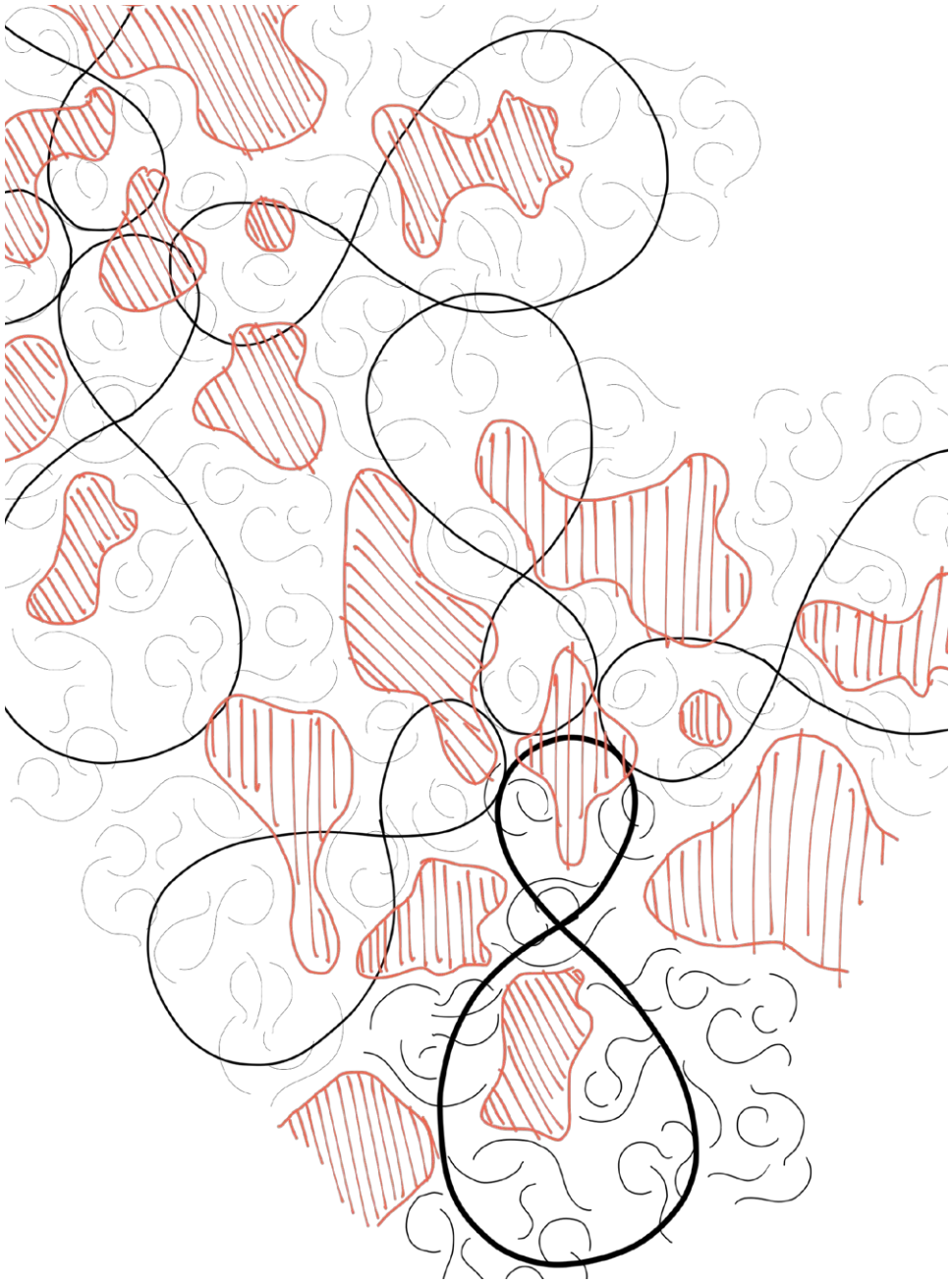


fig 5.17 between the houses, a labyrinth of extra-spatial matrix emerges

The composition from the previous page is a spatial expression of 'Amor Fati' and 'Eternal Recurrence', both concepts drawn from Nietzschean philosophy.

Amor Fati[1] is a latin phrase translating to 'love of one's own fate'; to love each and every moment, good or bad, as each is necessary parts of the whole.1 The concept of Amor Fati is perhaps only truly attainable at one's deathbed, where one has nowhere to gaze but fully to the past, where one can string all the memories which reflect back the image of self.

We need others to remind ourselves. Children remind us that we once were children, and elders remind us that we once will become old. Children, whose gazes are fully towards the future, see the grown-ups who are images of their own adulthood, while elders look back at children reflecting their own childhood. In the composition, one is never too far away from old people, nor too far away from children.

Eternal Recurrence[2] is "the idea that with infinite time and a finite number of events, events will recur again and again infinitely."

The infinite variation of the same figure 8 pattern, which goes from house I/self, house II/relationship, house III/child, house V&VIII/ family, then the repeat of the cycle as the offsprings depart to create their own version of the cycle, is the expression of never-ending cyclical story of life.

"What was once before you - an exciting, mysterious future - is now behind you. Lived; understood; disappointing. You realize you are not special. You have struggled into existence, and are now slipping silently out of it. This is everyone's experience. Every single one. The specifics hardly matter. Everyone's everyone." Millicent Weems, from film "Synecdoche, New York"[3]

1 The concepts of *Amor Fati* and *Eternal Recurrence* is central in Nietzsche's writings and a brief introduction and a summary can be found here: https://en.wikipedia.org/wiki/Amor_fati

2 https://en.wikipedia.org/wiki/Eternal_return

3 'Synecdoche, New York', 1:55:30

house I

fig 5.18 house I variations from Amor Fati

house II

fig 5.19 house II variations from Amor Fati

house III

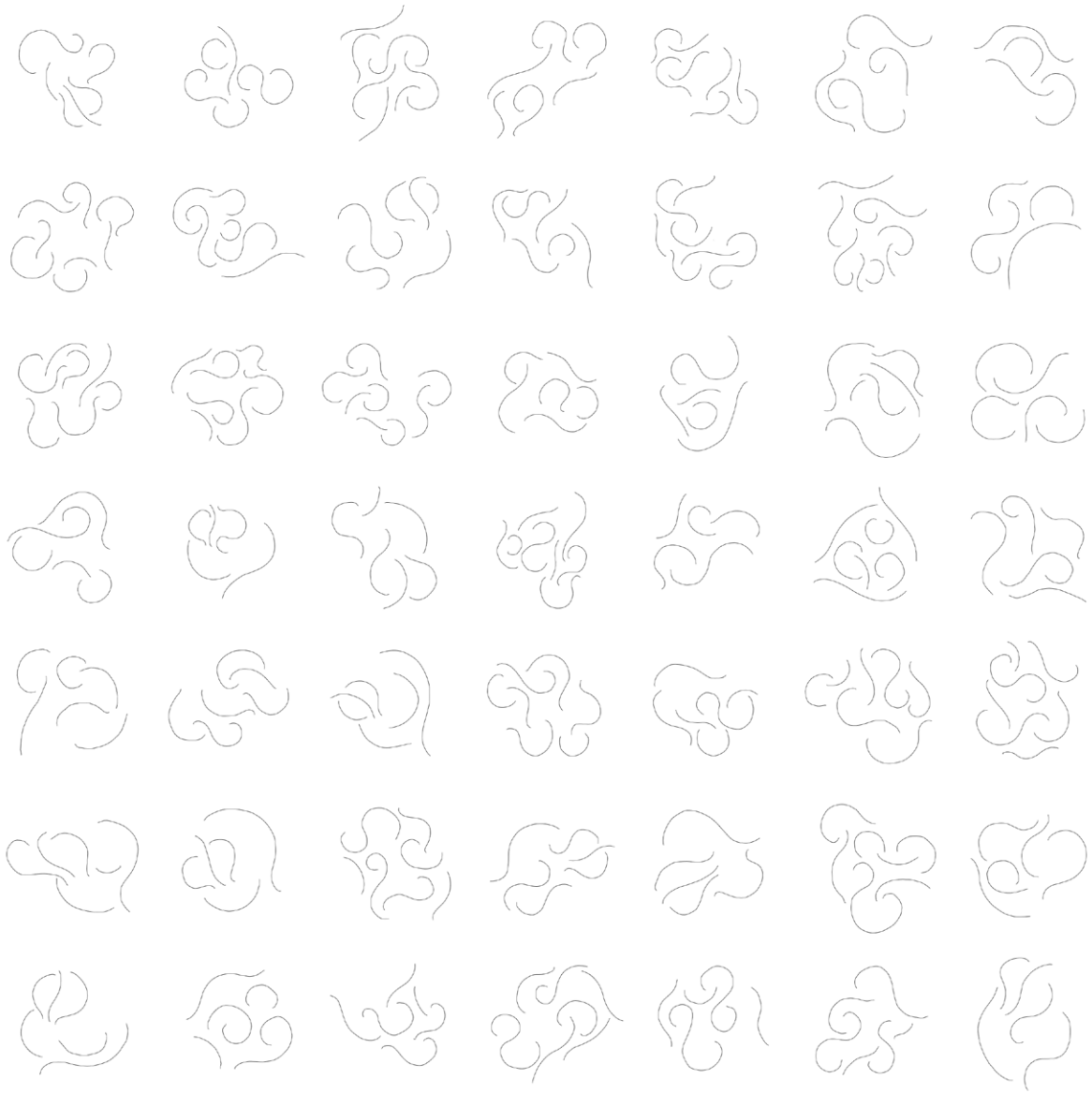


fig 5.20 house III variations from Amor Fati

house V

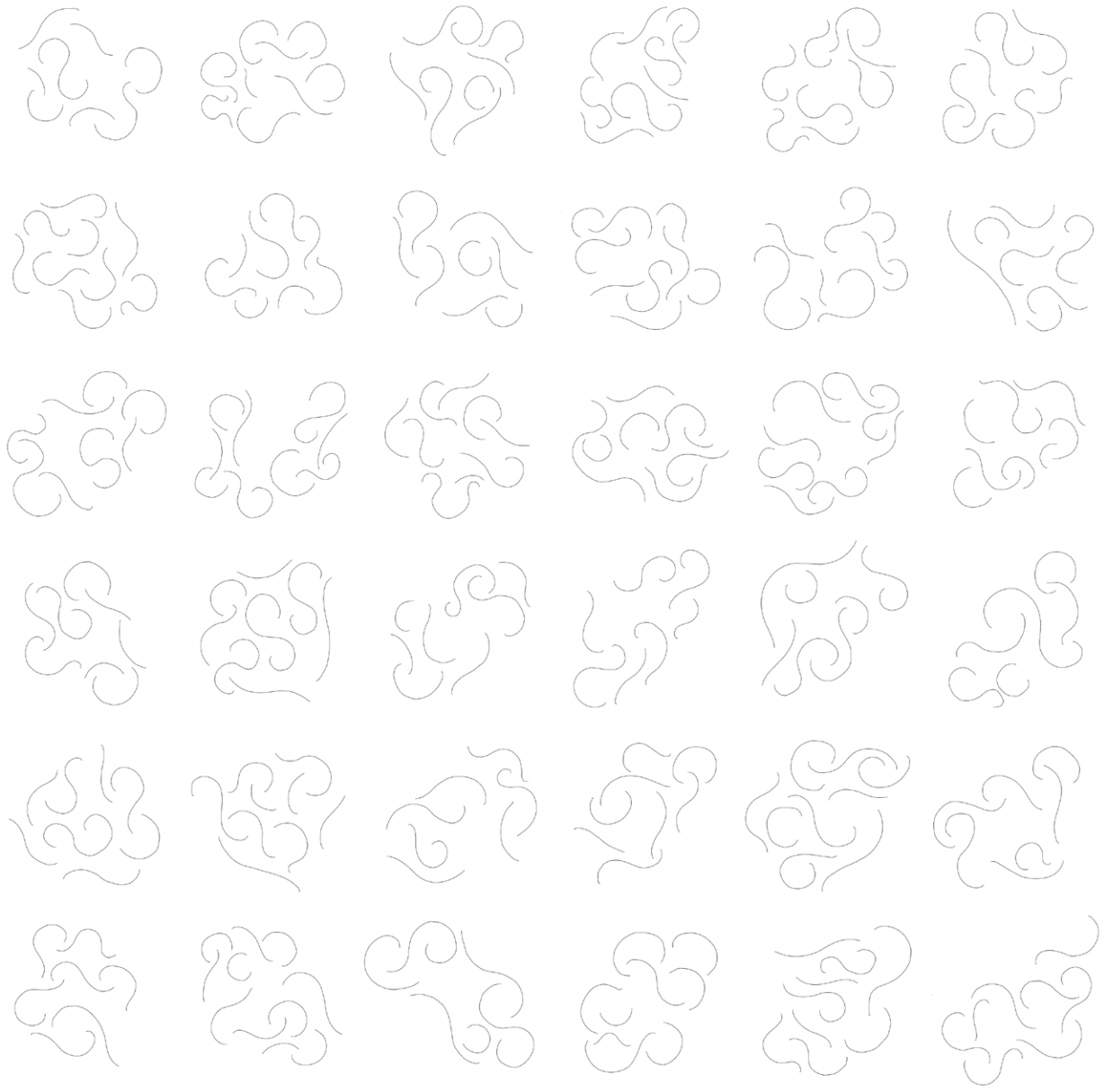


fig 5.21 house V variations from Amor Fati

house VIII

fig 5.22 house VIII variations from Amor Fati

X4 Reflection

This exercise began with an observation that we sense the universe and the construct of humanity through sensorial perception through the medium. All things matter act as distorted mirrors that bounce back the projection of mind.

How one behaves in one's own bedroom alone with the door closed is different with the door open, different than being in a living room, with a significant other, family, friends, stranger. As well, one also behaves differently in a small room, a large room, a library, a church, a corridor, a plaza, a theater, a bathroom, a classroom, an atrium. Objects, people, events, and symbols 'snap' us from our infinite eigenstate[1] into a single state. These 'matters' are contained by space which defines the boundary of the realm.

We perceive the world through series of boundaries, boundaries that block out perception in succession matters which frames the space. Each boundary reduces/simplifies one's reality.

When we are in our bedroom, the bedroom becomes the known universe. In our bedroom, our domain, we project ourselves across the entire room, filling the space like a gaseous state.

Space and matter act as a pressure that shapes us from this gaseous eigenstate into one version of our self.

On an infinite white plane, with no boundaries and near absolute symbolic destitution, a person spreads and thins out indefinitely.

The labyrinth generated in this exercise is an expression of 'no man is an island'. Every space is connected to each other and each space has unique local relationships. Here, the universe is a series of expanding frames of reality, which is perceived from the center of one's mind outwards, where things fade away into darkness the further one tries to expand the consciousness. Yet, the overall homogeneity of the space creates a sense of always belonging to a greater whole.

1 For more information on the term "eigenstate", refer to https://en.wikipedia.org/wiki/Introduction_to_eigenstates

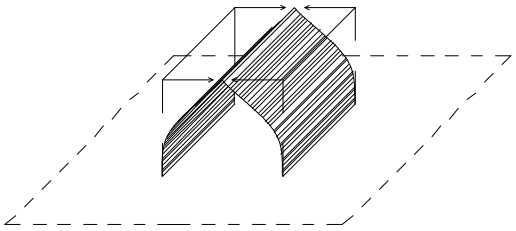


fig 6.01 pinching to enclose

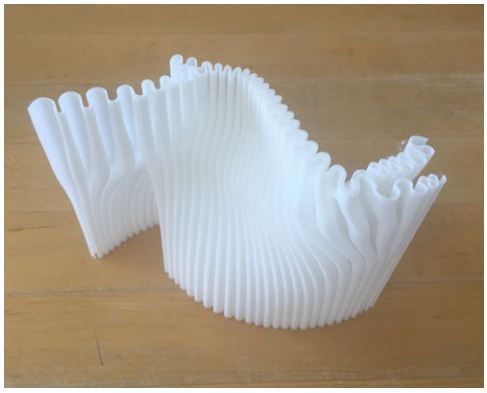


fig 6.02 continuous fold vertically

fig 6.03 fold 'relaxing' vertically

X5

Introduction

"A diagrammatic process extends the horizontal, affiliative character of the diagram directly into the field of construction itself, engendering an architecture of minimal means and maximal effects." Stan Allen[1]

In this exercise, the line composition from X4 is combined with the 3D printing method developed in X2 to create a three-dimensional diagrammatic architecture.

A flat planar wall is structurally unstable. By 'folding' or curving the line, such as an S shape, the planar wall becomes self-supporting. By double folding, the planar wall is given rigidity. The single and double folds are an expression of a structural minimum. The 'relaxing' from the double fold on the bottom to single fold on the top, executed by lofting the two curves, gives a gradient of in-between double and single along the vertical axis. This is an expression of applying structure only where necessary.

By pinching together adjacent walls, an enclosure is formed.

1 'Diagrams Matter', pg 16

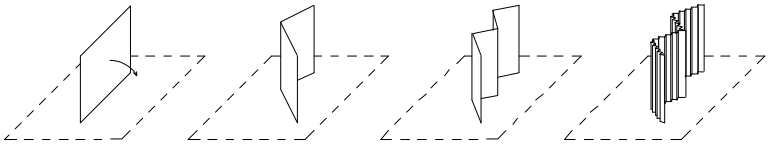


fig 6.04 folding to give stability at different scales

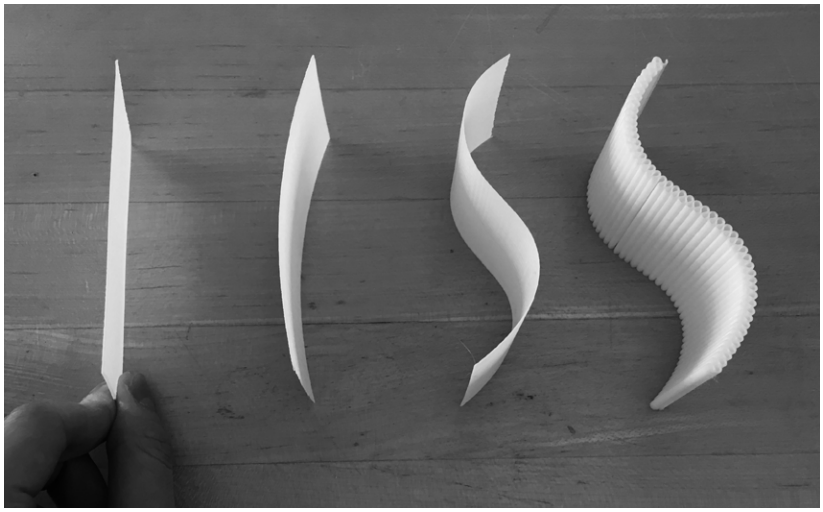


fig 6.05 fractal-like recursive folding

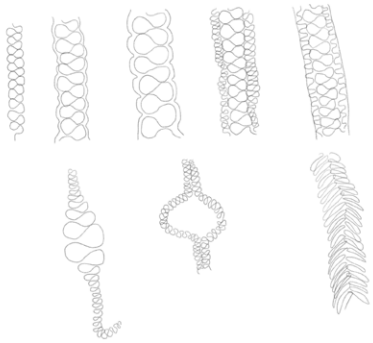


fig 6.06 a quick study on folding variations

A quick sketch of various types of folding. In this exercise, only the basic double-fold is used for its simplicity. However, one could easily imagine the folds being more complex depending on the functional needs (e.g. structure, service, function etc).

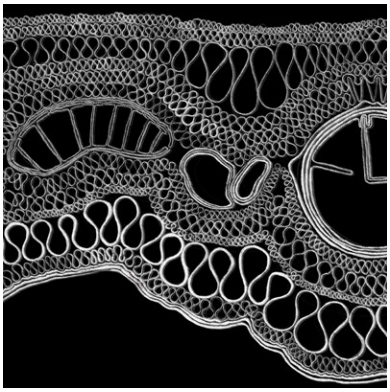


fig 6.07 a wall section inspired by cell walls

house I

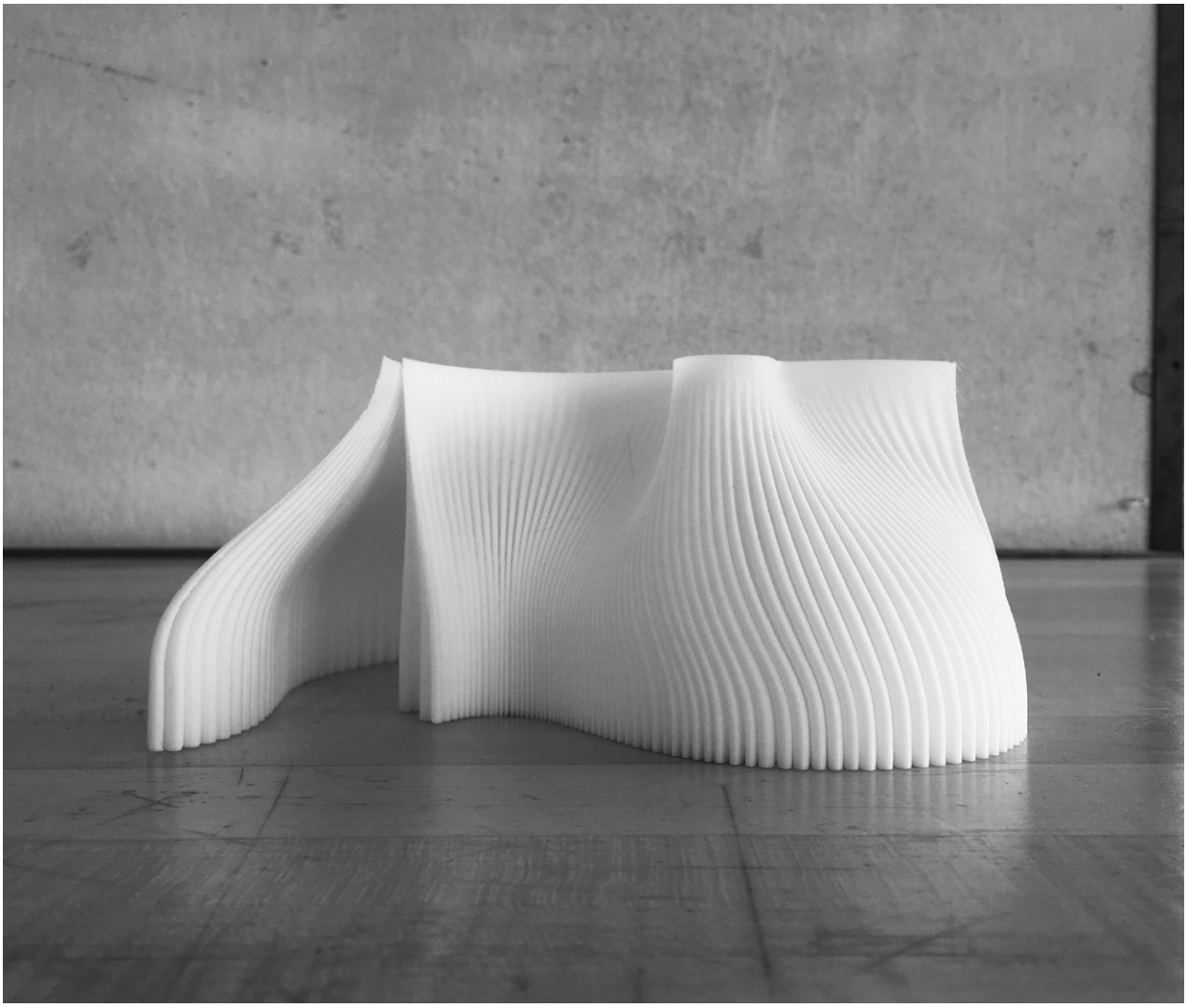


fig 6.08 house I, a primitive hut

The introduction of verticality allows an additional relationship to be explored for each space. Here, the sleeping area has an oculus-like opening at the top.

Double folded skin: the structure is the enclosure.

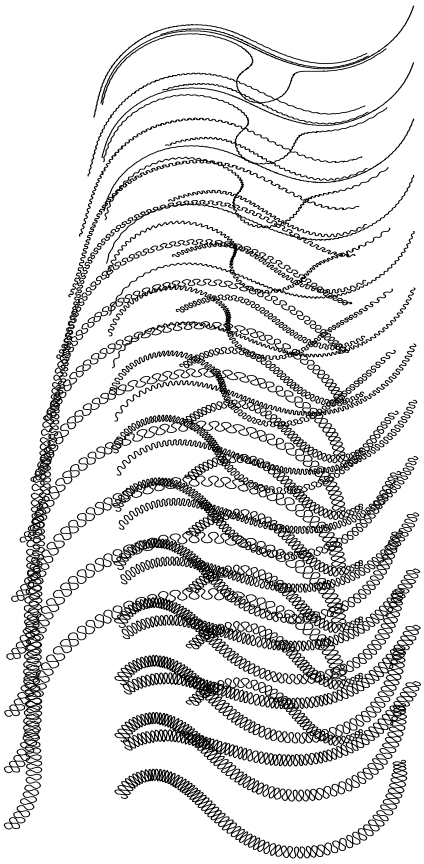


fig 6.09 house I, axonometric

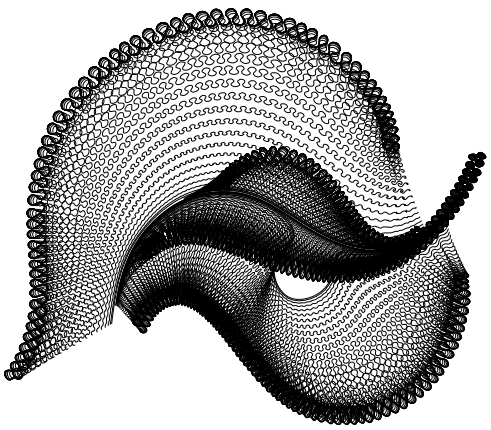


fig 6.10 house I, collapsed plan

house II

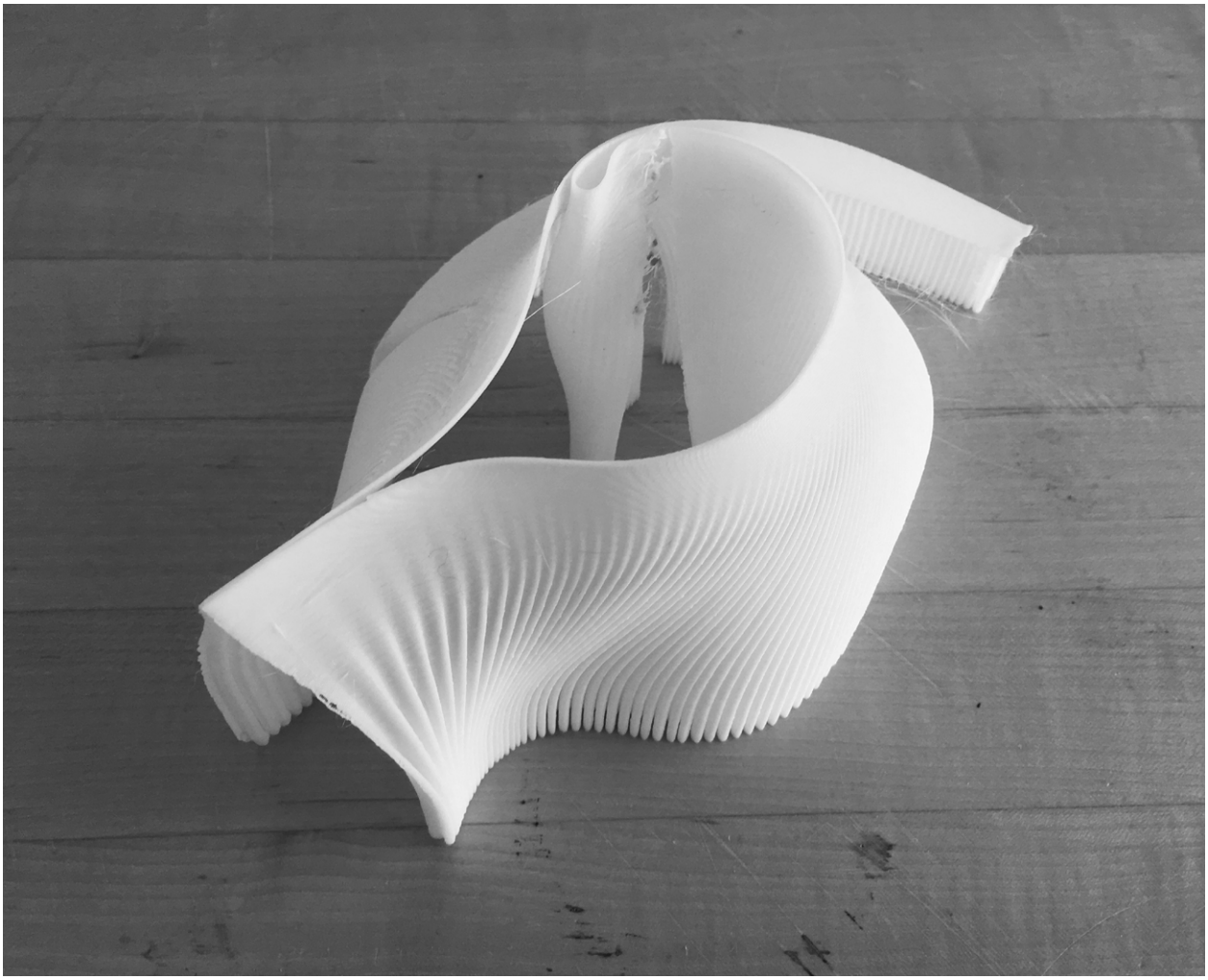


fig 6.11 house II

By controlling the way adjacent lines pinch, an inner courtyard can be created.

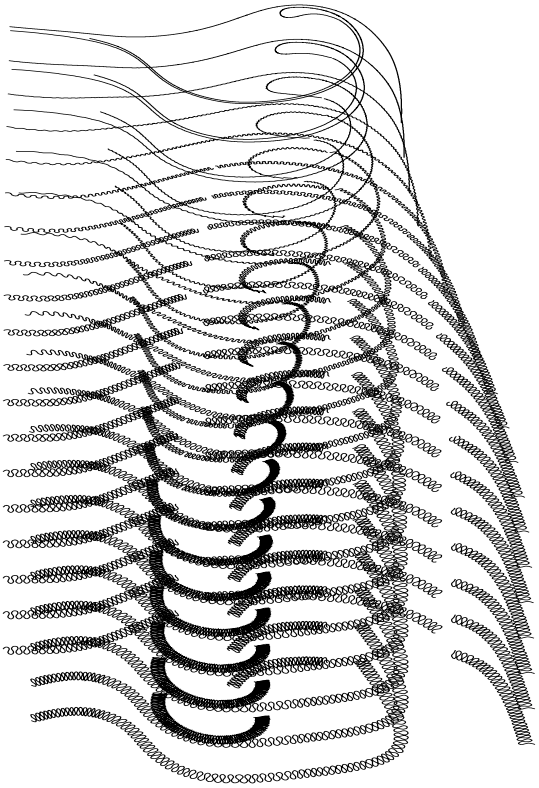


fig 6.12 house II, axonometric

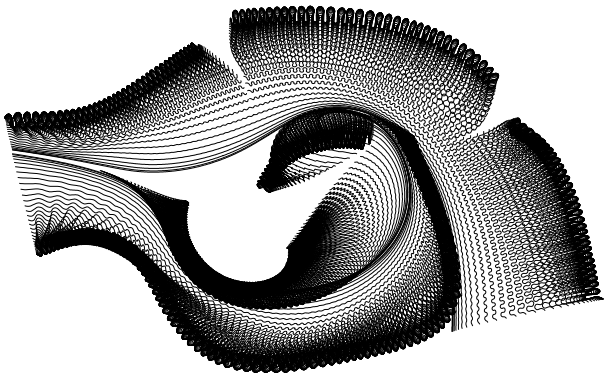


fig 6.13 house II, collapsed plan

house III

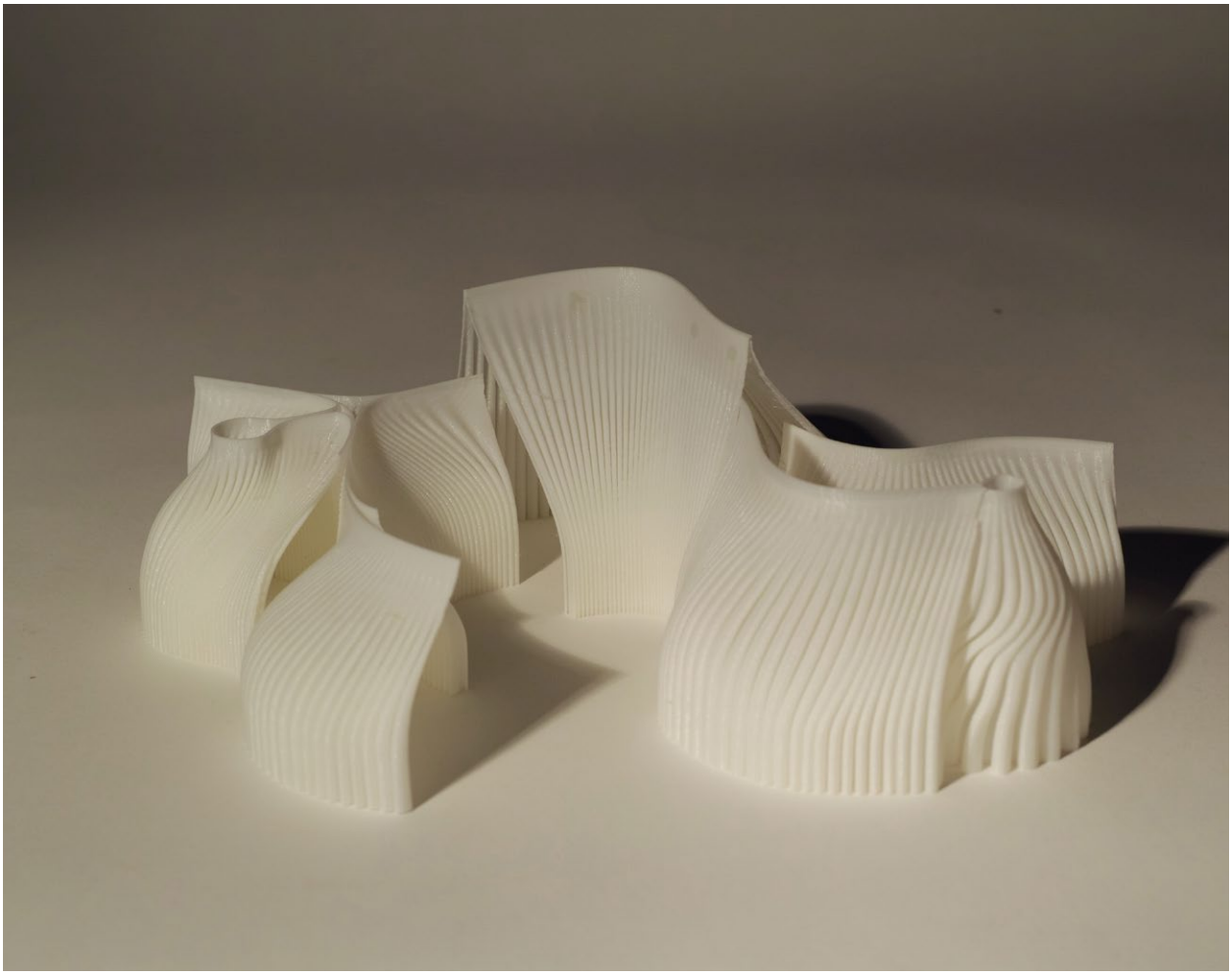


fig 6.14 house III

Act of enclosure helps to distinguish private spaces (e.g. bedrooms) and semi-private spaces (e.g. courtyard).

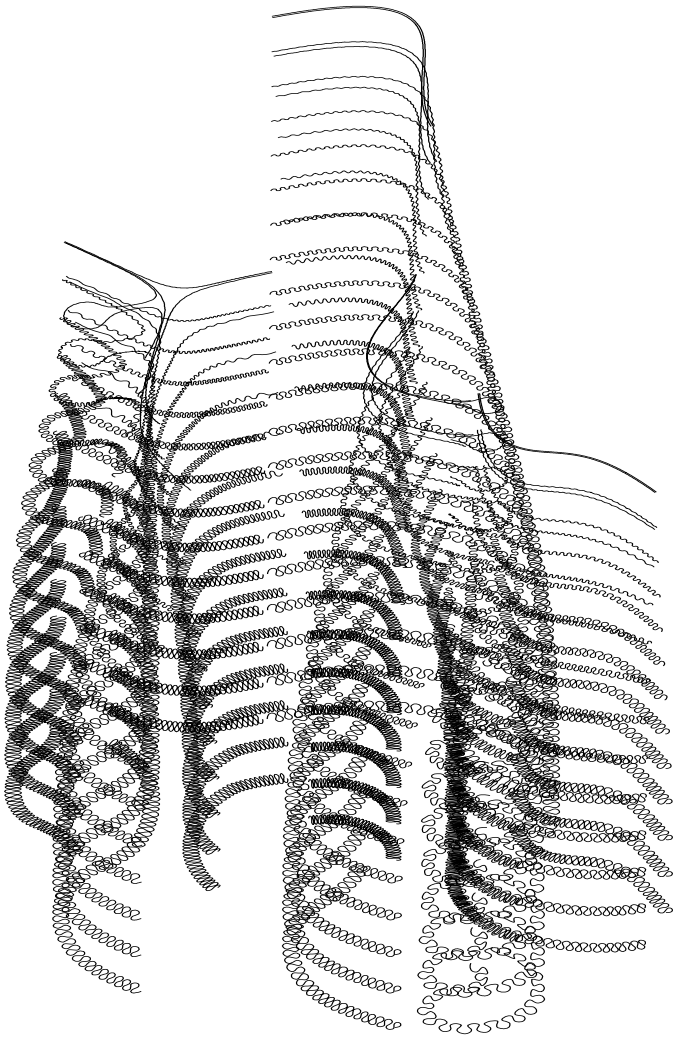


fig 6.15 house III, axonometric

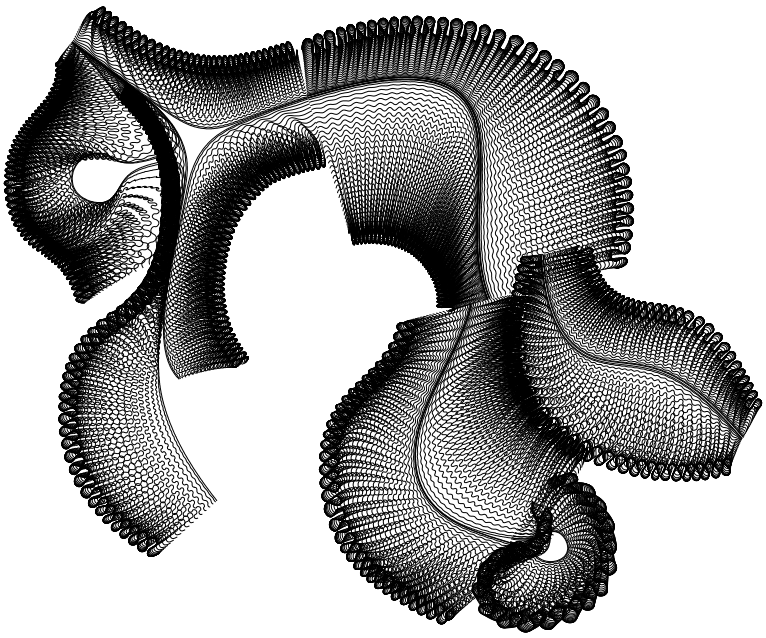


fig 6.16 house III, collapsed plan

house V

fig 6.17 house V

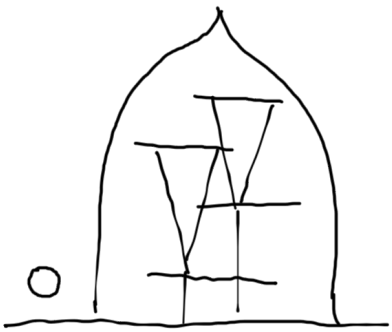


fig 6.18 space V, diagram

Whereas Interval I explores spatial relationships horizontally, vertical relationships can be explored in Interval II. Space V imagines a large volumetric enclosure in which vertical space is occupied by insertion of horizontal plates.

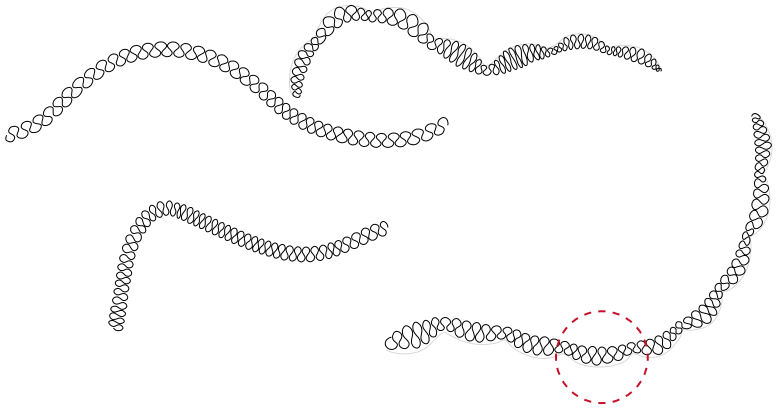


fig 6.19 house V, ground level plan
As the vertical height of house V is taller than previous houses, the folding of the lines are thickened at intervals to mimic column-like structural support.

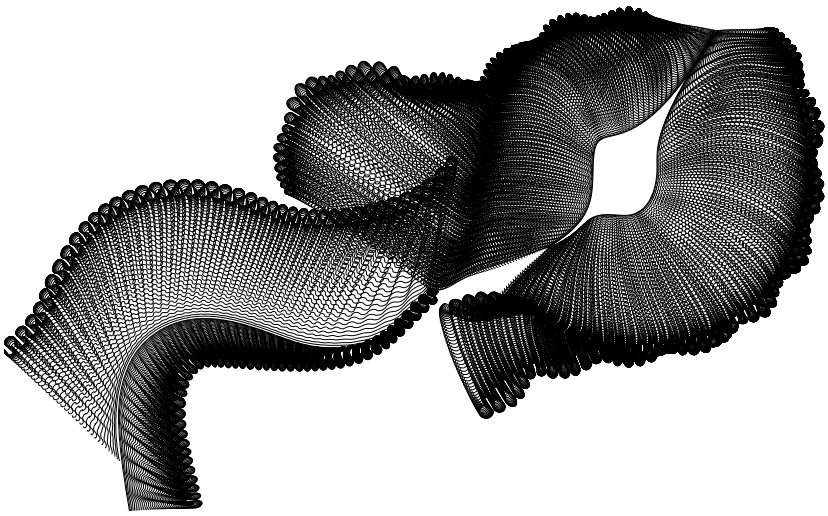


fig 6.20 house V, collapsed plan
A few have commented on its resemblance to a jellyfish. While the derivative of the form had nothing to do with organic forms or fluid dynamics, the film-like envelope and the relaxed lofting style does evoke an ephemeral and delicate organism

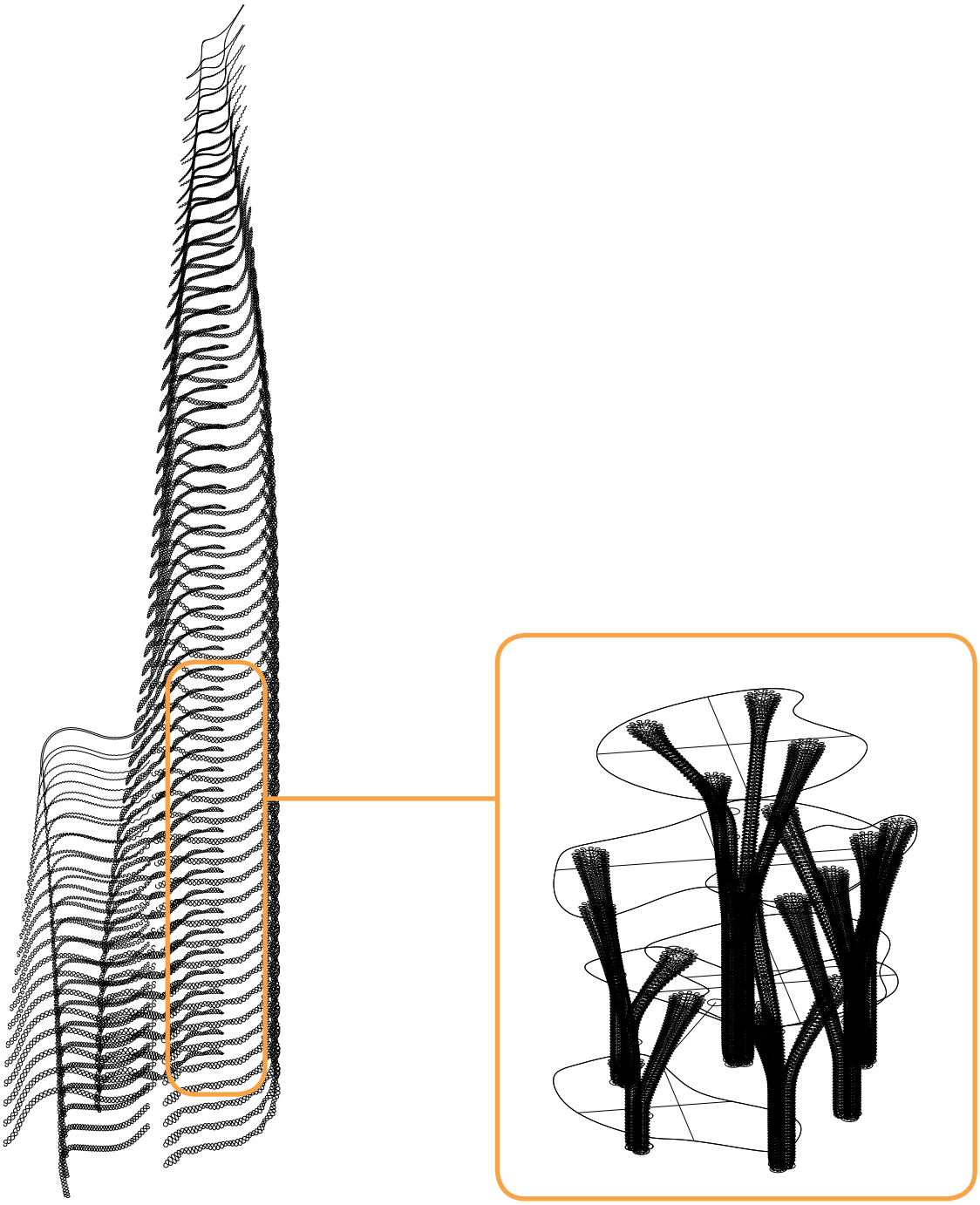


fig 6.21 house V, axonometric

the inner structure supporting horizontal plates to occupy the volume

fig 6.22 model of the outer shell

fig 6.23 model of the inner structure

fig 6.24 a labyrinth of enclosed and open spaces

fig 6.25 interstitial spaces between houses

fig 6.26 interstitial spaces between houses

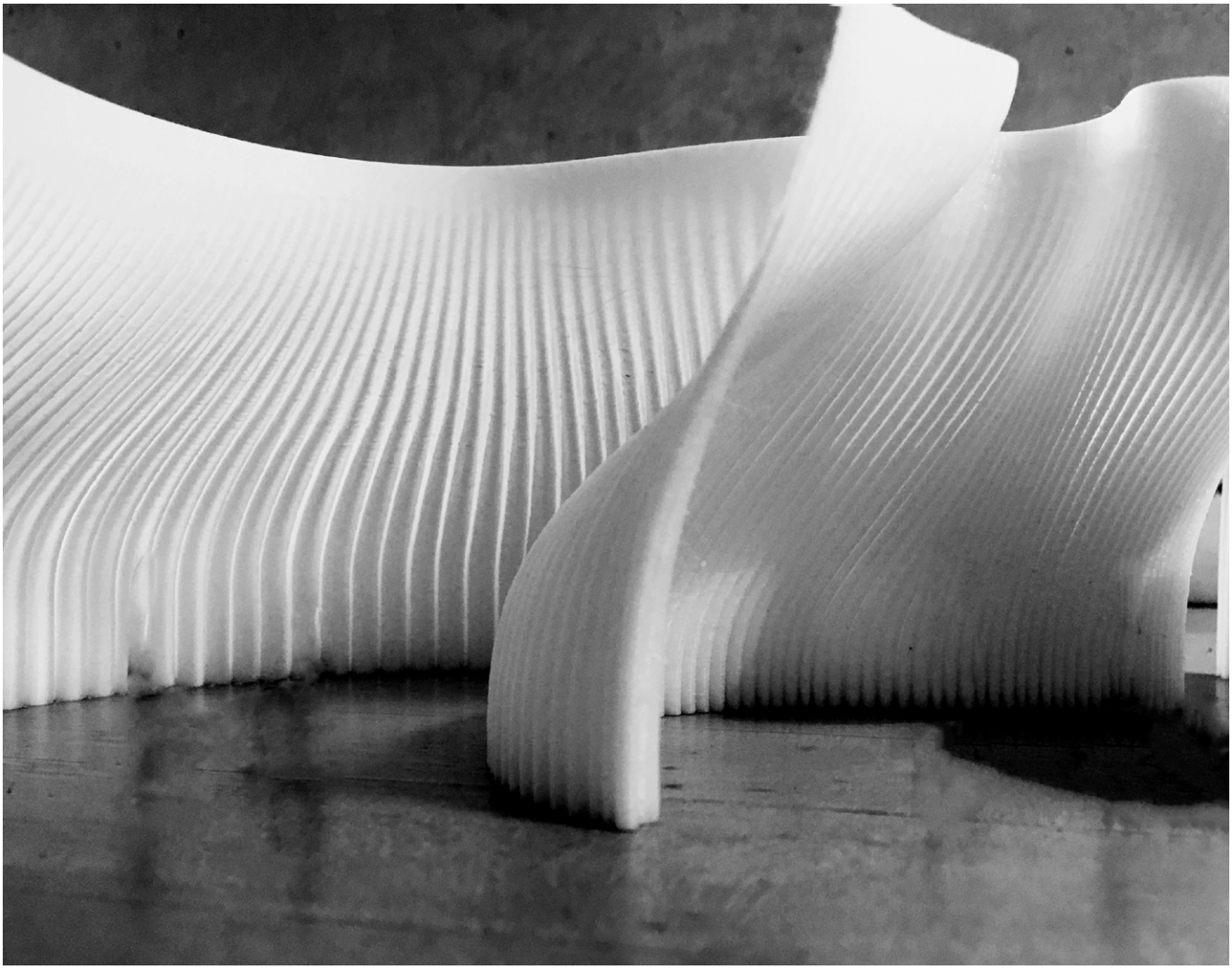


fig 6.27 an interstitial space between houses

fig 6.28 interior view of house III

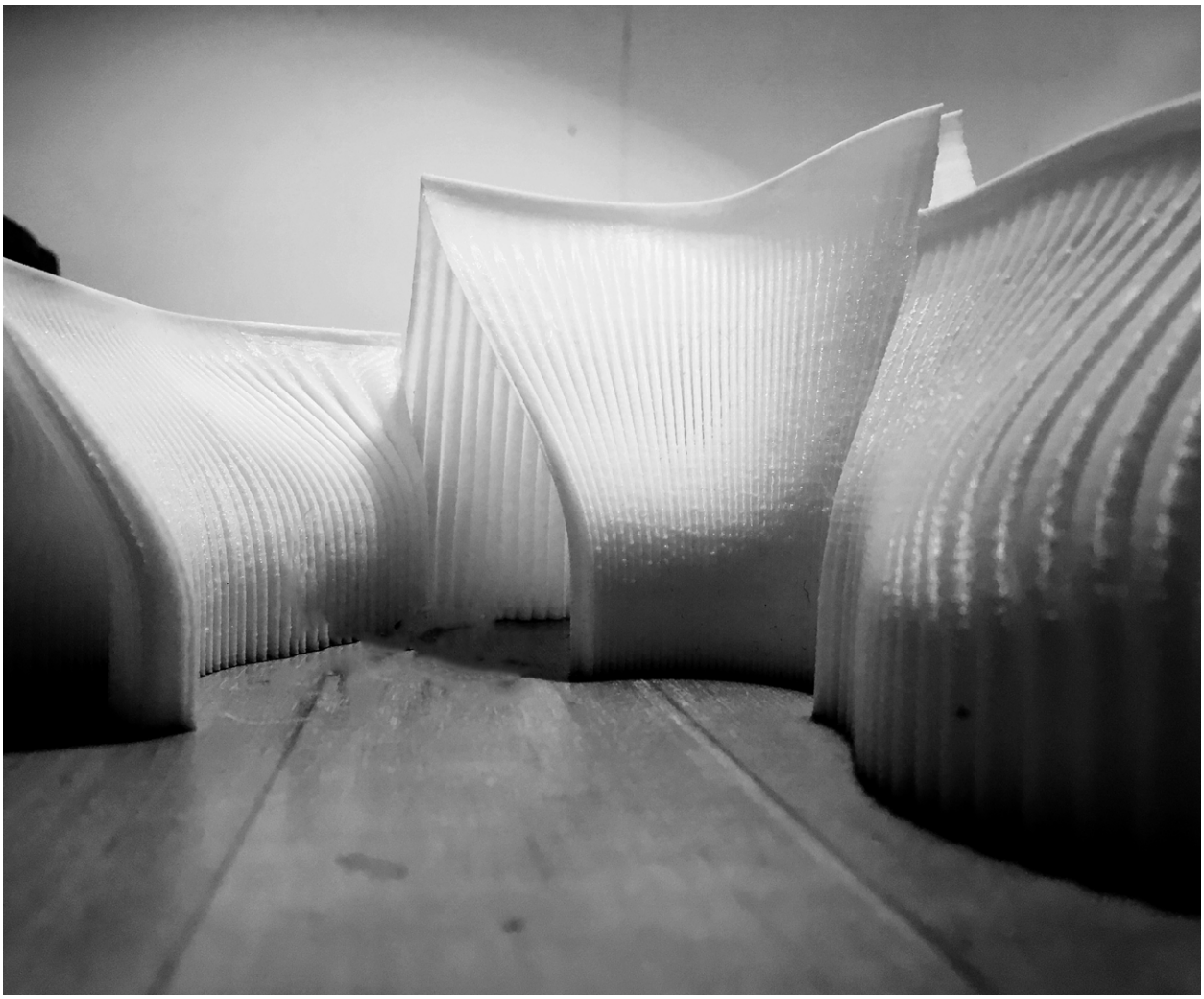


fig 6.29 courtyard of house III

fig 6.30 inner courtyard of house II

X5 Reflection

In X4, a horizontal labyrinth was explored, a series of bounds from any given space to as a way of creating privacy while maintaining fluidic local relationships.

In X5, this two-dimensional diagram is projected upwards using methods developed in X2 to create a three-dimensional diagram.

fig 6.31 tree/house #1, #2, #3

While the first three houses were simple translations of space between lines to space between planes, house V started to explore spatial relationships vertically, similar to the treehouse series from X2. For house V, a large shell was designed to enclose a volume in which the verticality is used as a way of controlling privacy, the higher one moves away from the ground plane, the more private the space. The bounding volume was imagined as a way of framing a large space in which contained a free-form structure that was independent of the outer shell.

In the tree/house series, the form was explored as not a relationship between the composition of subject (house) to the site (tree), but as one entity, a 'tree-like-house'.

In tree/house #3, the continuous lofted wall is broken by series of plates that allow one to occupy the space. However, the inflections of the curving wall give a sense of connection from one level to another. One can almost project what the next level would look like by tracing the inflection of the walls vertically. By looking at how the walls and openings inflect, one can gauge a sense of what the above and below space would look like. For example, when standing on level 2, the widening of the walls near the bottom gives a sense that the level below would have a large opening while the closing of the opening near the top give a sense that space above would be enclosed. Therefore, one can gauge how the space above and below would be, without actually knowing what the space is exactly.

X6

Introduction

X2 explored lines changing from one state to another. In the (inverted), a clover shape is inverted as it moves vertically, while in #12 the shape is compacting inward, in #13 the form contracts like a zipper and opens up.

In X3, some of the drawings were presented as diptychs of similar or contrasting concepts.

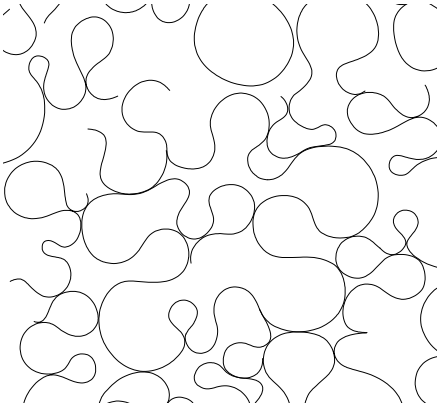
X4 looked at horizontal relationships and transitions from one space to another, from private to public.

In X5, two or more adjacent lines simply converged together at the top to enclose a space.

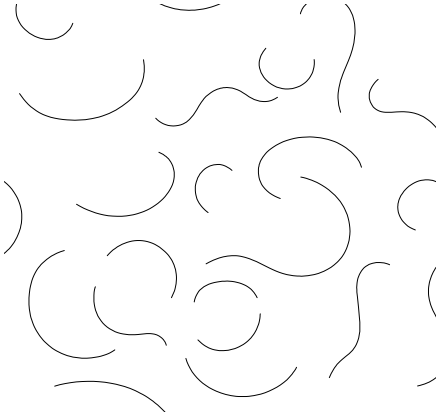
X6 imagines two contrasting patterns of lines superimposed on top of each other and lofted. Lines transform from one state into another along vertically. The result is a gradient of in-between state of the two patterns. Whereas one moved through space horizontally to negotiate space and privacy, this exercise explores vertical spatial relationships.

house IO

I = closed/inside/1
O = open/outside/0



'closed' state



'open' state

fig 7.01 diametric states

When the two patterns are lofted, in between spaces are created which morphs from the bottom, open space field, to the top, closed space loops.

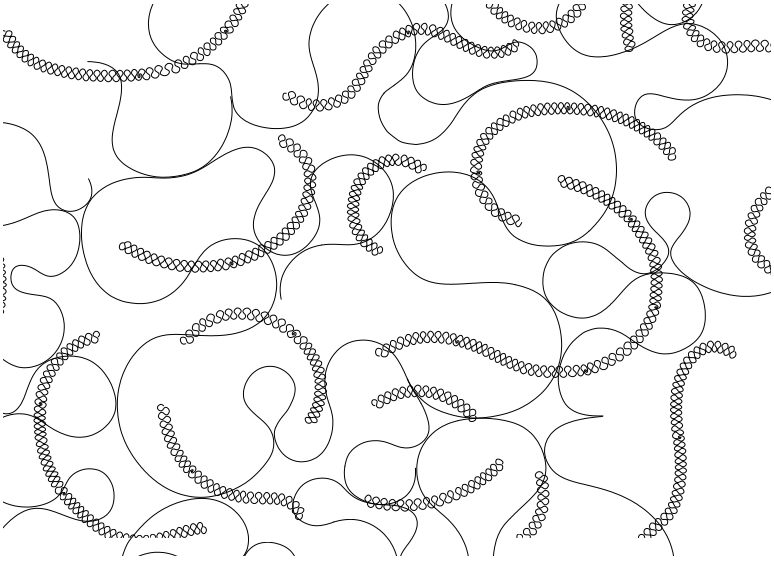


fig 7.02 the two patterns superimposed, the closed state on the bottom and folded and the open state on the top

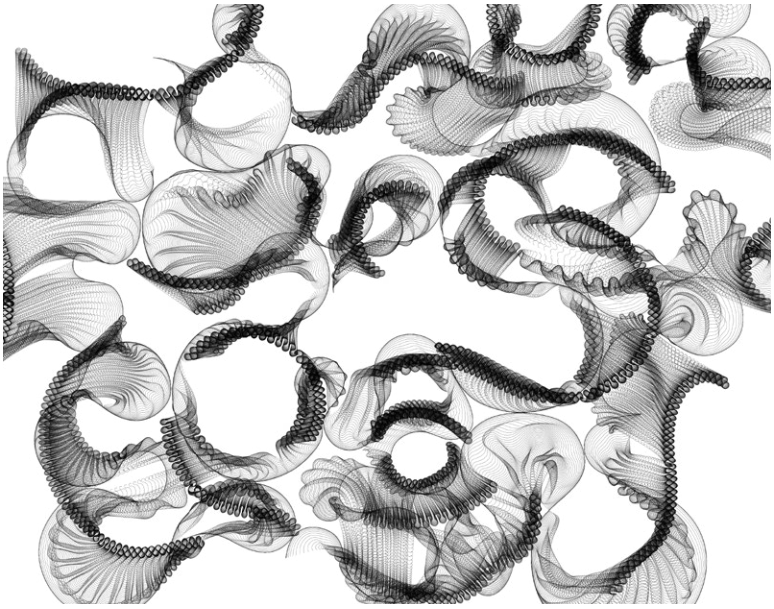


fig 7.03 the two patterns are lofted together

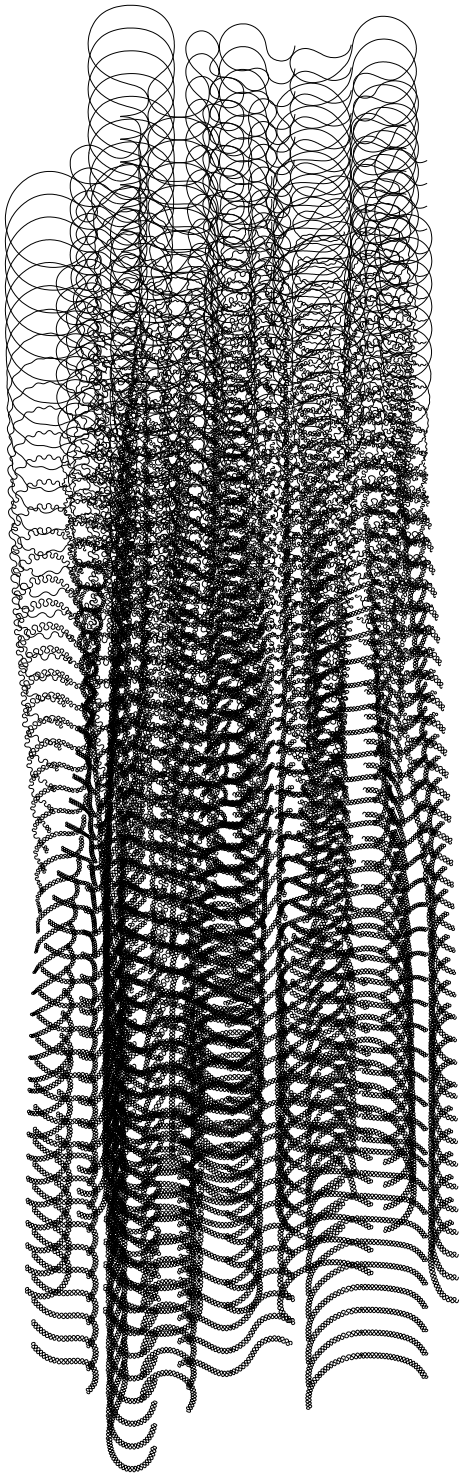


fig 7.04 house IO, axonometric

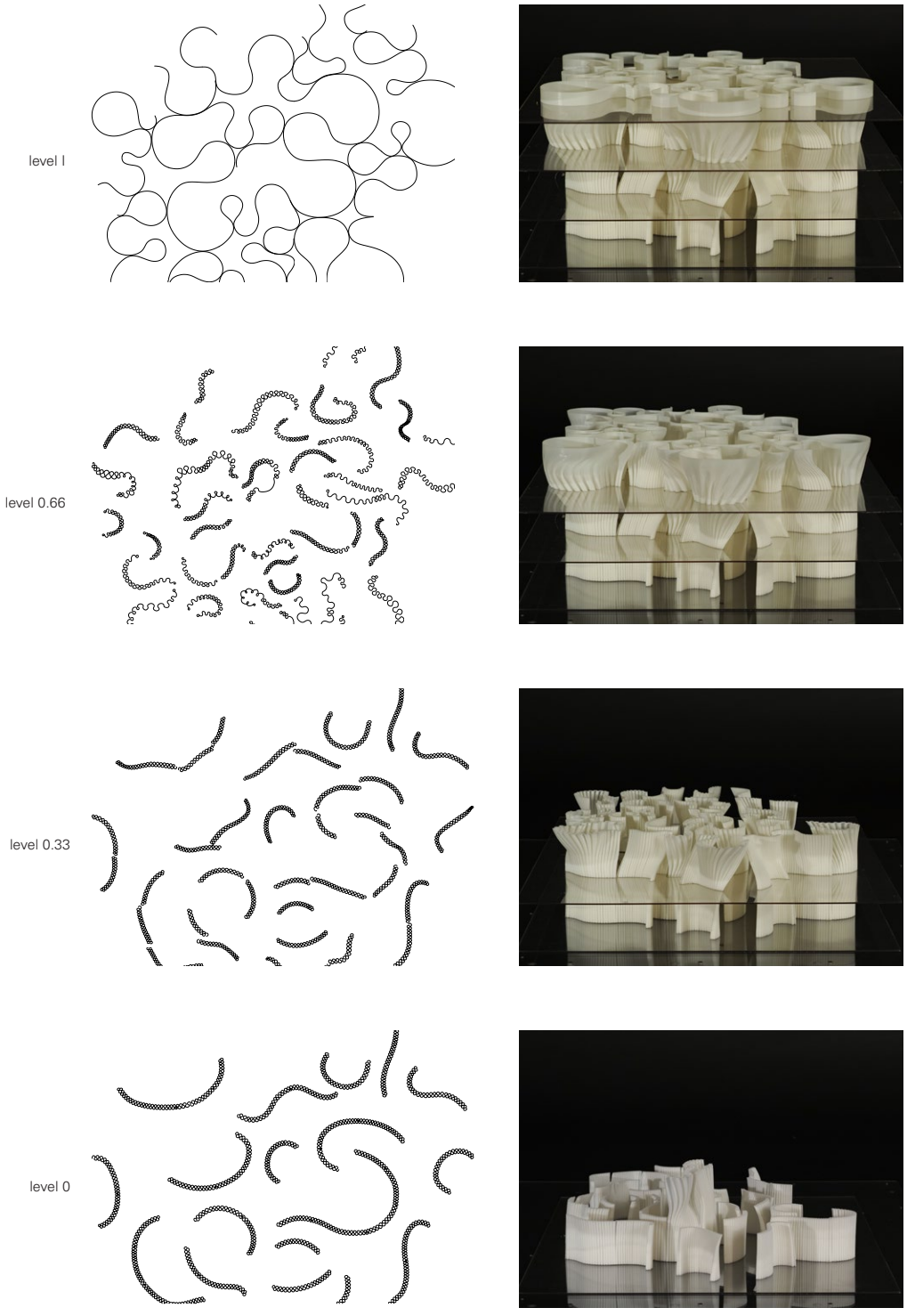


fig 7.05 space IO levels

If we see these lines are transforming from one state to another planarly while projecting vertically, the levels register spaces at different times.

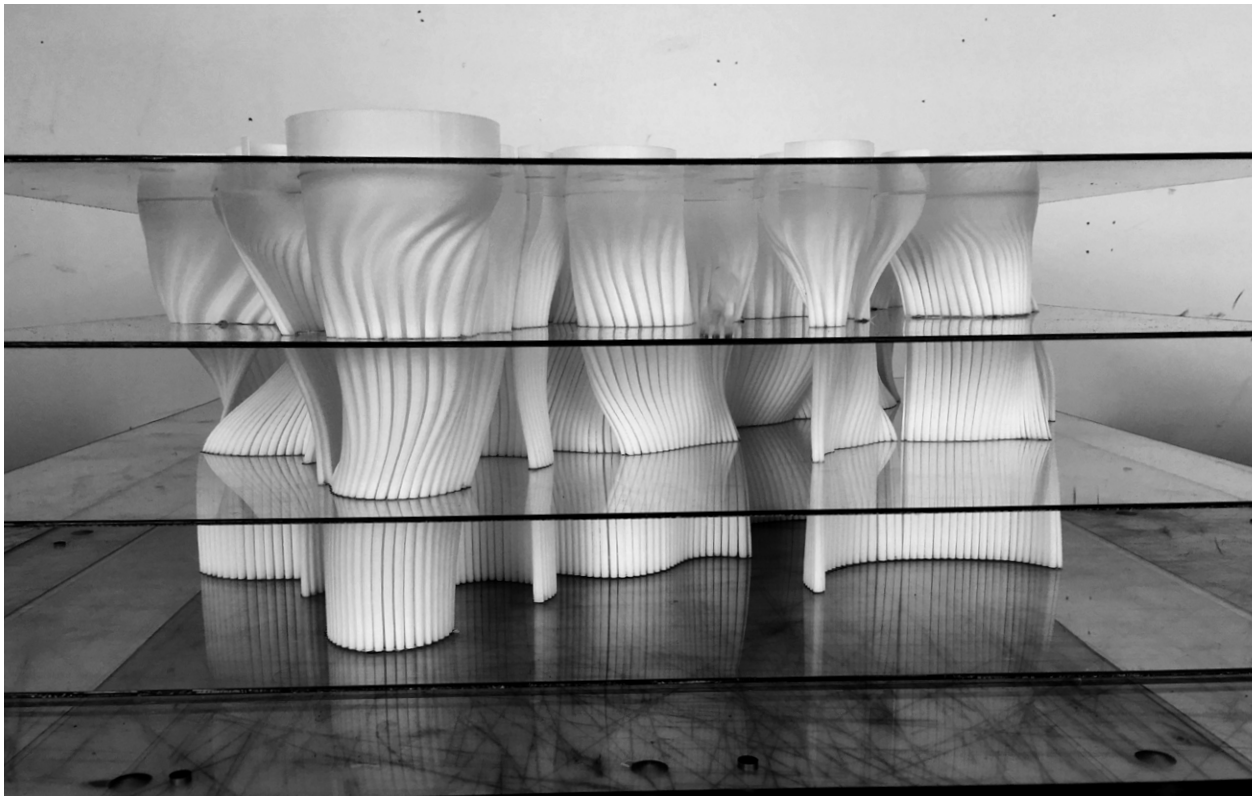


fig 7.06 model of house IO

fig 7.07 plan view looking down from level I

fig 7.08 interior view, level 0

fig 7.09 interior view of space IO, level 0.33

fig 7.10 view of the flowing vertical walls between levels 0.33 and 0.66

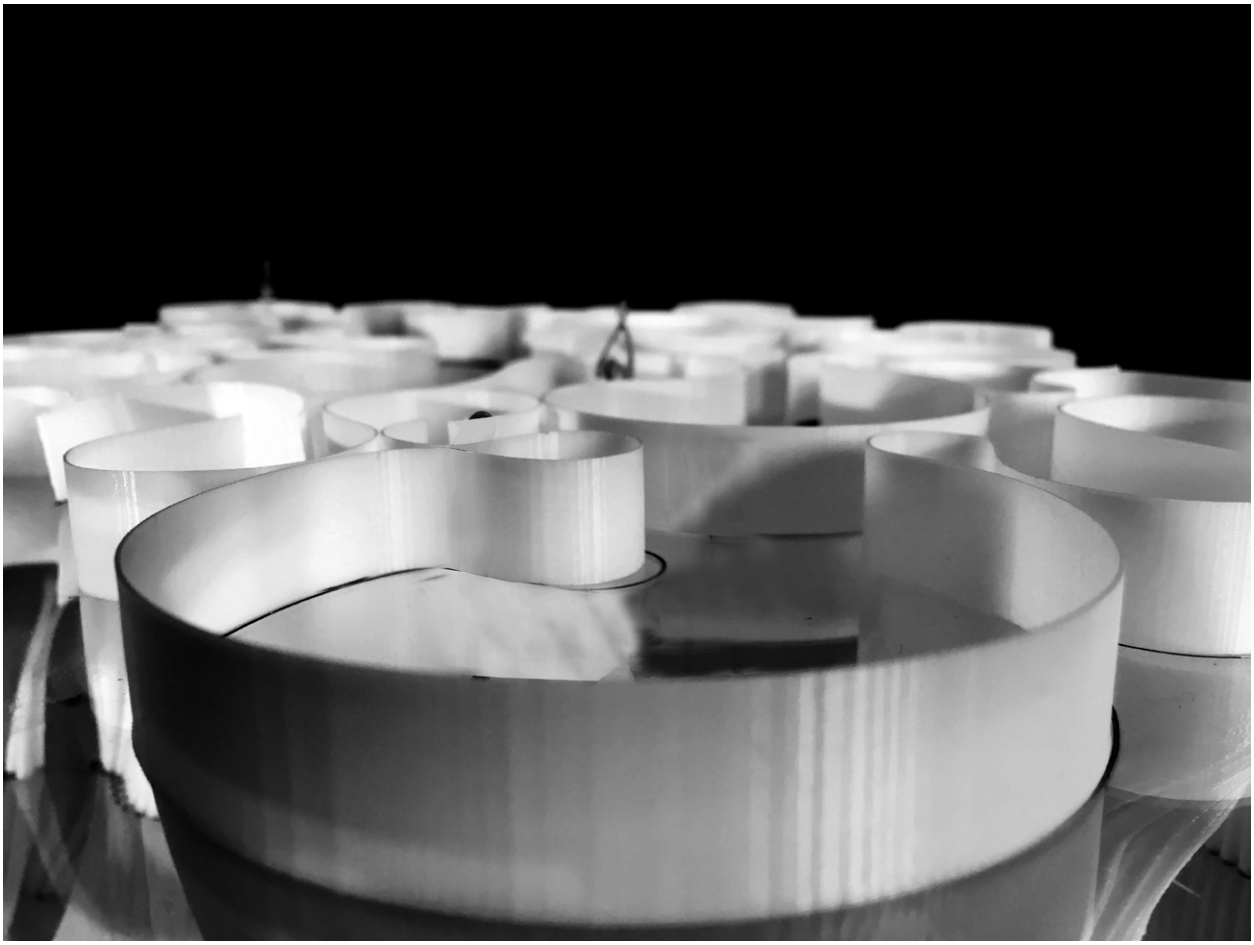
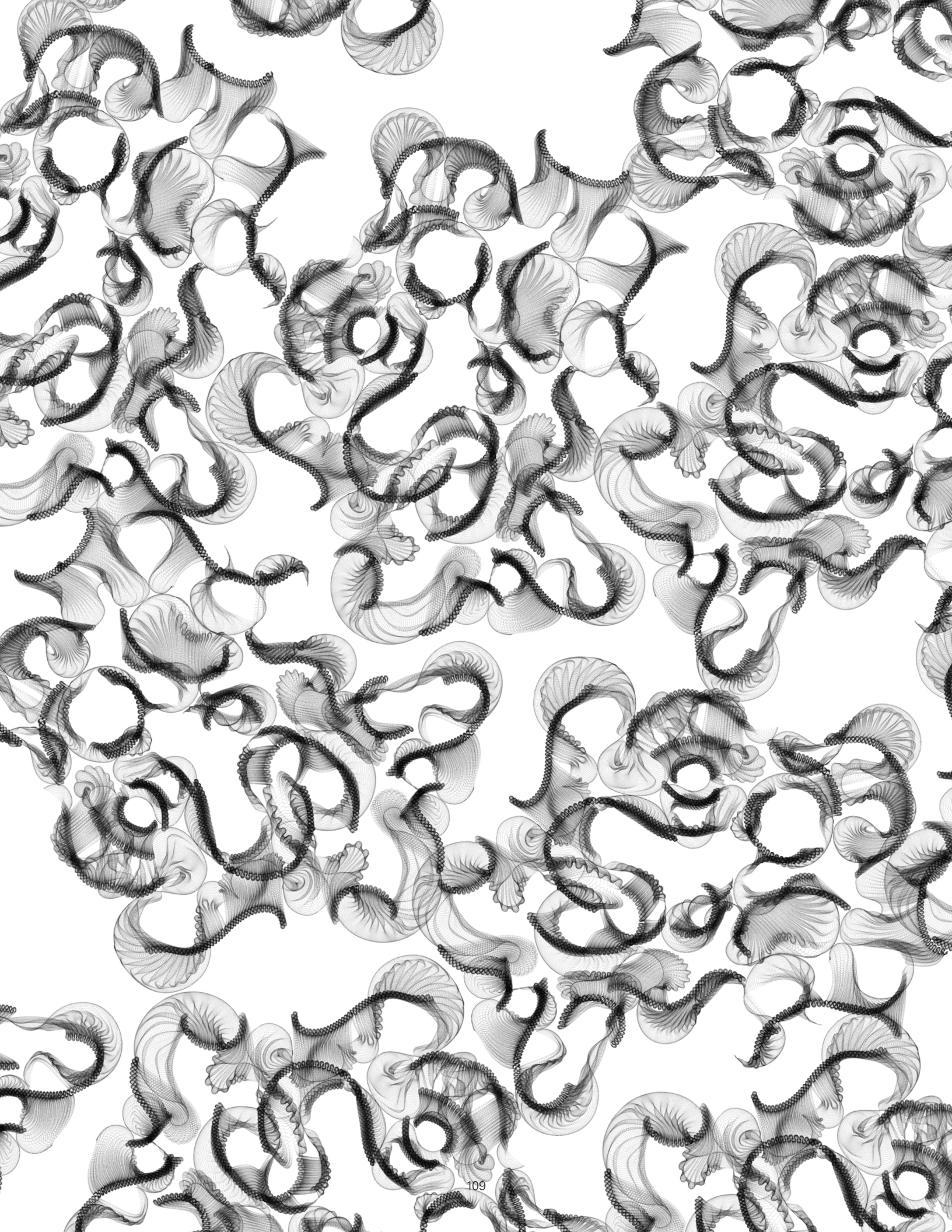


fig 7.11 view of level I



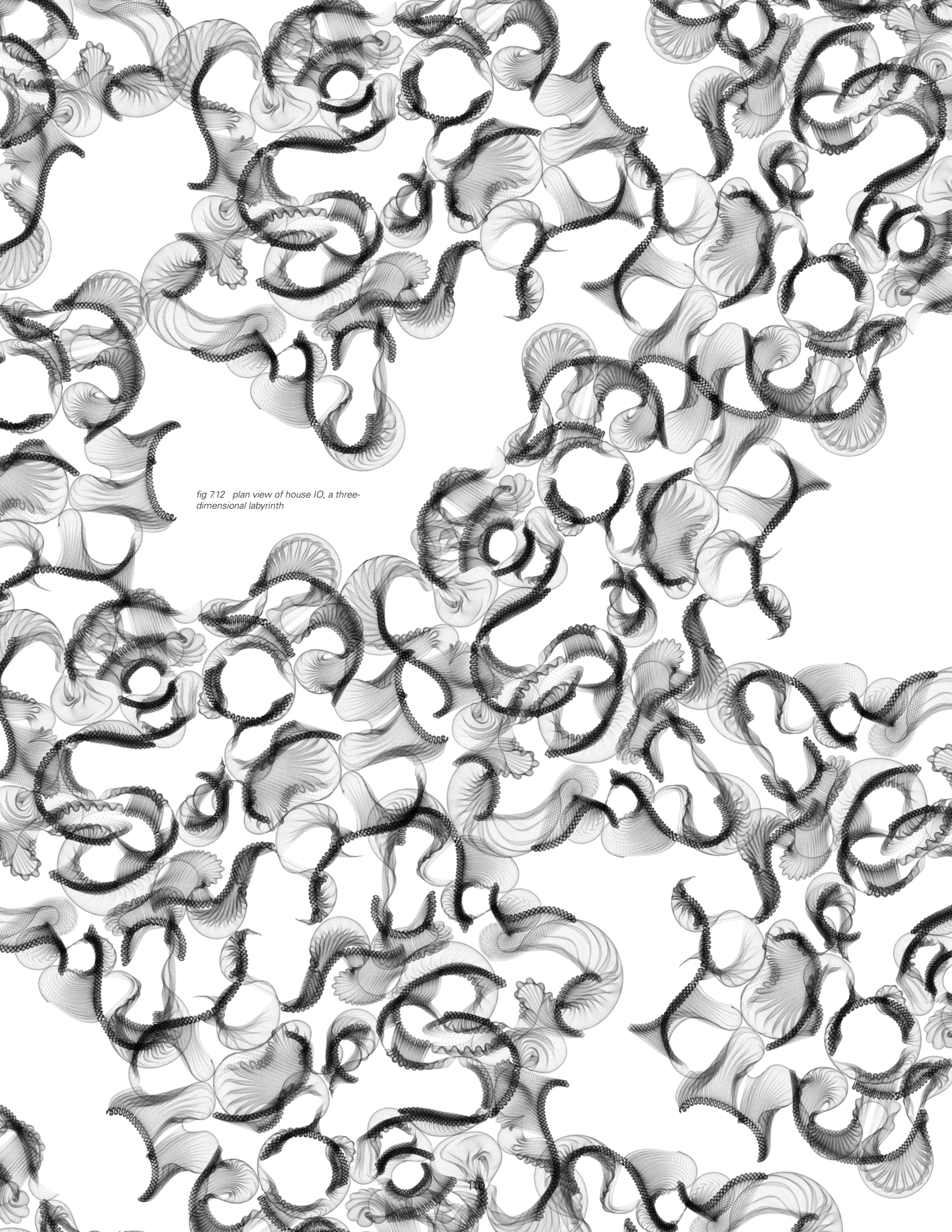


fig 7.12 plan view of house IO, a three-dimensional labyrinth

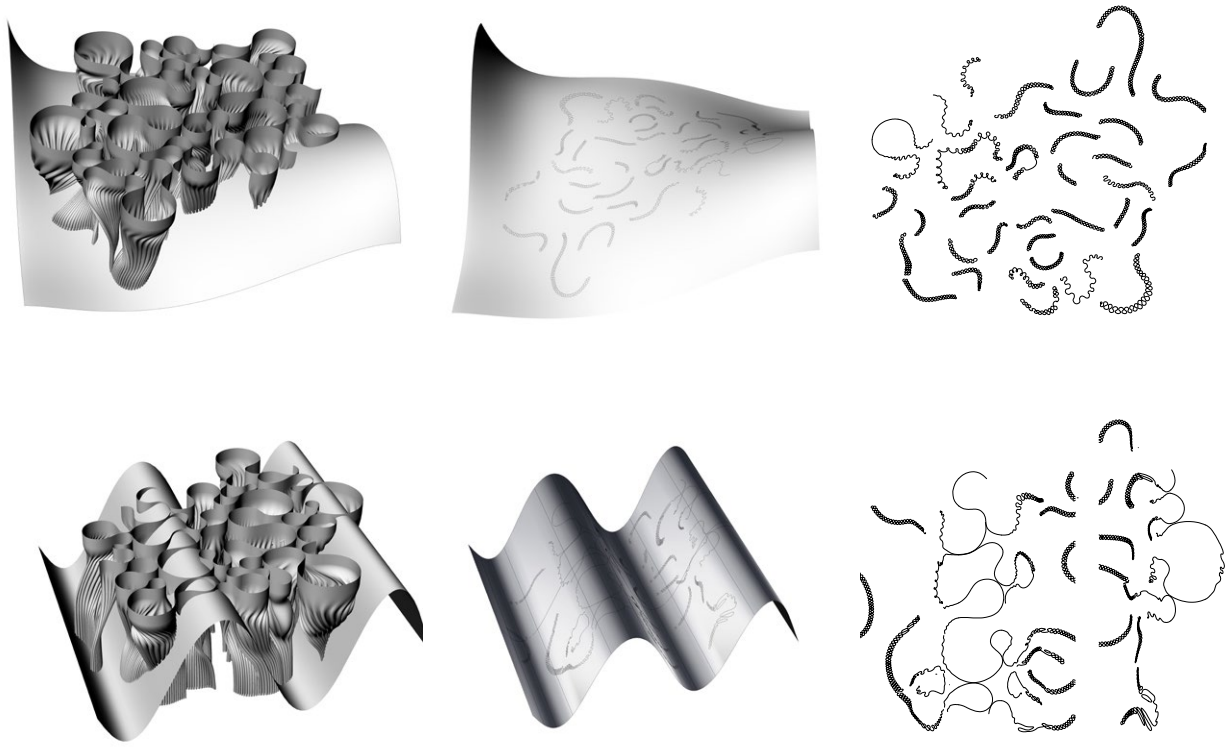


fig 7.13 future iterations: folding planes

X6 Reflection

In exercise 4 and 5, the spatial gradient, from private to public, is horizontally framed. In exercise 6, by superimposing open (public) and closed (private) on top, one moves vertically to negotiate the level of privacy. The plates intersected in between the two states create intervals of common planes.

Whereas lines form boundaries on a plane, the horizontal plates form boundaries in space, creating intervals along the vertical axis. The 'jumps' between the levels can be interpreted similarly to the jumps by electrons in hydrogen atoms between their orbital states. When a hydrogen atom absorbs energy, the electron jumps to a higher orbital level. In the higher orbitals, the electron is less stable, much more energized, and when permitted, will release the energy back to the environment, and jumps back to the lowest possible state. Similarly, we transition from our private space, where we are at our most natural and unconscious state, to increasingly public spaces, where it requires us to be more aware, and return back to our private space each daily cycle.

How this 'jump' might occur in this exercise is not fully explored. Currently, there are 'holes' on the plates that resemble 'wormholes', whereby the act of jumping or leaping outside of one's own dimension is assumed to be done through technological accomplishments (e.g. ladders, stairs, elevators, jet packs).

Human beings are rather restricted in vertical movement. While we exist in a world of three dimensions, gravity locks our vertical axis into a singular direction: up/down. Unlike birds (and aircraft pilots) who can freely move in 3 dimensions (pitch, yaw, and roll), or ants, who despite being two-dimensional beings can orient their dimension along any axis (e.g. traversing along a ceiling), our vertical movements are always restricted to one axis. Unless human beings grow wings, on earth we will always rely on technological means to ascend upwards.

Possible directions for further exercises could be exploring superpositions of other patterns and typologies, while exercise 7 could be an exploration on folding the horizontal planes so that a single plane cuts through different levels while being a continuous surface. By folding, a single plane cuts through different stages of the line gradation. Exercise 7 would be a dramatic departure from all previous exercises, as the printing method has so far only been investigated with lines drawn on a flat plane. Exercise 7 would require an extended working method that allows printing in three axis all at once, as the planes of intersections would no longer be flat.

Conclusion

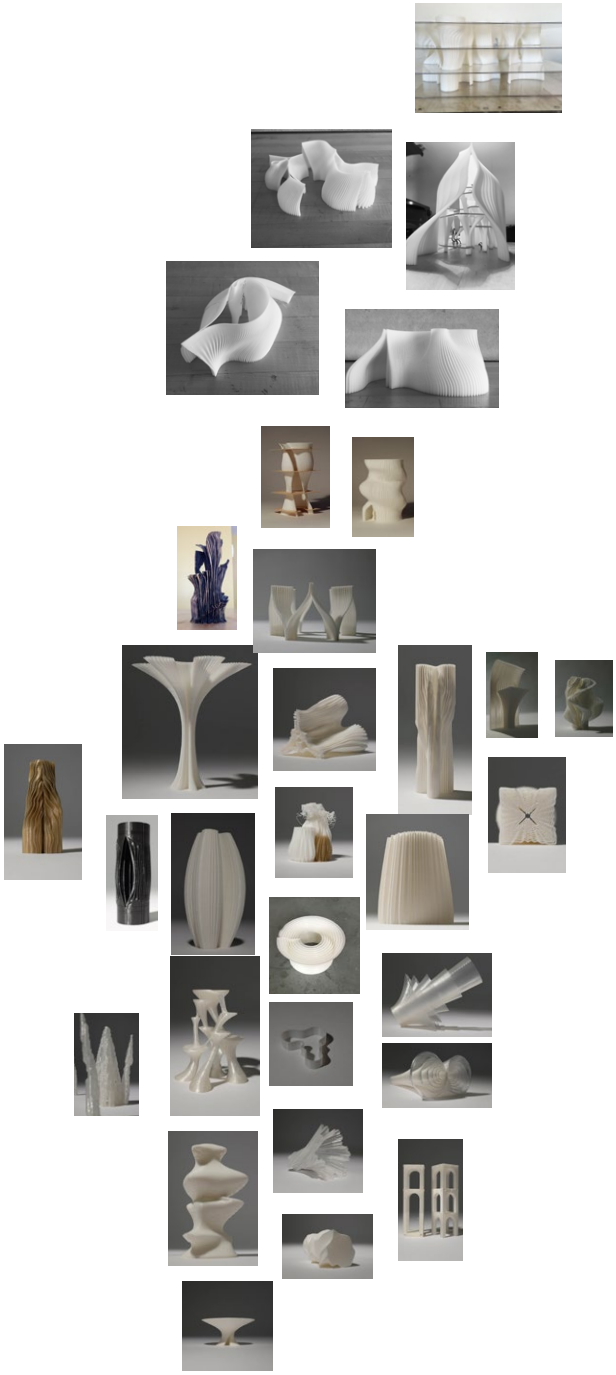


fig 8.01 images of the prints laid out in roughly chronological order

There is no end to the exercises. They could go on forever. As the exercises continue on, they would look less and less like the earlier exercises as some ideas are subsequently dropped off while new ideas are introduced.

The goal of the thesis was not about stumbling upon some hidden knowledge or finding something useful/functional through explorations. Rather, it was to explore digital design and fabrication as a means of expression through sketching spatial ideas using a 3D printer.

Embedded within the 3d printed objects are countless inspirations, some direct while other subconscious. From D'arcy Wentworth Thompson's On Growth and Form, to Graham Carin-Smith's hypothesis of emergence of DNA from inorganic crystals to organic polymers, Valentino Braitenberg's thought experiment 'Vehicles', Lars Von Trier's limitation-based filming technique Dogme 95 and use of imaginary sets using lines in Dogville, Gaudi's formal expression of religious ideology, Alan Turing's reaction-diffusion equation and emergent properties of simple rules, semiotic logograms of Chinese calligraphy, line drawing of the world of the dead by the indigenous Chukchee, the natural phenomenon of crown shyness of camphor trees, Abbot's satirical commentary Flatland, and the literary exploration of labyrinths by Jorge Luis Borges are just some of the influences that intertwine within the models, drawings, and the prints throughout the thesis. Other cursory influences are the analysis of the contemporary consumerism trance by Slavoj Zizek, psychoanalysis of Tarkovsky's Solaris, the emergence of urban horror myths of modernist architecture in the film Candyman, Yona Friedman's cartoons of mega cities, and Deleuze's fold and rhizomatic theory on spatial rhythms.

The majority of drawings and prints took place within a period of 6 months. However, trying to explain/express the numerous influences and inspirations as listed above using language and compile it into a book format proved to be extraordinarily challenging. Whereas abstract condensation of incongruent concepts expressed using non-verbal means is relatively smooth in one's mind, as one could argue such is the process of creativity, then to bring out that expression through language, precise and unambiguous, and book, linear and unidirectional, is an act of translation that I was not able to do so satisfactorily. In the end, the thesis is laid out in a roughly chronological order, although this is not entirely an accurate representation of the evolution of the exercises as many of them were imagined in parallel/concurrently.

"Medium is a medium is a medium, and therefore cannot be translated." - Kittler[1]

As digital fabrication continues to evolve and mature, it is very possible that 3d printing and other additive manufacturing will replace a large portion of human manual labour in architecture, as it has already begun in other disciplines.

This does not mean the complete disappearance of human involvement in making, but rather, that the gap between the maker and the object will be reduced, allowing the maker to articulate the spatial and architectural expressions more personally and clearly.

The future of 3d printing probably will not be what is available now or even similar in approach and workflow. For example, Neri Oxman's silkworm pavilion uses silkworms as an idea of what a future 3d printing technology may become, something much more organic and even self-guiding.

The focus of this thesis was to explore and investigate new mediums, define critical boundaries, and to work within the boundaries to give rise to forms. Whatever the future technology may be, it is the hope of the author to approach the medium with same respect and rigour to let each project be a whole that is greater than the sum of individual parts.

1 'Diagrams Matter', pg 17

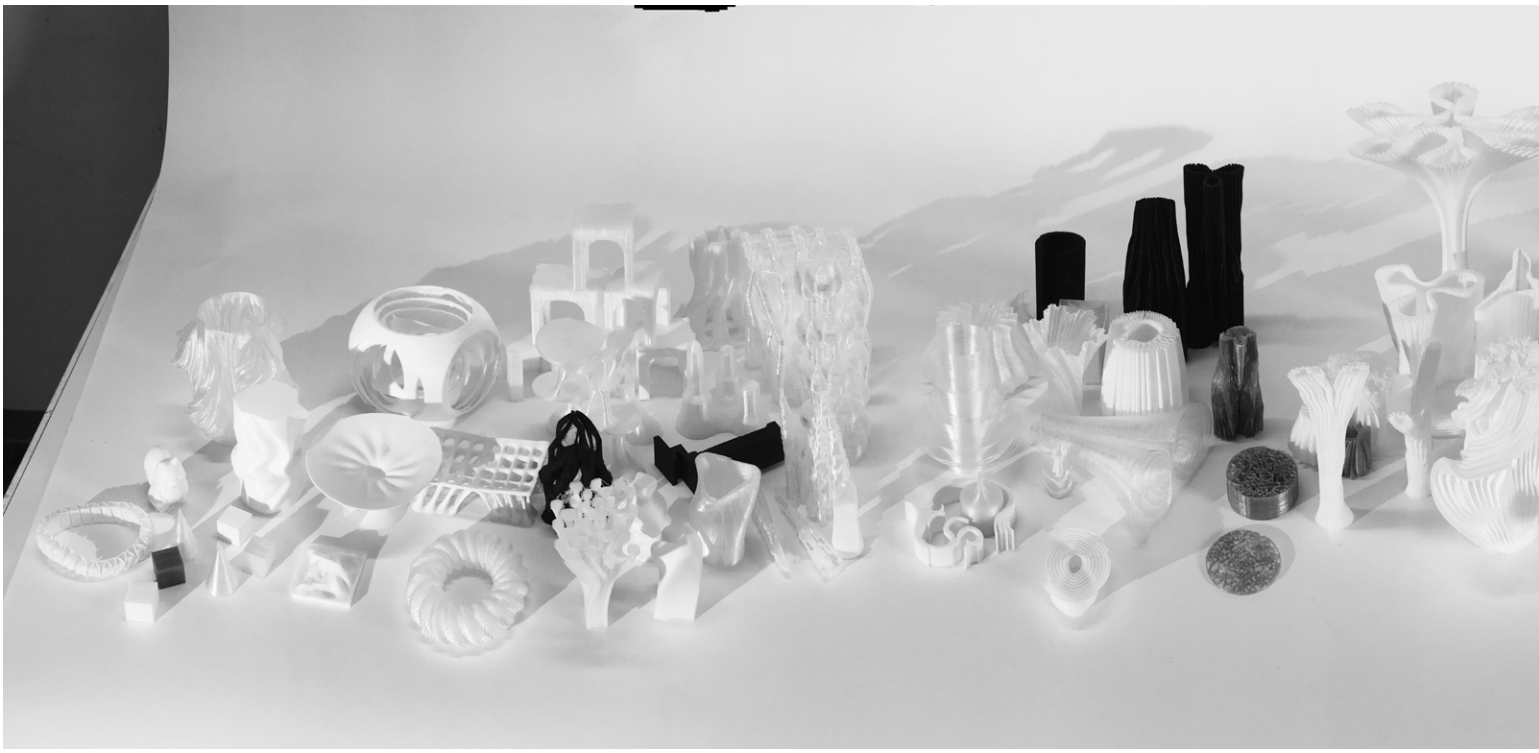
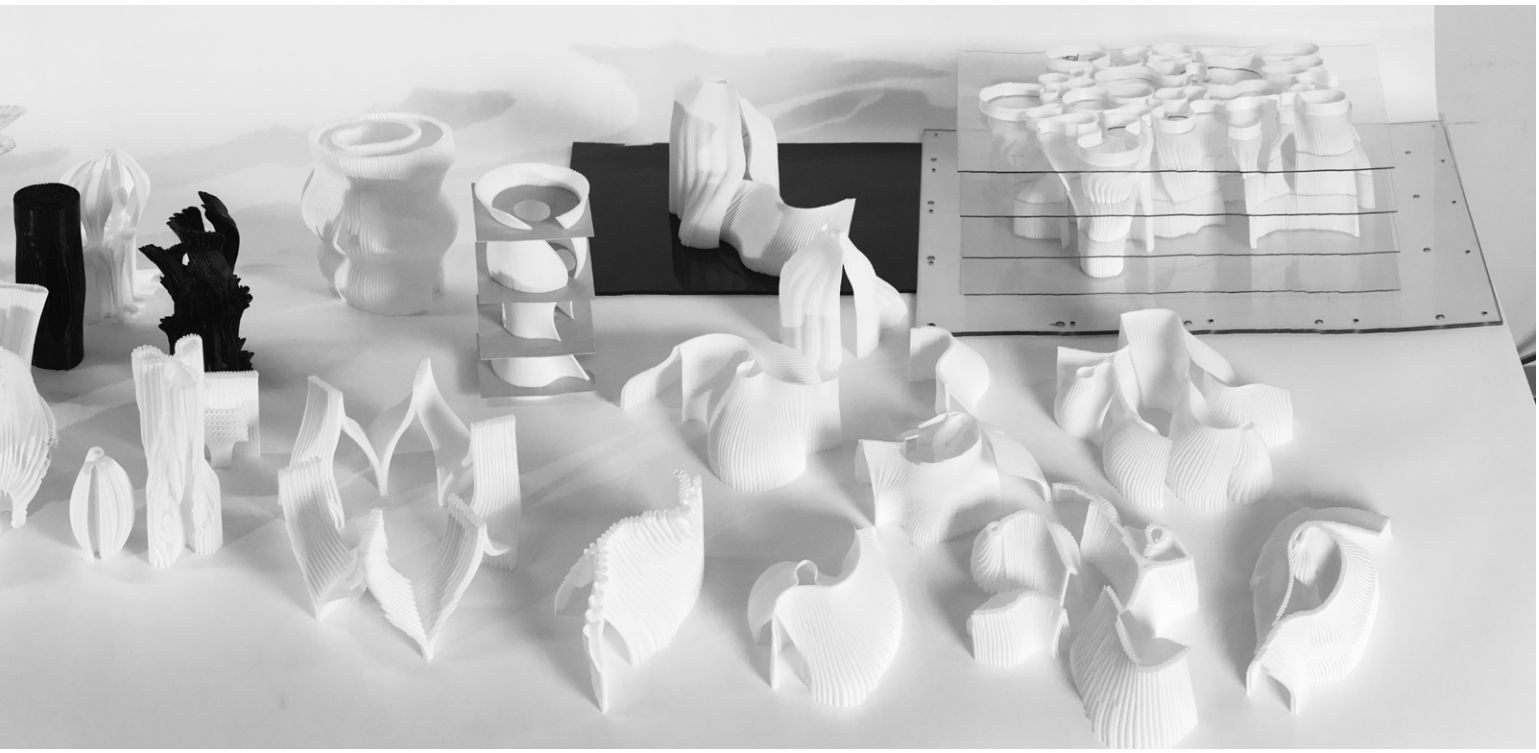


fig 8.02 all the printed models photographed together arranged in chronological order, showing the development of the formal language



Epilogue

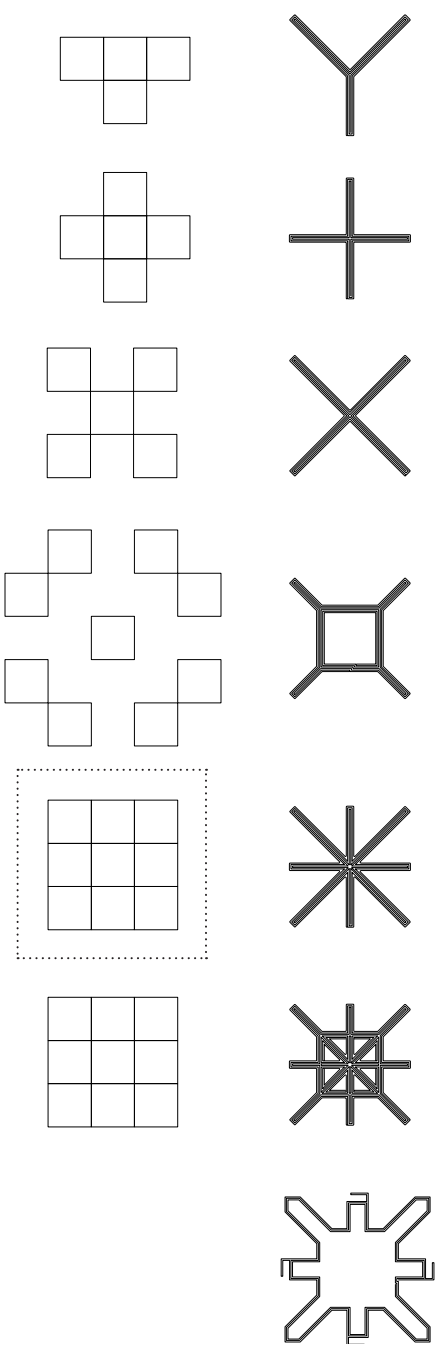


fig 8.03 the movement diagram

fig 8.04 the pieces

A compact chess set

After core thesis explorations were conducted, as a personal project a chess set was designed with techniques developed throughout the thesis. Whereas the thesis explores establishing boundaries in infinity, the game of chess has established rules.

Using lines, each piece is designed to reflect the movements and restrictions. The pawn, with the most restricted movement, is the simpliest in form. The 'king' piece is a superposition of all the previous pieces.

The grid of the board is the negative of the 'king' piece, which thereby also accepts all previous pieces. Small hooks at the end of the grid pieces allow them to be joined together to create a field. The grids are permanently joined together at 2 x 8 grid a group of 4. When the game is finished, all the pieces and the grids can be stacked on top to be stored.

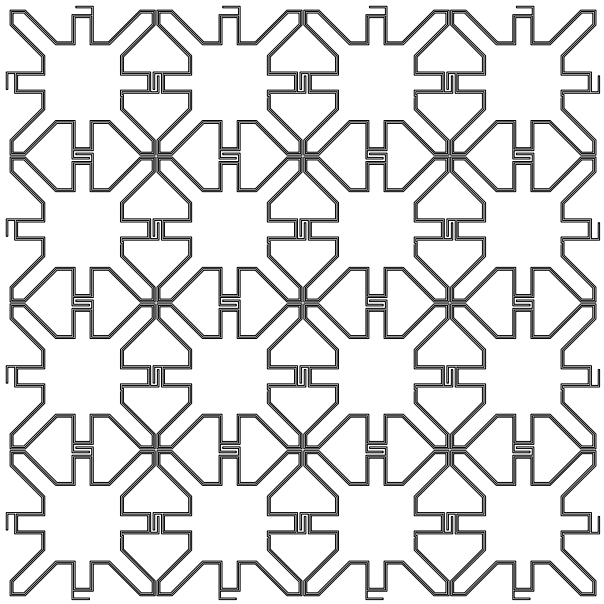


fig 8.05 the grid

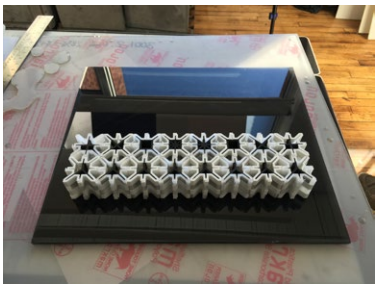


fig 8.06 packed

fig 8.07 unfurling

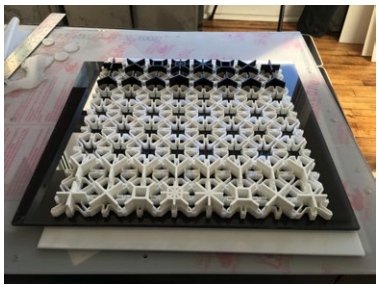


fig 8.08 unpacked

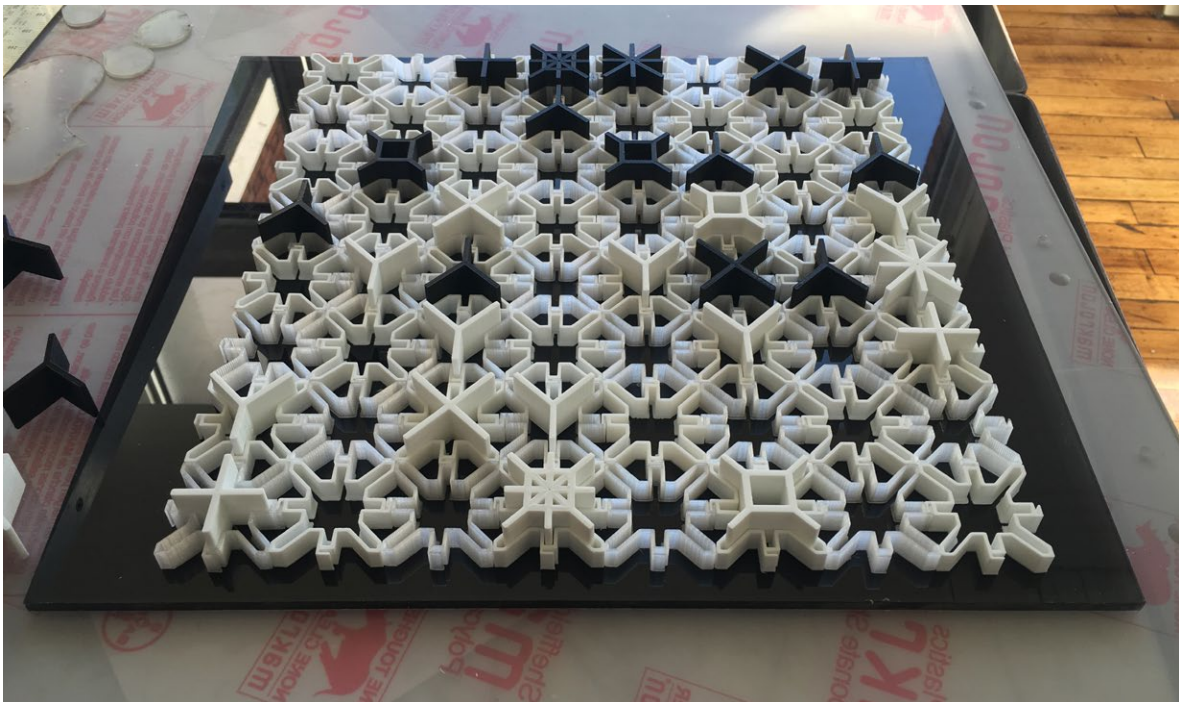


fig 8.09 play

FAQ

Why focus on lines as opposed to planes and volumes in the thesis? Why are they curves, and not straight lines?
Lines are one-dimensional information and therefore, can be easily translated from one medium to another without loss of information. Lines are medium independent, as it is a tracing of a point in motion. There is only 1 correct straight line. Any line that deviates from the straightness is not a straight line. Similarly, there is only 1 correct 90 degrees angle. Curves, on the other hand, are free from correctness; there is no right curve. As well, extruded curves become self-supporting.

Why only use double fold for rigidity?
The double fold is a quick way of generating a thickness for a given curve in a continuous motion. The double folds become cylindrical tubes when extruded, like a flower stems, giving the curved vertical structural stability.

Why not other folds?
Other folds have been quickly looked at, but the double fold is one of the easiest ways to give any curve (within the scope of the thesis) thickness.

Why not folds of different scale?
The 3D printer extrudes lines at 0.35mm width. This became the standard unit which set the scale of all the models. A double fold of 4mm in overall width was a good fold to line width ratio. Larger folds start to become structurally unbalanced with the 0.35mm line width.

Why plastic, why not other materials?
The material used is a PLA filament that is readily available to consumers. At the time of the thesis, there are many interesting materials, such as dissolvable filaments (HIPS), flexible filaments that can bend, wood-infused filaments that appears like wood and can be sanded, and even metal-infused filaments that can be polished. As well, with modifications to the 3d printer, paste materials such as clay, ceramic, and drywall compound, could be used to print lines.

The plastic filament in the thesis represented a 'meta-material', an all-purpose material to render lines as a physical medium. As the thesis is not an investigation in materiality, or a prototyping of a functional object, the white PLA was a suitable and affordable solution.

Why is the material white?
White is simultaneously nothing and everything. For example, a white light is the mixture of all colours. At the same time, white surface allows every other colour on the surface to be observed unbiased. White is an expression of 'all potentials'.

Why does X3 and onward explore infinite white plane as the site?
The infinite white space is not a place of nothingness. Rather, it is a place of maximum potential and maximum entropy; anything can happen. Architecture as a framing device is to reduce the maximum potential and entropy to micro potentials and cohesions through limiting possibilities of events such that desired events can occur without being imposed by undesired events.

Why is the site flat?
Flatness, or the erasure of topology, is an expression of maximum potential and removal of a foreign influence on the subject. The desire for the flatness can be seen even in the prehistoric times in the cave paintings of Cheveaux, where the cave painter erased the surface features of the cave to reveal a smooth and whiter rock surface beneath. Similarly, many interfaces for input, whether it be paper or computer screen, are flat, because it is not the role of the interface to influence the input.

Architecture rarely occurs on flat land. Architecture must contend with the topological and topographical features of the reality. However, as this thesis is more of a sketch of imagination, the flat infinite white space is the third dimensionalization of the white paper.

The strictly planar approach in the thesis is one that acknowledges that gravity sets a universal directionality for all human beings on earth. For example, there is only 1 correct way of hanging a painting on a wall. All human beings are bound by the gravity, and the vertical movement is always perpendicular to the center of the earth. The flatness is the suppression of all external influences but one that also does not escape the gravity.

Why explore 'house' on infinite white plane?
"If anything is described by an architectural plan, it is the nature of human relationships." Robin Evans, Figures, Doors and Passages, pg 73

"Can there be anything like an "everyday architecture," similar to the notion of "everyday life"? One must first ask, what is everyday life? How does it manifest itself? Does everyday life have a form or is it formless?" Georges Teyssot, Boredom and Bedroom, pg 45.

"Habitations are actually places for long habits, places where habits may be inscribed in a space that awaits them." Georges Teyssot, Boredom and Bedroom, pg 53

Where is the 'washroom'?
Even in the space, there are toilets. However, they are not really washrooms. Washrooms are a modern convention that does not hold certainty in the future of architecture. This is not to say that excrements and bowel movements will be circumvented in the future, but that they are not one of spatial necessities. For example, one can imagine Neri Oxman's spacesuits as an external extension of our colons that could process our bodily waste into 'gold'.

What is the significance of labyrinths?
For me, a labyrinth represents anti-consumerism, anti-military, anti-corporation 'machine'. It is the unconstrained, unconditioned and undefined place where any attempt to subordinate large area by force is futile. It can only be explored by exploring, by recognized and by recognizing, rather than to claim knowledge through proxy actions such as 'purchasing'. As well, the labyrinth, while confusing to foreigners, is in fact a map to the occupants like a native traversing in forest who knows exactly where he is through the density and types of trees or sailors who knows where to go by reading the constellations in the sky. A labyrinth is a place where ownership is through knowledge rather than power.

What about issues of scale?
"A diagrammatic practice is relatively indifferent to the specifics of individual media." Stan Allen, 'Diagrams Matter'
This thesis strictly worked with the scale of the tools available: the 0.35mm thickness of lines, the bounding box of the printer volume, and the infinity of virtual software. The thesis looks to work with the given limitation rather than inferring a potential projection. The thesis explores strictly at a diagrammatic level, which is scaleless. Therefore, it is the machine, the final output, that determines the scale, which does not affect diagrams as they are medium-independent.

Why does the "X" in the chapter titles stand for?
X = exercise/exploration/experiment

Why is slash, "/", used as a punctuation throughout the thesis?
The slash (and-or) may be considered an informal punctuation in academia as unnecessary and could be better expressed though another words. However, there are moments in the thesis where the author feels the thing to describe is precisely the "and-or" relationship rather than 'and' and 'or' as a separate junction. For example, on page 31, critical sections are referred to as 'moment/movement'. The slash suggests that a section can either be a moment in time or a movement in time, or simultaneously both. The ambiguity of the slash blurs the distinct meanings of vocabularies which the author feels it reflects the message more closely to the statement.

Works Cited

Abbott, Edwin A. Flatland. New York: Dover, 1952 (first publication, 1884).

Agamben, Giorgio. What is an Apparatus? Translated by David Kishik and Stefan Pedatella. Stanford: Stanford University Press, 2009.

Baudrillard, Jean. Simulacra and Simulation. Translated by Sheila Glaser. Ann Arbor: University of Michigan Press,1994.

Bogner, Dieter and Peter Noever. Frederick J. Kiesler, Endless Space. Ostfildern-Ruit: Hatje Cantz Verlag. 2001.

Borges, Jorge Luis. Ficciones. Translated by Emece Editores S. A. New York: Grove Press, 1993.

Bouman, Ole and Roemer van Toorn. The Invisible in Architecture. London : Academy Editions: 1994.

Buchanan, Ian and Gregg Lambert. Deleuze and Space. Toronto: University of Toronto Press Inc, 2005.

Braitenberg, Valentino. Vehicles. Cambridge: The Massachusetts Institute of Technology, 1994.

Cache, Bernard. Earth Moves. Translated by Anne Boyman. Cambridge: Massachusetts Institute of Technology, 1995.

Carpo, Mario. The Alphabet and the Algorithm. Cambridge: Massachusetts Institute of Technology, 2011.

Deleuze, Gilles, The Fold: Leibniz and the baroque. Translation by Tom Conley. Minneapolis: University of Minnesota, 1993.

Eisenman, Peter. House X. New York: Kenner Printing Co., 1982.

Emmer, Michele. Mathland: From Flatland to Hypersurfaces. Translation by Stephen Jackson. Basel: Birkhauser, 2004.

Evans, Robin. Translations from Drawing to Building and Other Essays. London: Architectural Association, 1997.

Friedman, Jonathan Block. Creation in Space: Vol. 1: Architectonics. Dubuque: Kendall/Hunt Publishing Company, 1989.

Friedman, Yona. Pro Domo. Barcelona: Actar, 2006.

Fujimoto, Sou. Futurospective Architecture. Koln: Verlag der Buchhandlung Walther Konig, 2013.
Fry, Ben and Casey Reas. "Processing: A Programming Handbook for Visual Designers and Artists." Cambridge: MIT Press, 2014.

Hensel Michael, and Christopher Hight and Achim Menges. Space Reader: Heterogeneous Space in Architecture. Chichester: John Wiley & Sons Ltd, 2009.

Ingold, Tim. Lines: a brief history. Oxon: Routledge, 2007.

Scheer, David R. The Death of Drawing. Oxon: Routledge, 2014.

Truby, Stephan, Hans Werlemann, Kevin McLeod and Rem Koolhaas. Corridor. Italy: la Biennale di Venezia, 2014.

Journals

Allen, Stan. "Diagrams matter." ANY, No. 23 (1998): 16 - 19.

Kittler, Friedrich and Matthew Griffin, Susanne Herrmann. "Technologies of Writing: Interview with Friedrich A. Kittler." New Literary History, Vol. 27, No 4 (1996): 731-742.

Krauss, Rosalind. "Sculpture in the Expanded Field." October, Vol. 8 (1979): 30 - 44

Teyssot, Georges. "Boredom and Bedroom: The Suppression of the Habitual." Assemblage, No. 30 (1996): 44 - 61.

Vidler, Anthony. "Diagrams of Diagrams: Architectural Abstraction and Modern Representation." Representations, No. 72 (2000): 1 - 20.

Websites

Centre National d'Art et de Culture Georges-Pompidou. "Brancusi's Studio." Accessed August 4, 2016. https://www.centrepompidou.fr/en/Collections/Brancusi-s-Studio

Dillenburger, Benjamin and Michael Hansmeyer. "Digital Grotesque." Dillenburger/Hansmeyer, 2013. Accessed March 9, 2016. http://www.digital-grotesque.com/

Holloway, Adam and Arthur Mamou-Mani, Karl Kjelstrup-Johnson. "Silkworm." Accessed June 22, 2015. http://projectsilkworm.com/

Oxman, Neri. "Silk Pavillion." MIT Media Lab, 2013. Accessed April 5, 2016. http://matter.media.mit.edu/environments/details/silk-pavillion

Richter, Gerhard. "Paintings." Accessed August 7, 2016. https://www.gerhard-richter.com/en/quotes/mediums-3/painting-15

Zizek, Slavoj. "The Thing from Inner Space." Accessed August 10, 2016. http://www.lacan.com/zizekthing.htm

Media

"Candyman." Directed by Bernard Rose. Culver City: TriStar Pictures, 1992.

"Dogville." Directed by Lars Von Trier. Santa Monica: Lions Gate Entertainment, 2003.

"The Matrix." Directed by The Wachowski Brothers. Burbank, The Warner Bros., 1999.

"The Pervert's Guide to Ideology." Directed by Sophie Fiennes. New York City: Zeitgeist Films, 2012.

"Synecdoche, New York". Directed by Charlie Kaufman. Los Angeles: Sidney Kimmel Entertainment, 2008.