The Digital Friend

A conversation between
the architect and its tools

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Thesis project
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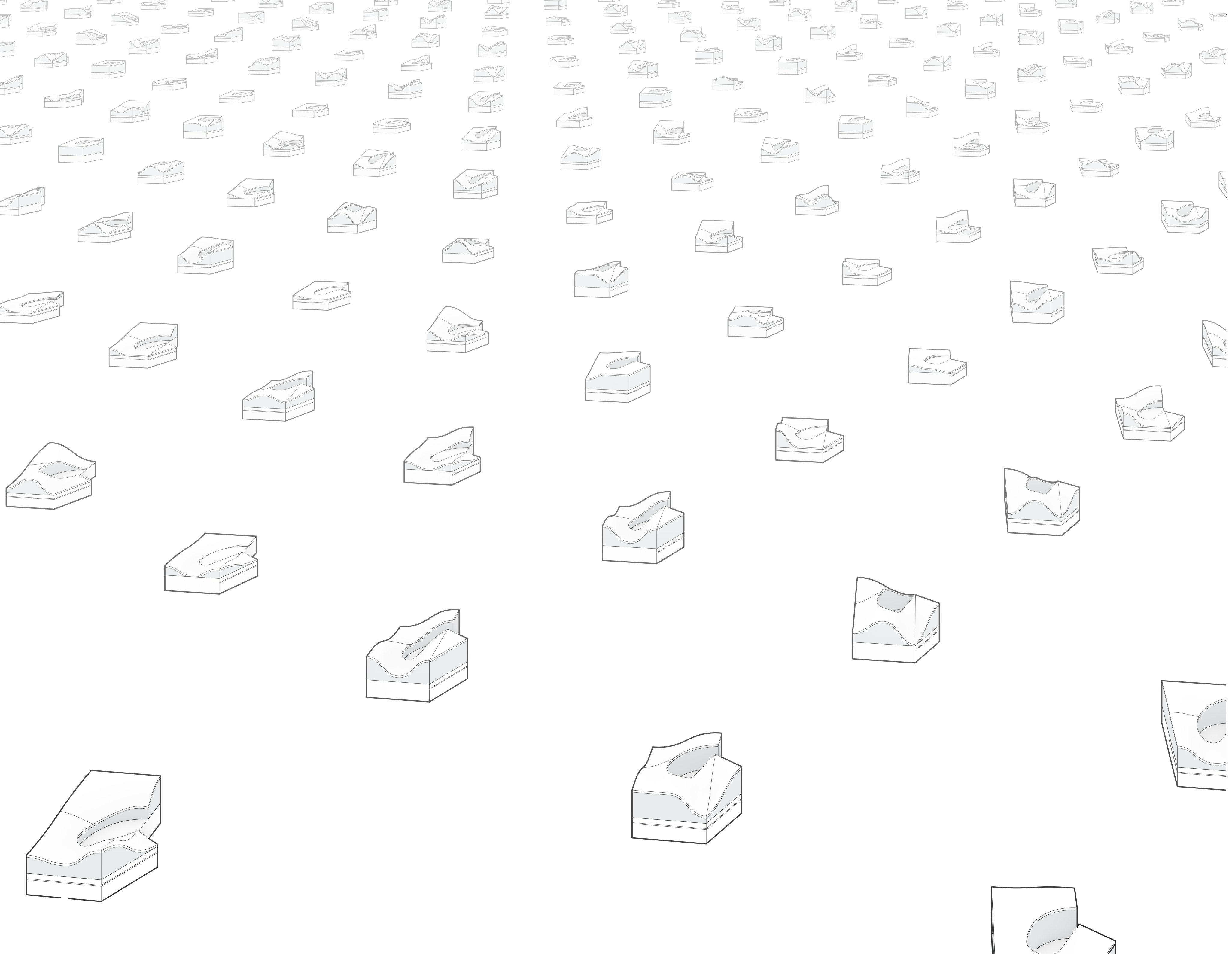

Abstract

This thesis examines the relationship between the architect and its digital tools, from the perspective that technology constantly is evolving. We believe that the architect's relationship with its tools changes with the advancement of technology. That being said, we developed an investigative methodology based on generative design that we later applied to a more conventional architectural project. The implication of a methodology based on generative design, and subsequently artificial intelligence, meant that we could work with data in a completely new way. Instead of sketching with a couple of sketch models, the computer offered us thousands of iterations in which we could pick and choose from. This way of working offered new possibilities, but also challenges, therefore, we also evaluated the methodology and further discussed how we think architects will use new digital technology in the future.

Keywords:
Generative design, Museum, Computation, Algorithm, Evolution, Artificial Intelligence

Acknowledgements

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Stockholm, June 2020
Daniel Norlkrantz & Elias Brulin

Contents

1. Introduction

The architect and the digital tools

It´s the tools that largely define the role of an architect. As new tools continually develop, the role of the architect simultaneously shifts. New technology redefines the act of designing. Working with paper and pen will always be an explorative and constructive act. It is a powerful way to explore design, and there will always be a "special connection between the hand and the pen." In an analog design process, we sketch, and then actively look and evaluate the result. Flaws are removed and strengths refined as we continue sketching. We learn by our mistakes and the design evolves. This process continues until we reach a stage where we are satisfied. With the help of representations such as plans, sections, and elevations, we try to visualize and evaluate the building. To fully understand a building based on drawings requires a great deal of experience and knowledge, but also intuition; how does the shadow fall if I extend this wall? How much heat will I loose with this window area? Questions like these can take a long time to calculate and decisions are therefore often based on a mixture of science and intuition.

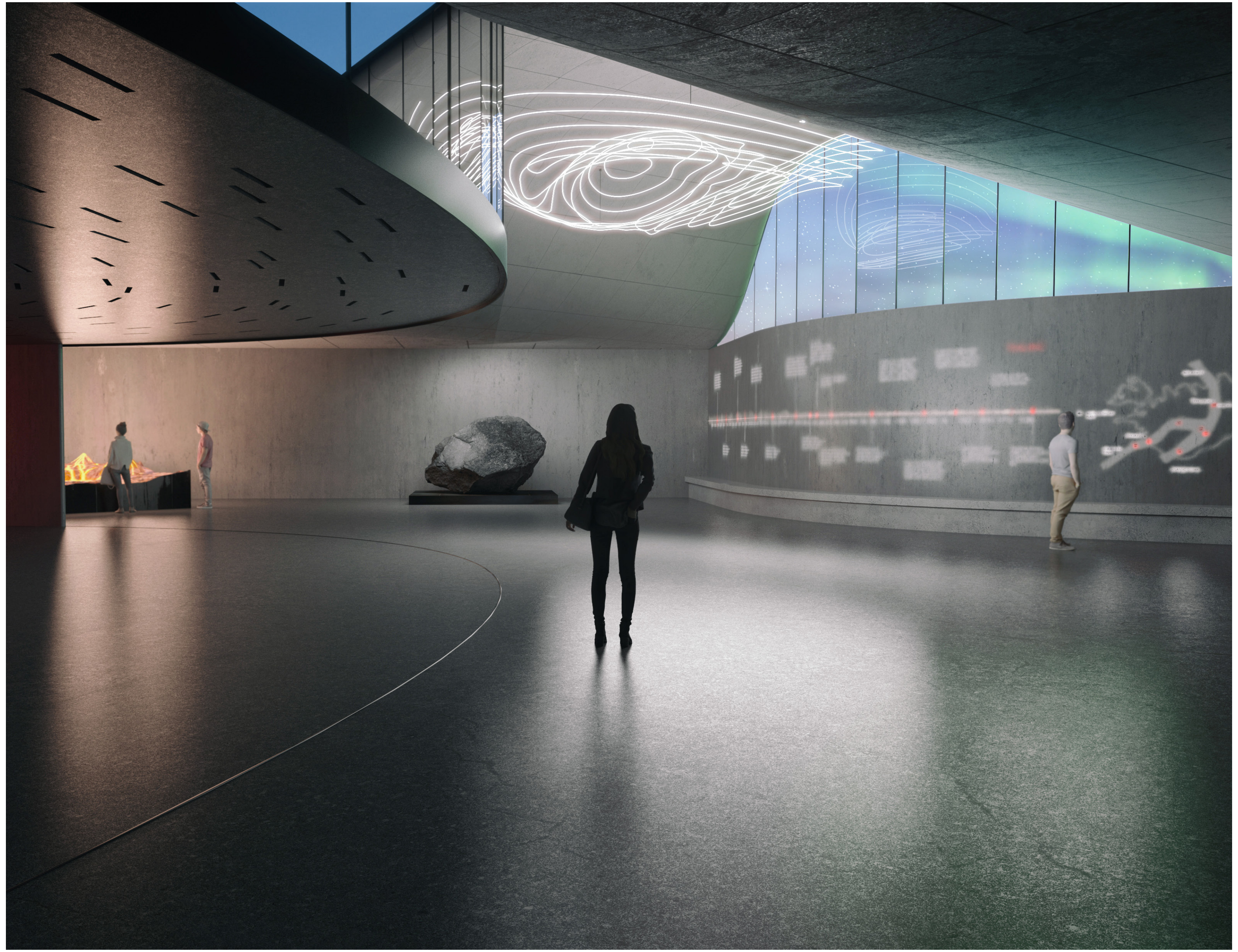
New simulation tools offer interactive information about the building's performance. Feedback increases our awareness during the design process, it helps us make faster and more informed decisions. With generative design, instead of drawing a building and analyzing it in the end, we can reverse the order and instead start at the "end". We start by defining the building's behavior, based on desired objectives. Using algorithms, we can formulate a design hypothesis. The computer then generates thousands of iterations that are optimized for the given objective. The architect actively evaluates the results and modifies the parameters. If there is a special connection between the hand and the pen, we would argue that that also translates to the hand and the computer. And as computers become smarter and smarter, we have to ask ourselves questions like; For how long will we regard the computer as merely a tool? When will we instead consider the computer as a collaborator? What will the consequences of this be? How much control should the computer have over us? And how much should we have over it? We believe the architect's role will go from a creator to a curator. The architect might no longer be the one who actively designs the building, instead, the computer will. If this is true, the architect's main focus will be on dictating the premises.

This essay discusses these issues by proposing a design methodology based on generative design. The methodology is applied to a competition entry for a Volcano Museum in Iceland. This specific competition offered exciting challenges and questions for the subject matter. The result is three main parts of the thesis: The development of a methodology, the application of it to a project, and lastly the evaluation of it. We also discuss the relationship between theoretical aspects and optimization, and how we think we will use digital tools in the future.

Hypothesis

- We put forth that the development of digital tools will allow architects to work within a methodology where the software act as creative collaborator.

The purpose of the thesis is to investigate the implications of generative design in the architectural discipline, and how it will affect our role as architects. We raise questions like; Will the architect go from being a creator to a curator? How do we represent and communicate large amounts of data? What is the relationship between optimization and aesthetics? And how will future implications of digital tools look like?



Interior rendering, Icelandic Volcano Museum.

Design work

This thesis culminated in a competition proposal for a Volcano Museum in Iceland. The competition was announced by the international competition coordinator Bee Breeders, where both students and offices participated.

Although the main emphasis was on the development of a methodology, we felt the need to apply it to a real project in order to validate it.

The two main reasons for choosing this particular competition were that the program was well suited to our methodology as it required specific features that could be optimized: microclimate, light, and views are just a few examples.

We also saw interesting upcoming conflicts between the optimized performance of the building, and the aesthetic aspects of it. A volcano museum in Iceland is very much about the atmosphere and the narrative, which was something we wanted to investigate in relation to the optimized.

2. Background and context

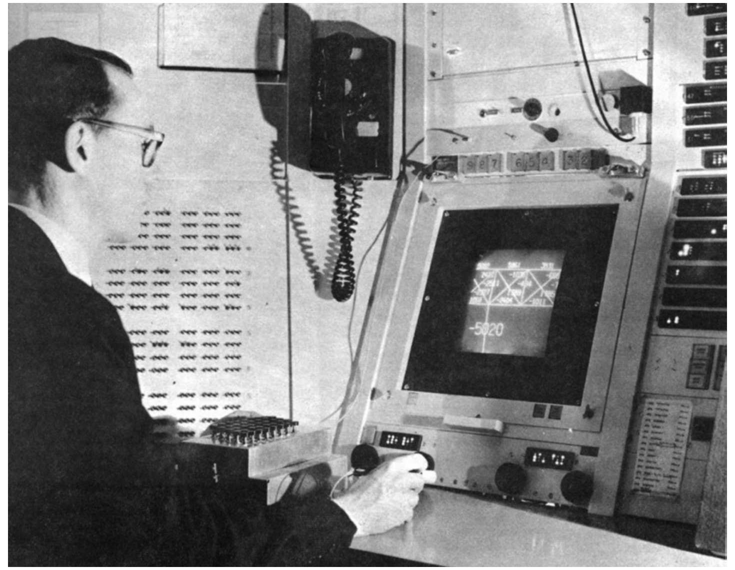
Computerisation vs. Computation

Today, most practicing architects use digital drawing tools to facilitate and streamline their design process. This way of utilizing the computer has been termed computerization. In the case of computerization, the computer is mainly used as a virtual drafting board, but the design process in itself is still relatively unchanged.

The term computation, on the other hand, is used to describe a more complex use of the computer. Here, one uses more of its capabilities. Visual programming software, such as Grasshopper, allows architects to use the computer on a deeper level without any prior knowledge of programming (Peters 2013.1).

Sean Ahlquist and Achim Menges define computation as *'the processing of information and interactions between elements which constitute a specific environment; it provides a framework for negotiating and influencing the interrelation of data sets of information, with the capacity to generate complex order, form, and structure'*(Menges & Ahlquist 2011. 13). Computation changes our relationship with the computer and is in many cases regarded as a novelty within the discipline, while computerization largely is presumed in a modern architectural office.

The use of computers in the discipline can be traced back to 1963 when Ivan Sutherland created the first computer program with an architectural purpose.



Ivan Sutherland and his invention Seketchpad (Vintage news daily 2018).

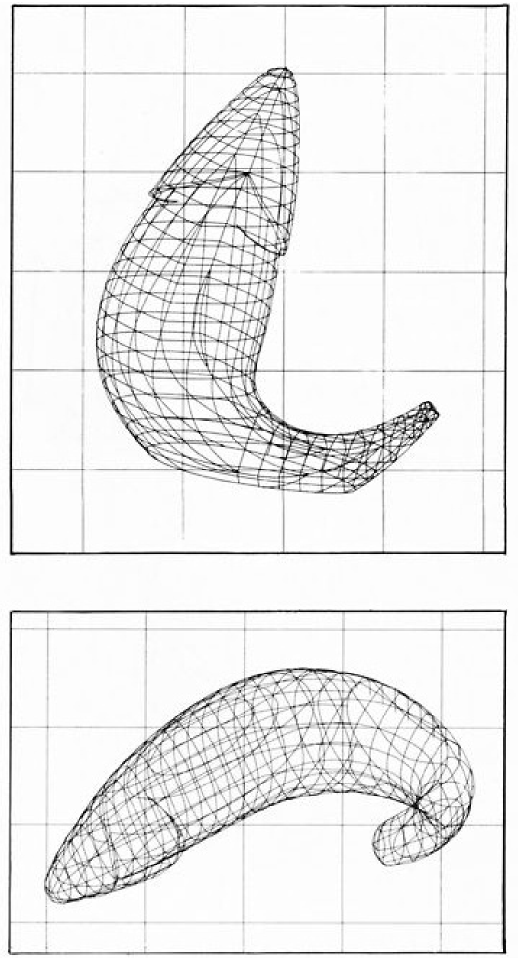
The software enabled the user to draw simple geometries on a computer screen. An important property was the relationship between the various elements of the drawing, a characteristic called associative modeling. Although the technology is long-standing, it was not until the digital revolution of the 1990s that the offices began to use 2D-drawing software seriously.

Computer-aided design can be divided into three historical eras: 2D drafting, BIM (Building information model) and design computation (Peters & Peters 2018. 3).

A simpler version of BIM (Building Information Model) was introduced in the 1980s before digital drawing tools became established. BIM is a digital tool used to manage information in construction projects. It facilitates the design and communication between architects and engineers. In the early 1990s, more and more architectural offices began to use digital drawing tools, which were termed as CAD (Computer Aided Design).

In the late 1990s, architects began borrowing knowledge and software from other fields such as the game development- and aerodynamics industry. Frank Gehry was an early pioneer who borrowed modeling tools from the aerospace industry to find ways to realize his organic forms.

Gehry used a parametric tool developed to virtually model double curved panels for aircraft bodies.This technology was for example implemented in the making of the Golden Fish Sculpture in Barcelona and the Guggenheim Museum in Bilbao (Chang 2015).

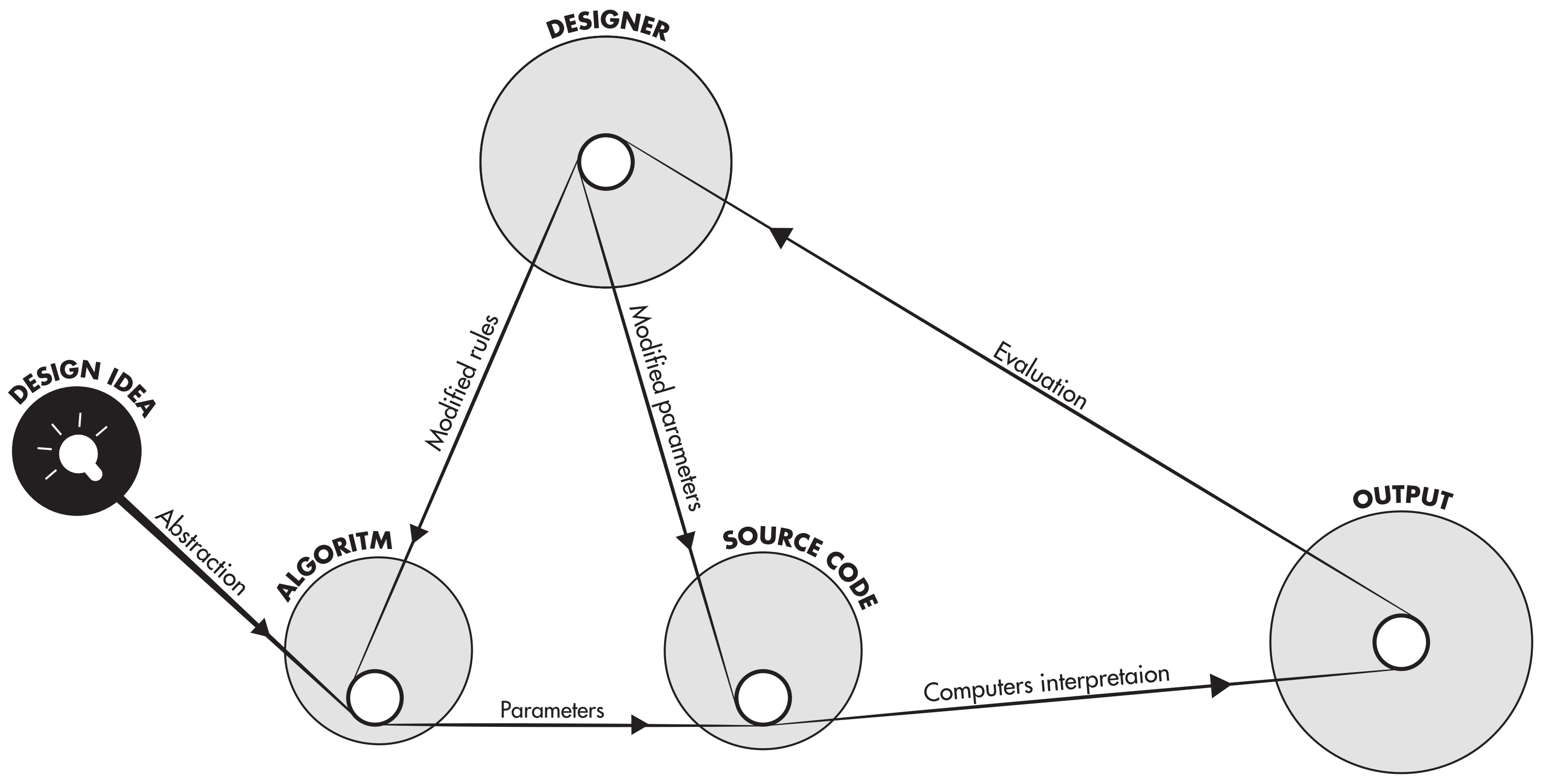


Fish model, Frank Gehry (Archive of Affinities 2011).

Computational design

Computational design is an umbrella term that covers several digital work methods. It is not necessarily synonymous with digital drafting or 3D modeling. Contradictory to traditional methods, in computational design, the architect is not the one in charge of directly modeling the building. Here, the architect rather designs the algorithms and systems that generate the 3D model. This allows the computer to be interactively involved in a new way. By adjusting parameters in the algorithm, the shape and behavior of the building adapt. The software efficiently generates large quantities of iterations of the same building, which the computer then analyzes based on selected factors. The architect receives feedback and modifies the algorithm. The computer interprets the updated algorithm and performs a new analysis. This can be repeated an Infinitum, thus making this process circular (Chalmers 2018).

Since the Industrial Revolution, we have relied on mass production where large quantities of standardized products have been manufactured. This homogeneous standardization has defined our architecture and limited our ability to create bespoke designs. When we combine computational design with new fabrication methods, such as robotics, we can move away from the mass-produced. We can now take a step towards mass customization and experiment with the heterogeneous. This creates more space for spatial variation (Peters & Peters 2018. 44-45).



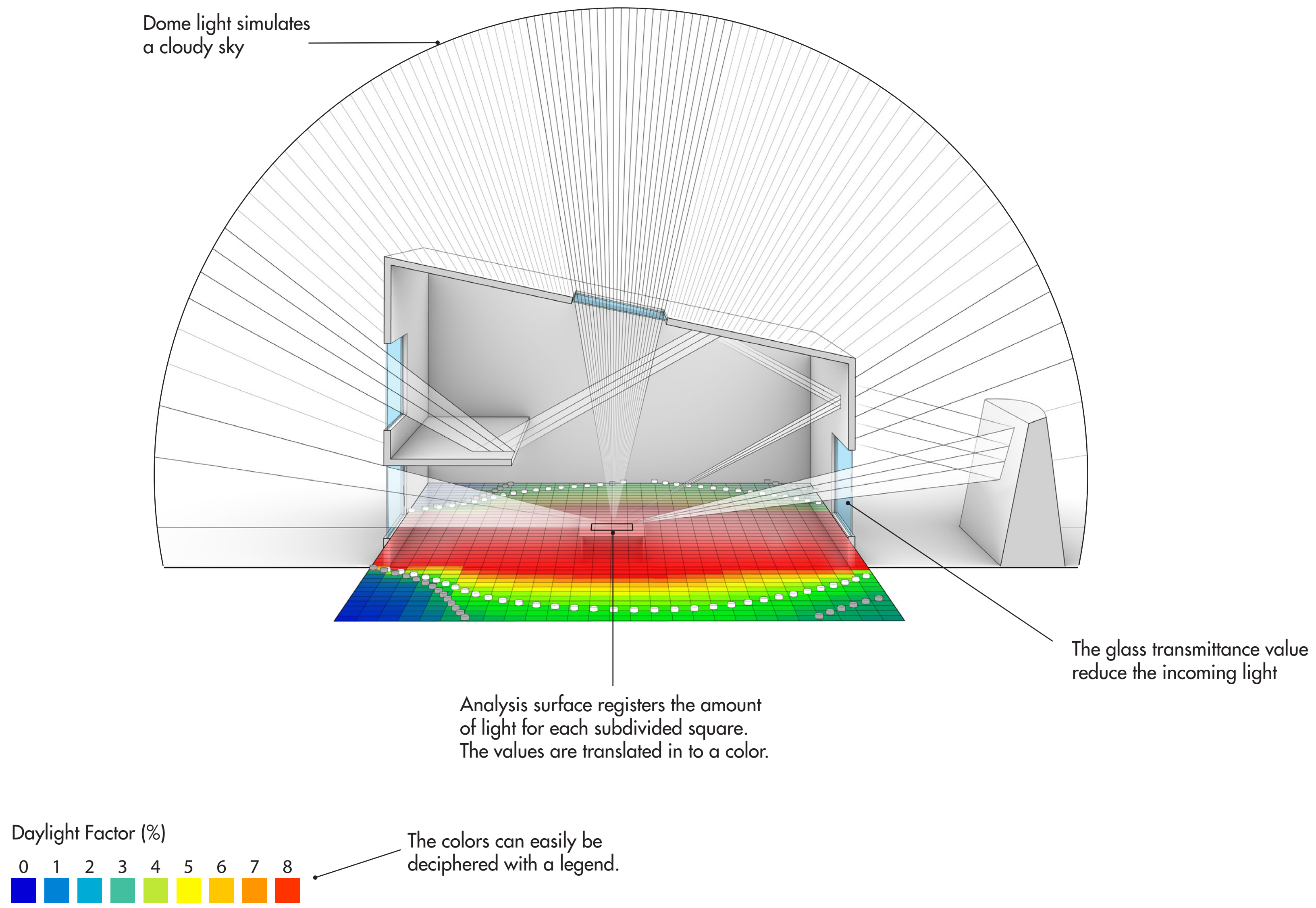
Circular design process

Simulating information

The communication between the architect and the computer is based on large amounts of information. In order to enhance this communication, we must strive to create as clear and distinguishable abstractions of this information as possible. The computer's way of conveying the information is in lists of numbers. To make the information more intuitive and accessible to us architects, we let the computer simulate the figures in the form of images and diagrams. We can now visualize information that the human eye typically can not perceive. Atmospheric factors such as sound, temperature, and wind can now be simulated and conveyed as a kind of drawing.

Evaluating the performance and behavior of a project has historically been a time-consuming and complicated task, traditionally reserved for engineers. Now, architects can receive real-time feedback and explore new design options efficiently. The simulation software provides information at all stages of the building process, creating a more responsive design process (Brady 2013. 6).

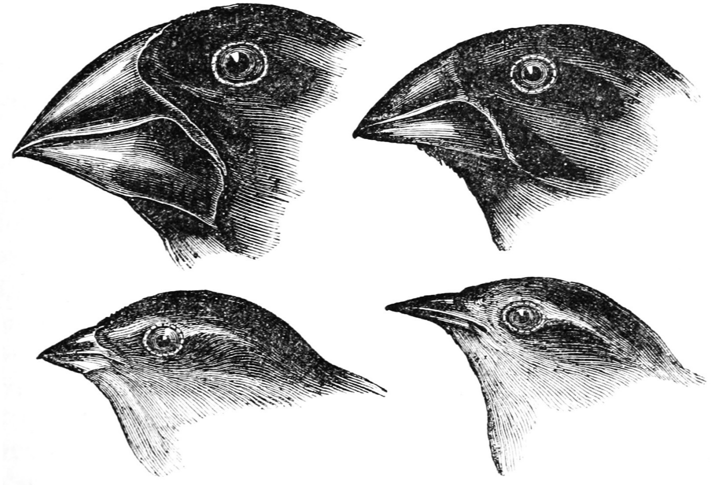
Daylight factor analysis



Generative design

Generative design is a branch of computational design that uses algorithms based on the evolutionary principle of natural selection. The method is an autopoietic process where the designer defines performative or spatial goals for the algorithm. The software explores all the permutations of a solution. The fittest (based on the given goal) genome extends to the next generation. It basically learns what works and what does not work, and the result of each generation is successively refined. The architect curates the outcome and chooses the *best* iteration. If the result is not satisfactory, the algorithm is adjusted (Autodesk 2020). Generative design integrates simulations as a tool.

We described above how the architect actively evaluates the simulation result and adjusts the parameters. In generative design, the architect is in a way replaced by the computer: it is the computer that evaluates the results, and then adjusts the parameters.



Evolutionary differences
between four types of birds (The Guardian 2018).

Evolutionary algorithms

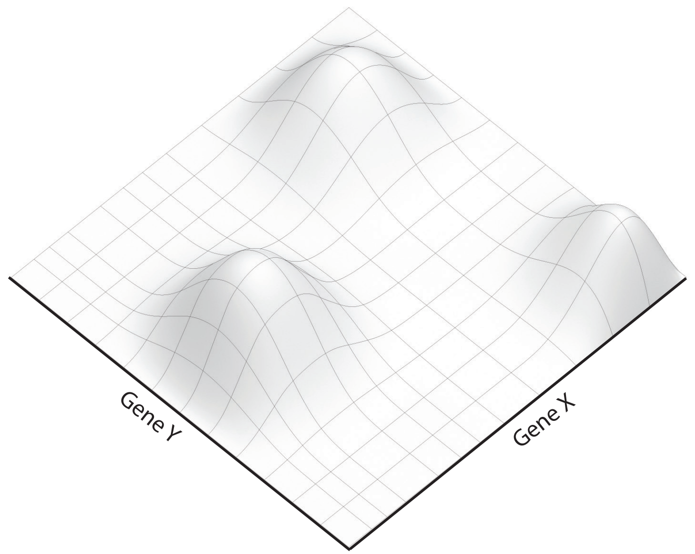
The notion of an evolutionary algorithm arose at the beginning of computer science. It is mentioned for the first time by Alan Turing in his paper Computing Machinery and Intelligence which was published in 1950. Turing philosophizes on artificial intelligence. Best known is *The Imitation Game* which is a test that measures artificial intelligence. In the same paper, he also writes about how to use evolutionary theory in machine learning. It is the first time this is mentioned in such a context.

The first description of an actual evolution-based algorithm for computation was published by John Holland in his book Adaptation in Natural and Artificial Systems, which was published in 1975 (Nagy 2017).

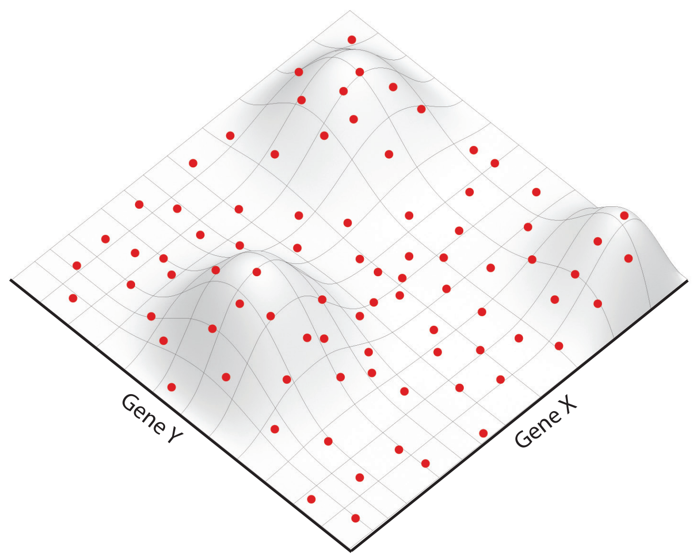
To explain the process behind the algorithm, we use one of Galapagos developer David Rutten's example. It is simplified but provides a basic understanding of the process:

The diagram to the right shows a landscape with three hills. The goal of this algorithm is to try to find the highest point in the landscape. X and Y are the variables that can be changed to move a point across the landscape to reach the peaks of the hills.

In evolutionary computation, these are called genes. We can change the value of X or Y to get a better or worse result. The variables are linked to each other, so each X value can be combined with a Y value and vice versa. By finding the ultimate combination of these values we can find the fittest solution, i.e. the highest point. Usually a problem is built up with far more variables and goals but for the sake of clarity, the example is limited to these two.

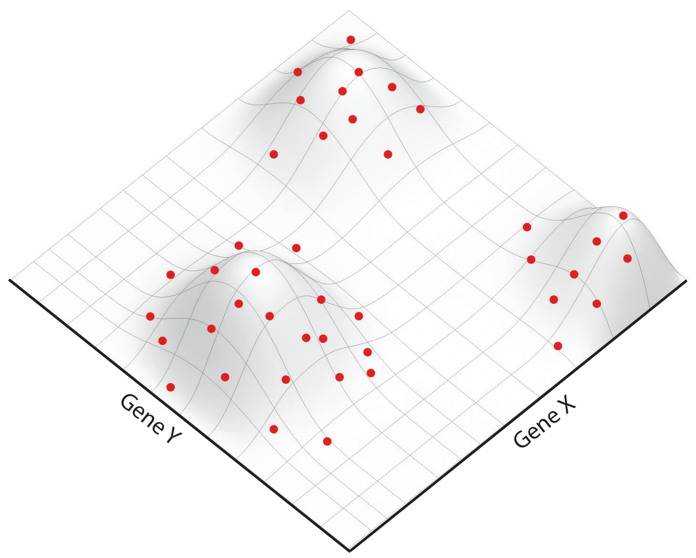


Landscape with three hills.



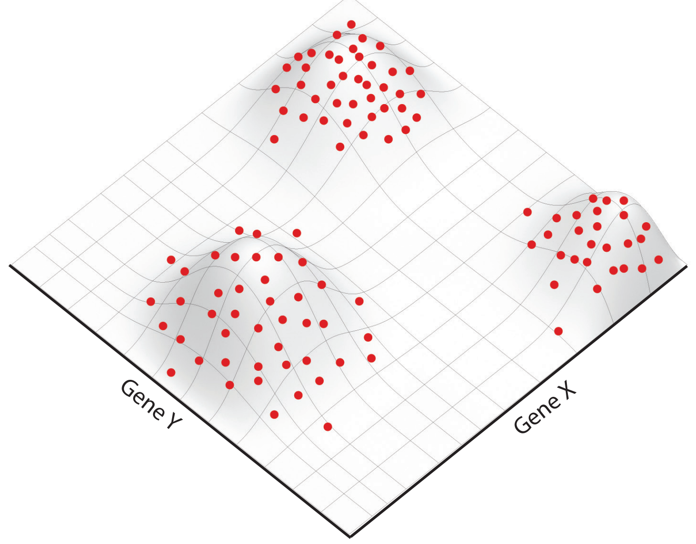
1. Generation

Initially, the computer have no idea what the landscape looks like. So the first step is to place the first generation (Generation 0) of points with randomly selected combinations of X and Y, these are called genomes.



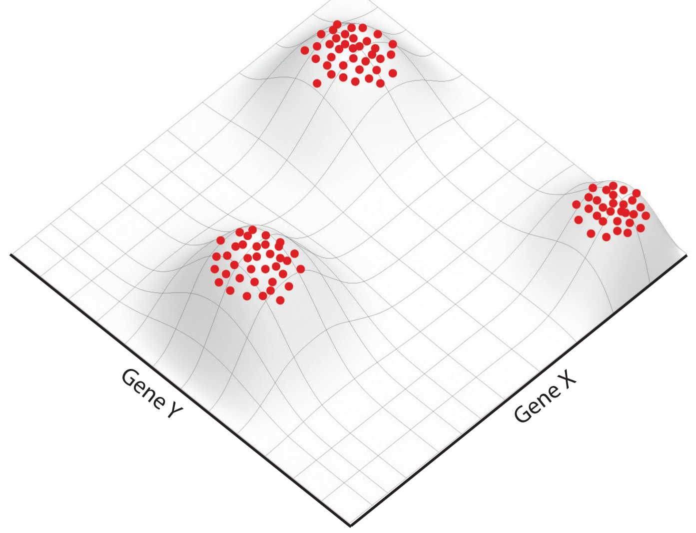
2. Selection/Ranking

The Z value of each point is evaluated. The higher up, the higher the fitness value. All genomes are ranked from the best to the worst. The genomes with the highest Z value selected while the others are sorted away.



3. Crossover

Since the points in generation 0 were placed randomly, it is not very likely that any of them reached the highest point, therefore it is not sufficient to select only the highest performing genome in the first generation. Instead, a new generation of genomes is created by matching the properties of the high-performance genomes. The concept is derived from breeding in evolutionary theory. It is based on the conclusion that the genomes that passed the first annealing ring should have properties that are advantageous for survival and subsequently also increased chances of reproduction.



4. Mutations

Selection and crossover ensure that we bring the optimal characteristics of each generation. But there is a risk that no gemome hit parts of a hill in the first generation. Therefore, there is an imminent risk that this information will never be included. Just as in nature, we need a mechanism that can change the introduction of properties based on randomness. Therefore, a small portion of each genome's genes are randomly altered.

The mating is repeated over and over until the genome climbed to the top of the hill. The differences between the genome and the generations are now small and we have reached the so-called resting phase. We are never guaranteed to reach the absolute best solution but a solution that is close enough (Rutten 2010).

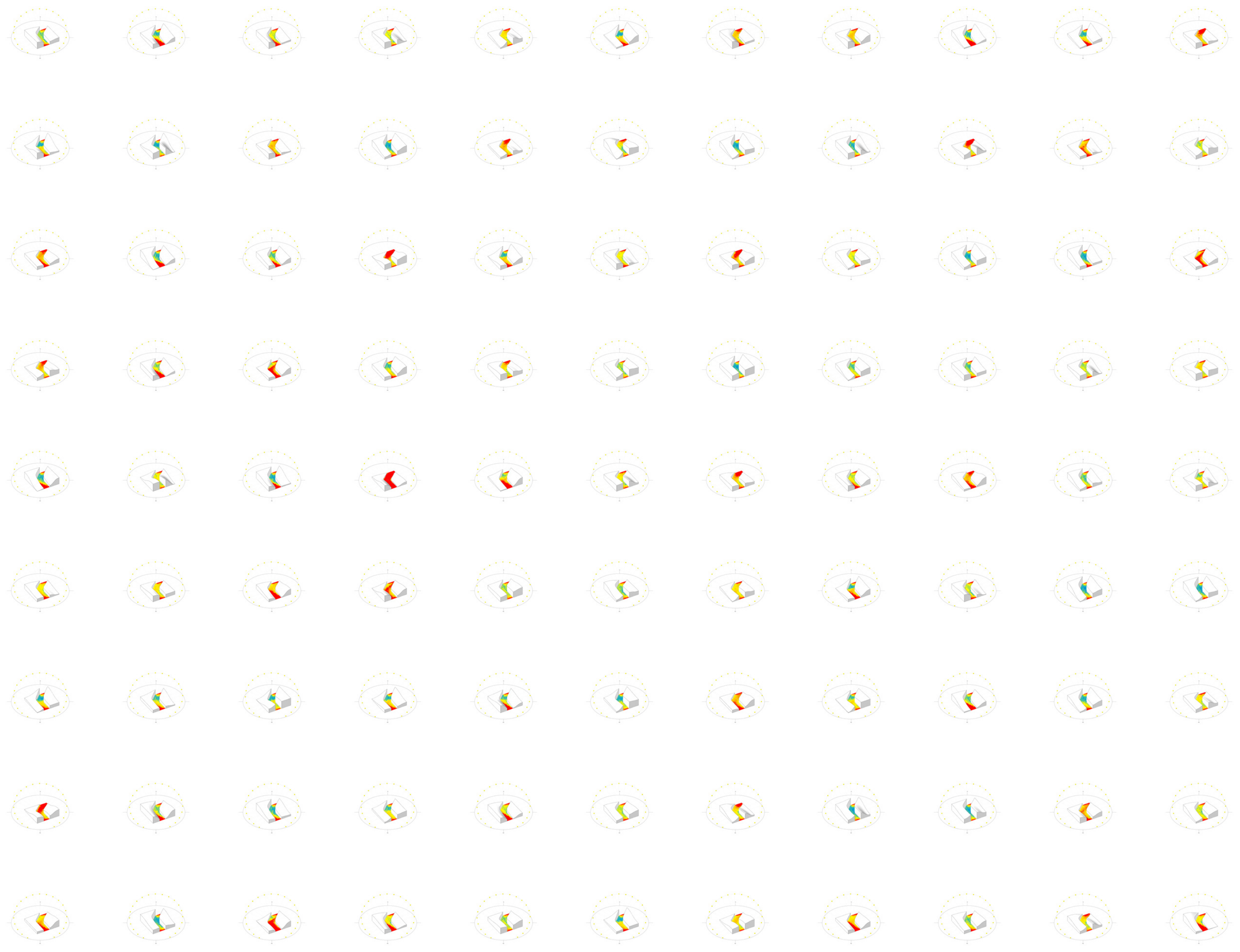
3. Methodology and Competition

Methodology

After an in-depth study of the theoretical parts of generative design, we began to explore the tools in a practical manner. The methodology evolved through the premise that the designer defines a goal (an objective) and constructs an algorithm. The computer performs the algorithm and simulates the shape's behavior and performance. The architect then evaluates the results and adjusts the initial parameters of the algorithm based on the feedback from the simulations. The design process thus becomes circular instead of linear.

In theory, it is possible to set as many goals as possible. From the optimization of microclimate or structure, to the optimization of temperature or project costs, every property is in theory possible to optimize. We chose to focus on three objectives: microclimate (on a courtyard), views (towards a given point), and interior daylight factor. During the process, we realized that it is not possible to simply optimize one factor. If the goal is to maximize the sunlight for the interior courtyard, the algorithm will minimize the volume until the building is completely flat as that outcome results in more sunlight in the courtyard. That's why we always introduced a contradiction. For example, if the goal is to optimize direct sunlight, we would add a goal to simultaneously maximize the volume of the building. This forces the computer to find more creative solutions. Examples of contradiction may be: maximizing volume/maximizing sunlight, maximizing sight lines/maximizing volume, or minimizing window area/maximizing light.

It was important for us to conceive this part of the thesis as an experimental and open-minded activity. We worked without clear frameworks and restrictions which allowed us to fully explore the tools. Through trial and error, we learned how to use algorithms as a creative driver, and what role they have in the design process



Solar optimization iterations

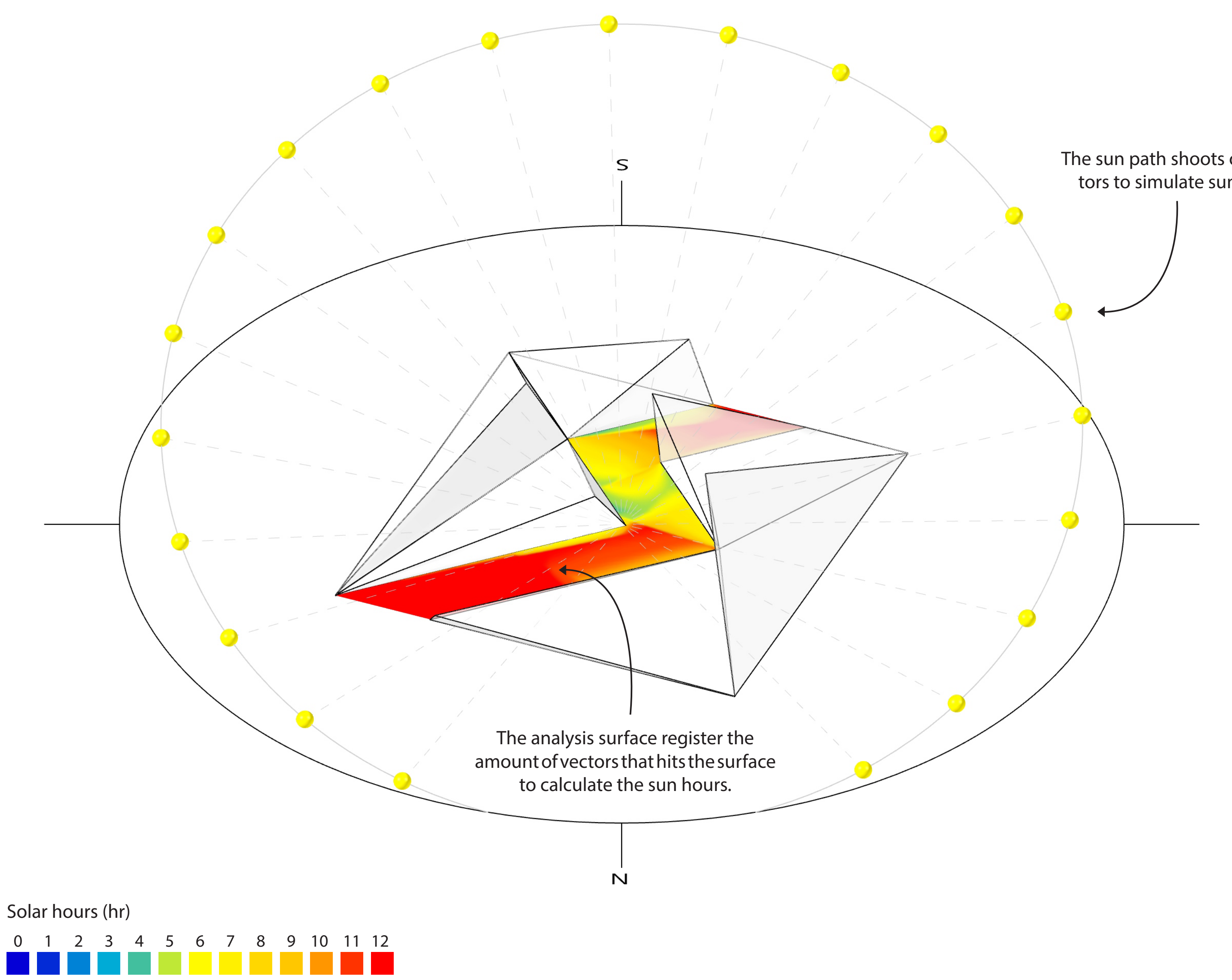
Workshop 1: Direct Sun

As a point of departure, we started with a suitable beginner's task: direct sun. The premises were simple. The goal was to optimize the number of solar hours for a pathway between two volumes. As contradiction, we added an additional goal: to let the buildings maximize their volume. This created an incentive for them to adapt to the solar angle, instead of just extruding down to the ground. By simulating a heat-map of the results, we got feedback on which ones were successful and not.

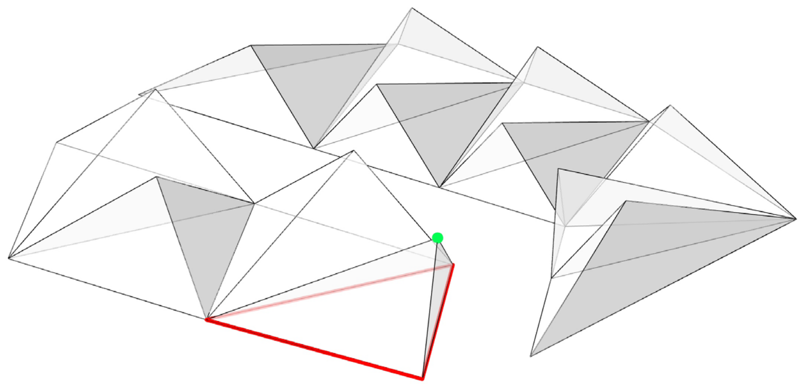
The typologies were divided into three families; tetahedrons, boxes and landscapes. The best of each family was selected for further development.

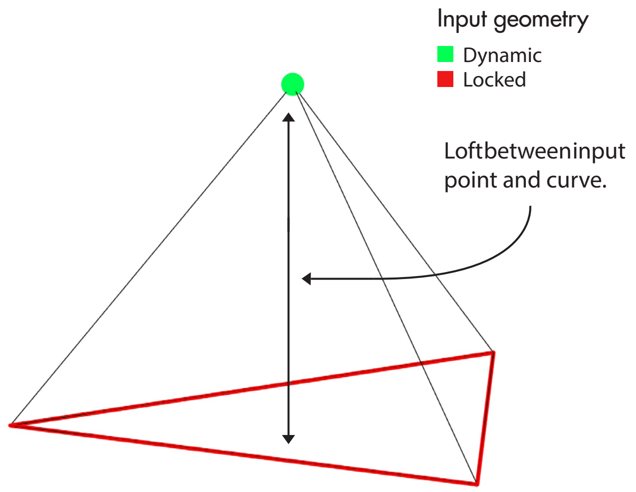
The following pages shows examples of the different families and their frameworks.

Direct sun analysis

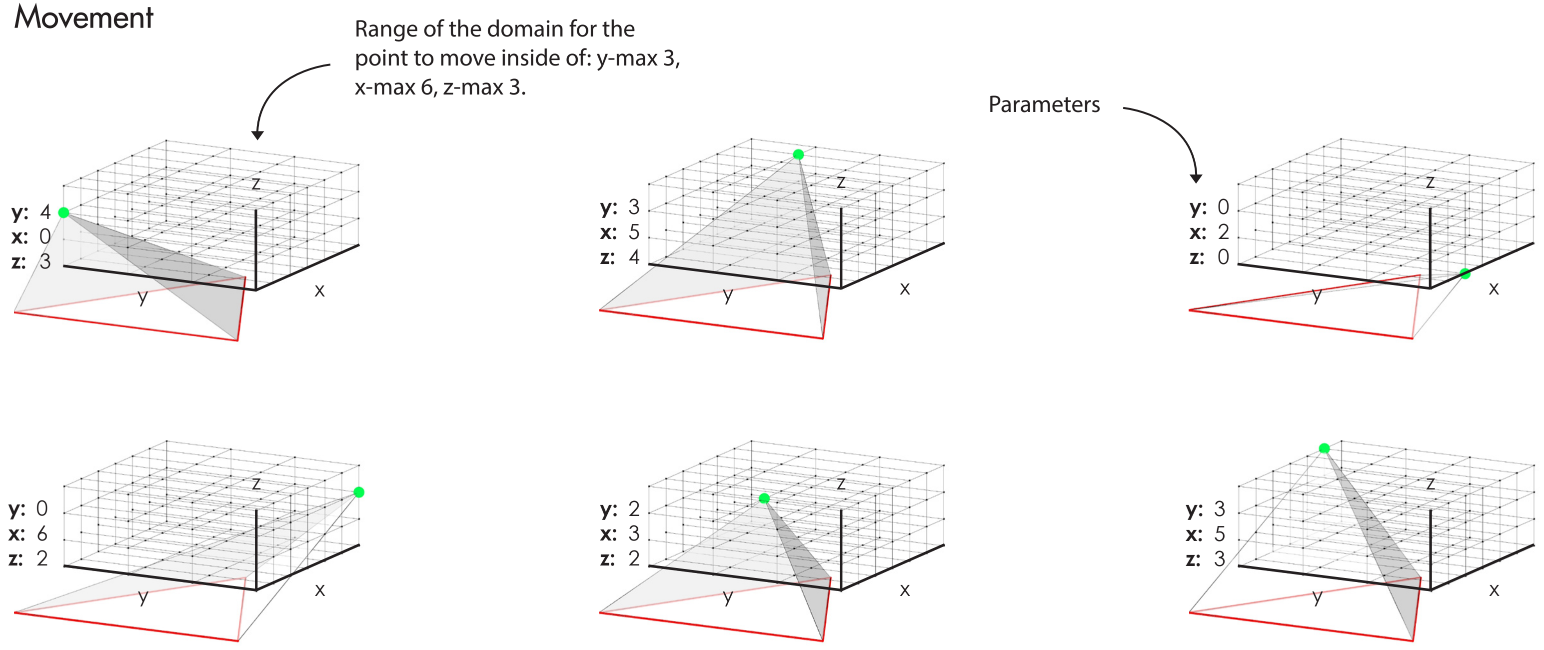


Tetrehedon A

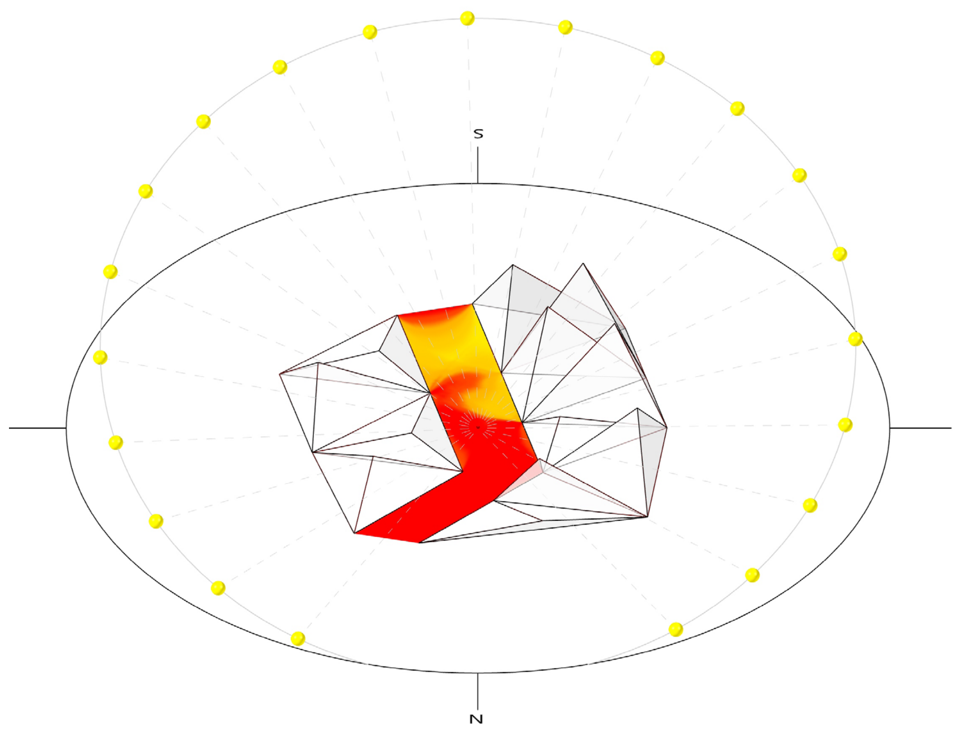




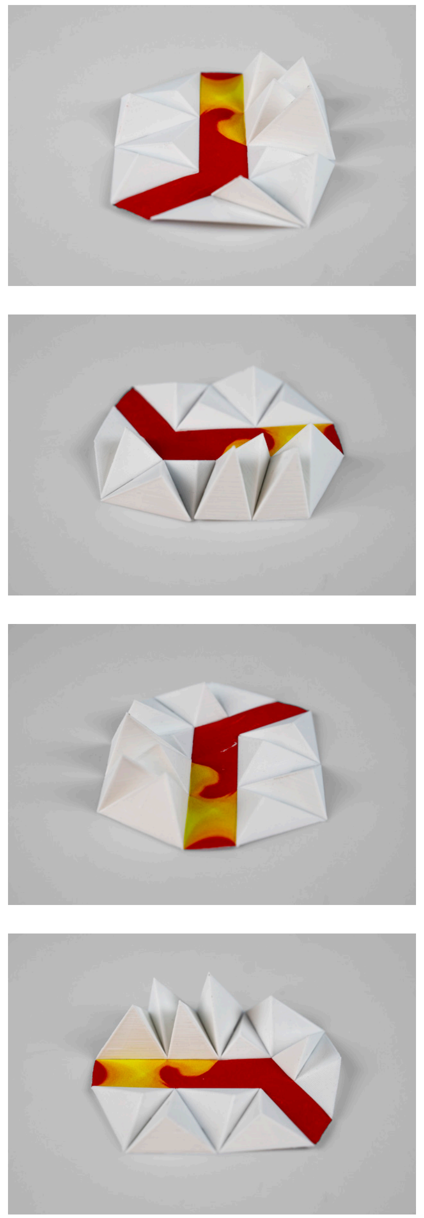
Movement



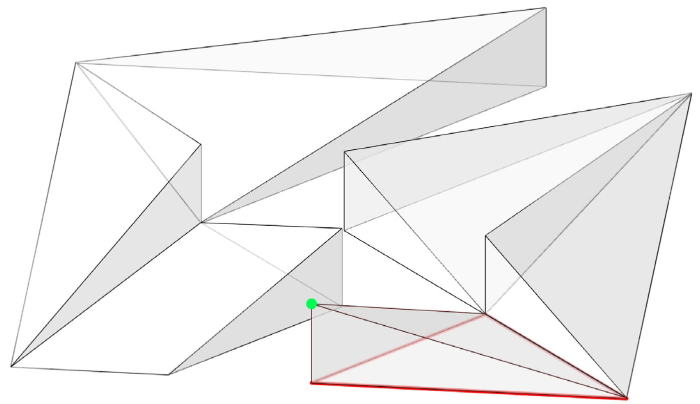
Direct sun analysis

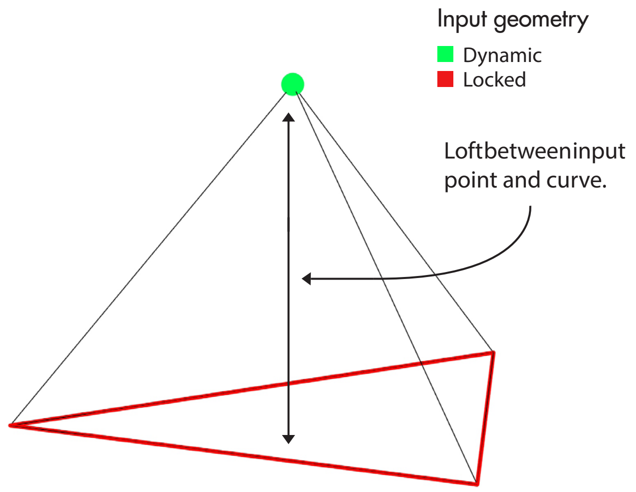


3D - Print

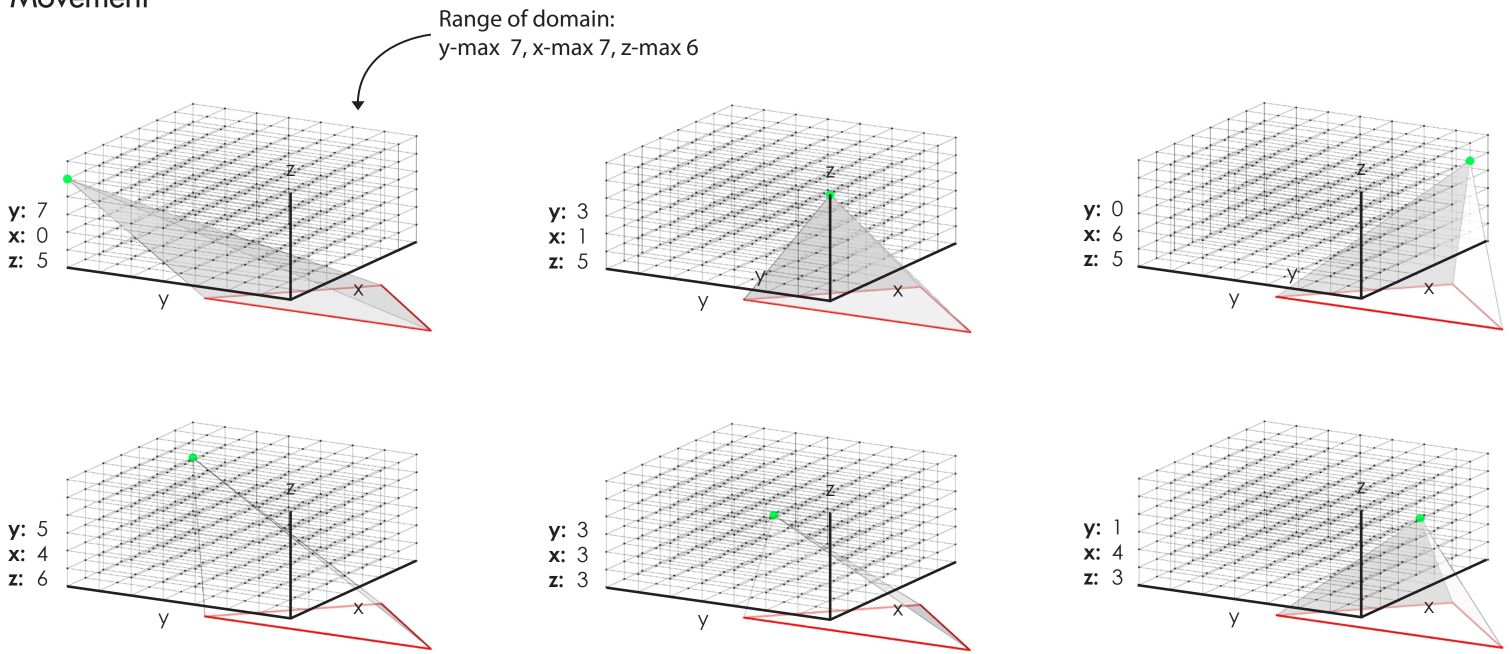


Tetrehedon B

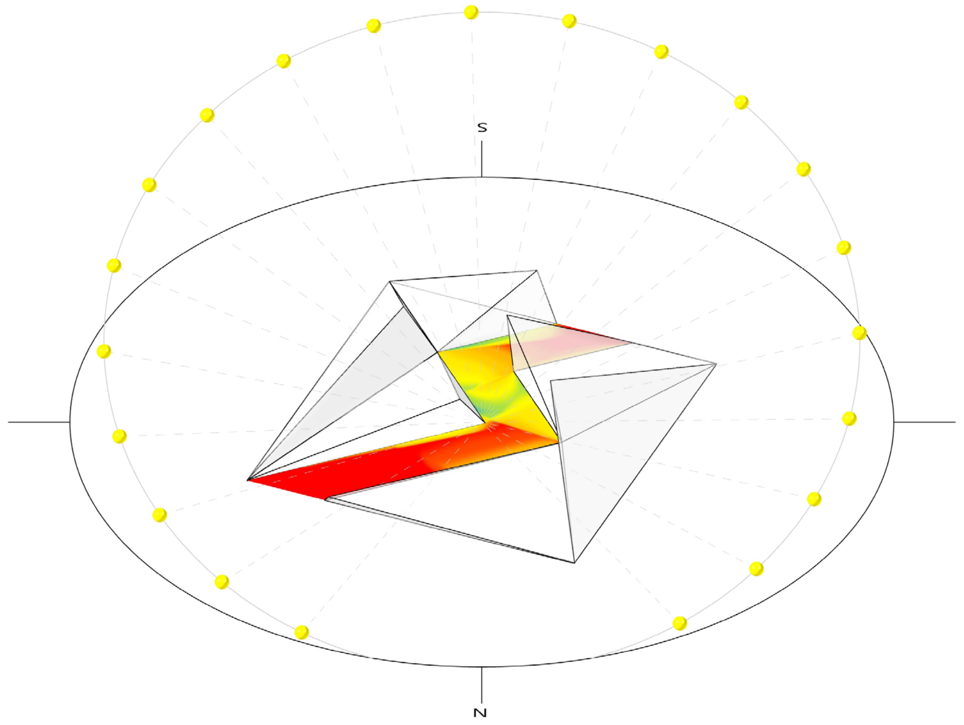




Movement

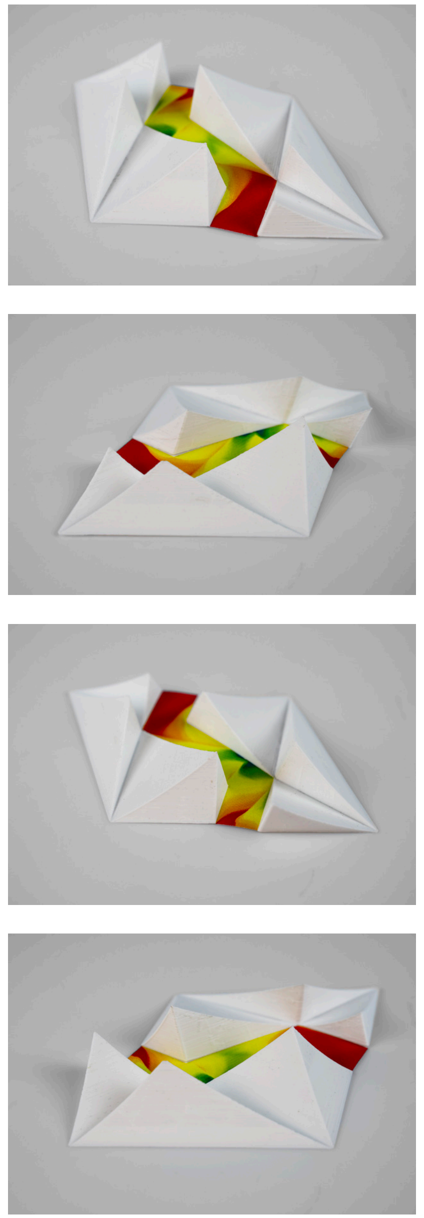


Direct sun analysis

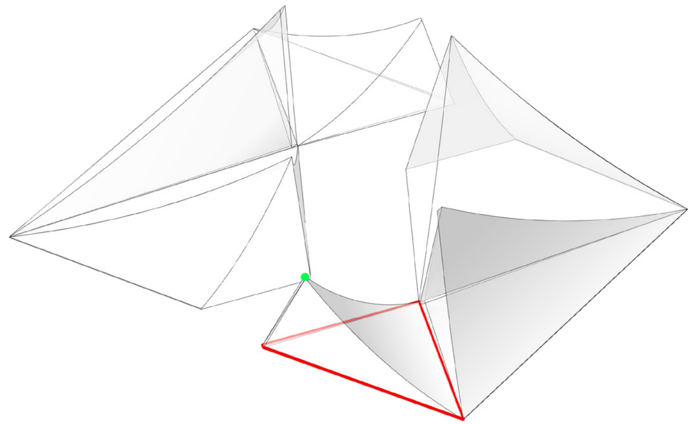


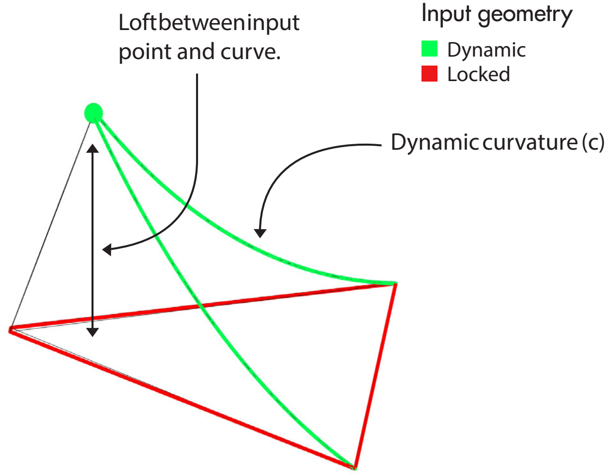
Solar hours (hr)

3D - Print



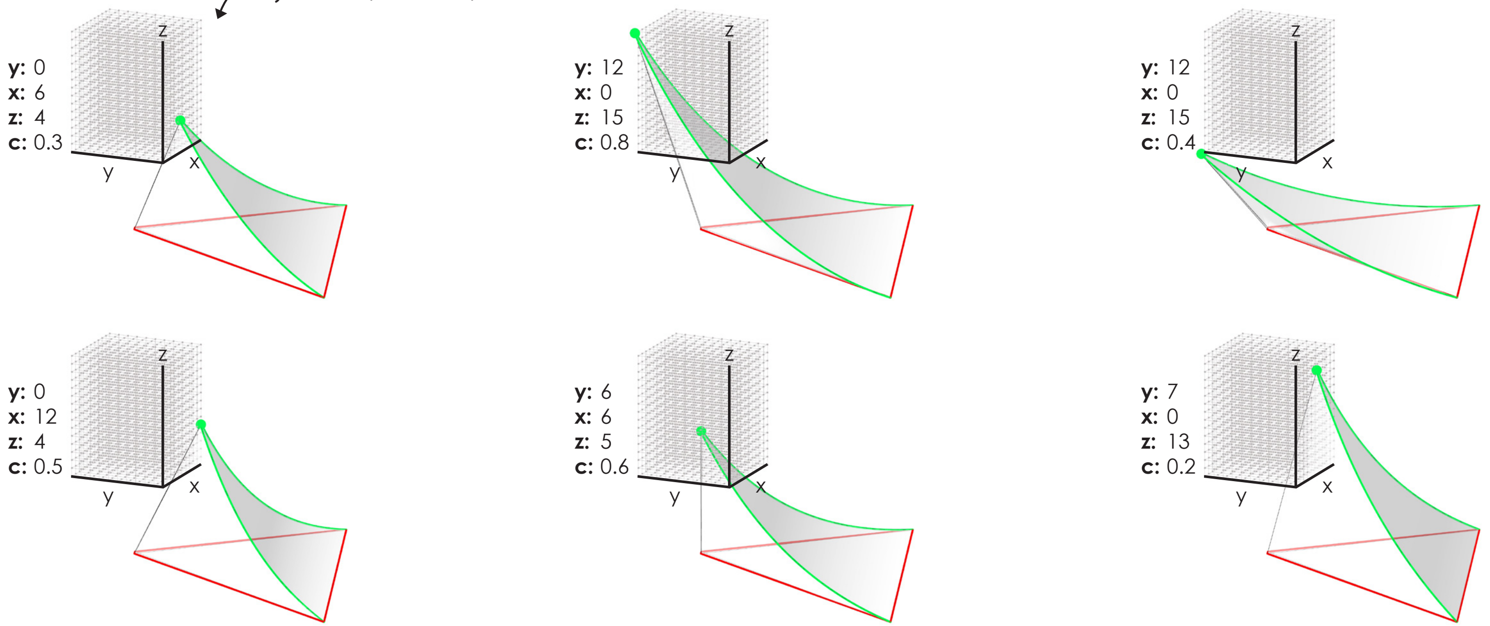
Tetrehedon C



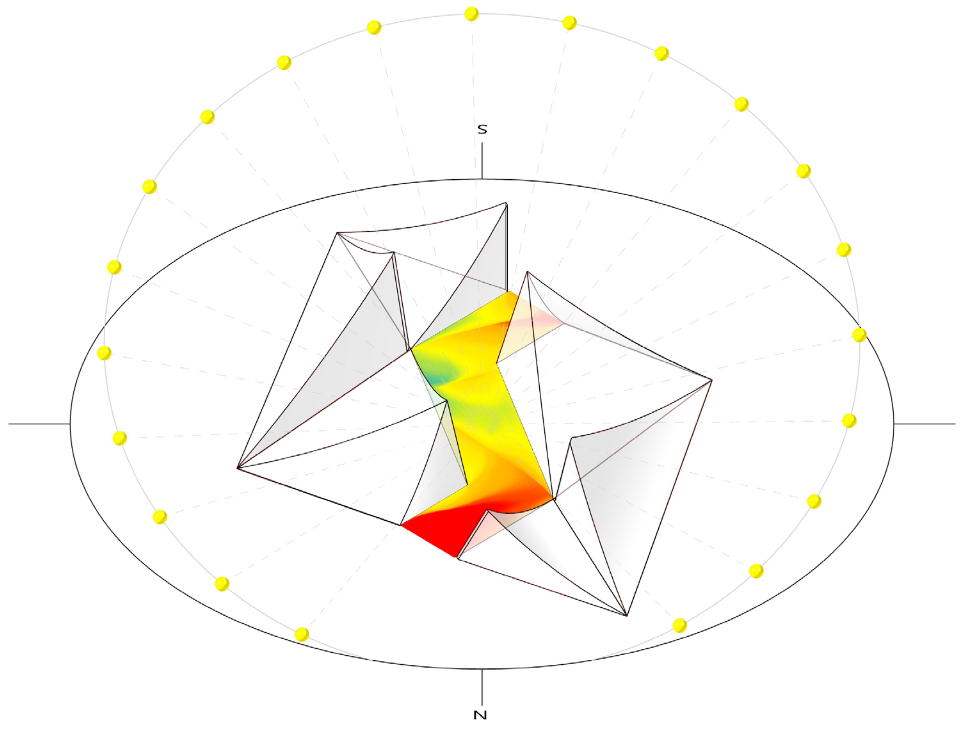


Movement

Range for this domain:
y-max 12, x-max 12, z-max 15



Direct sun analysis



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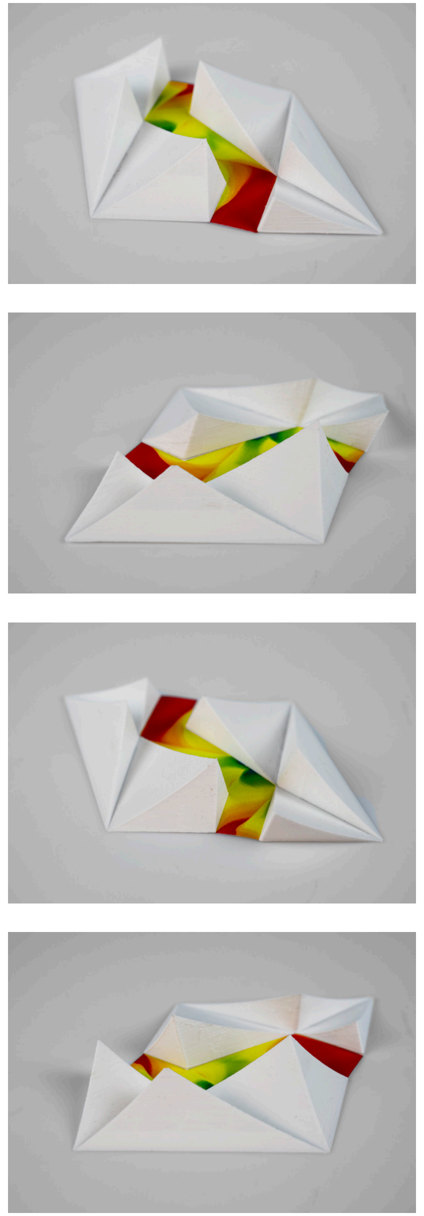
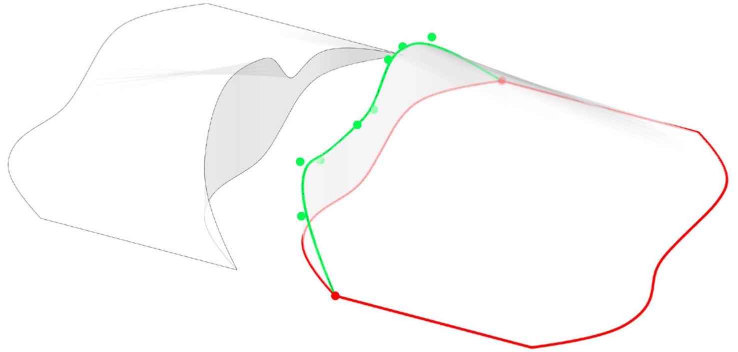
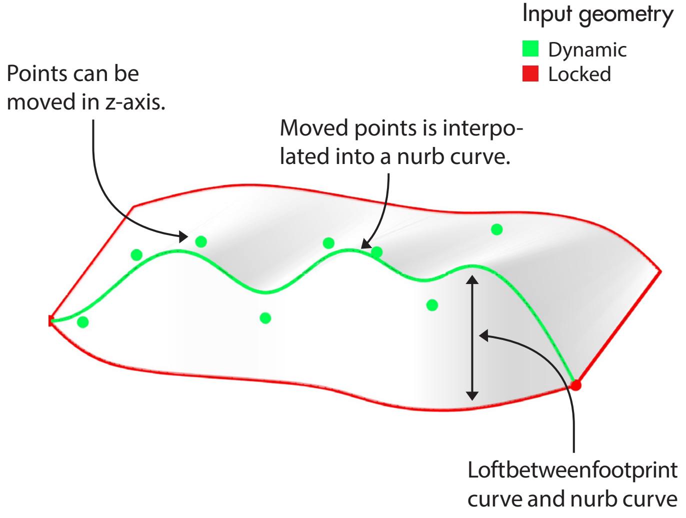
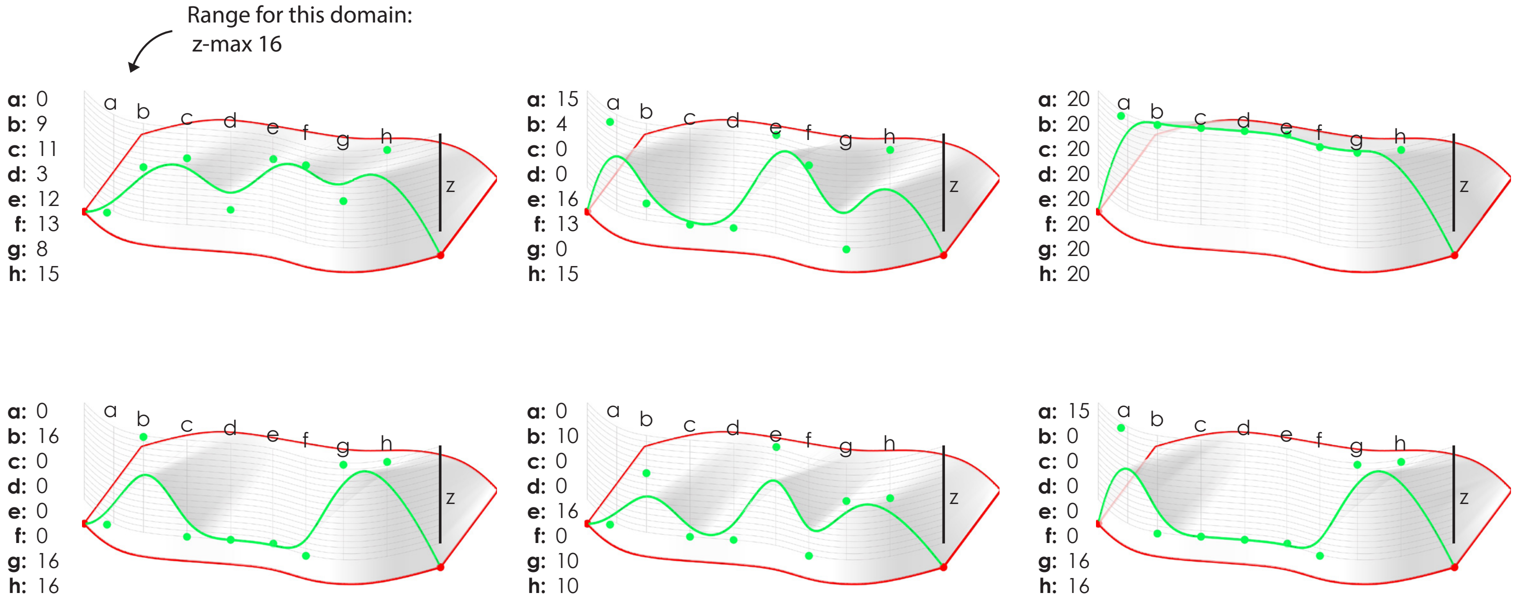


Landscape A

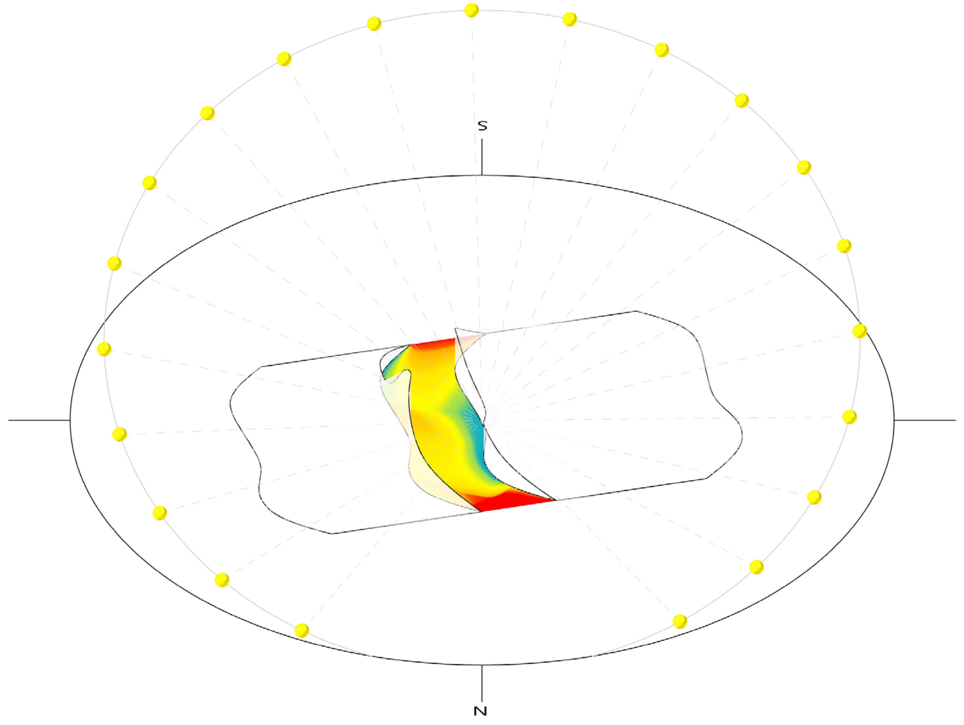




Movement



Direct sun analysis



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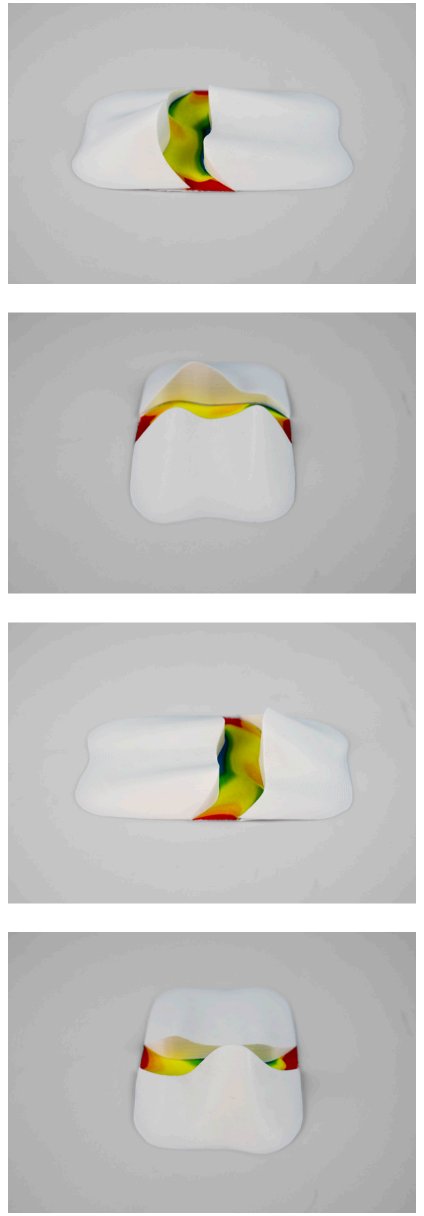
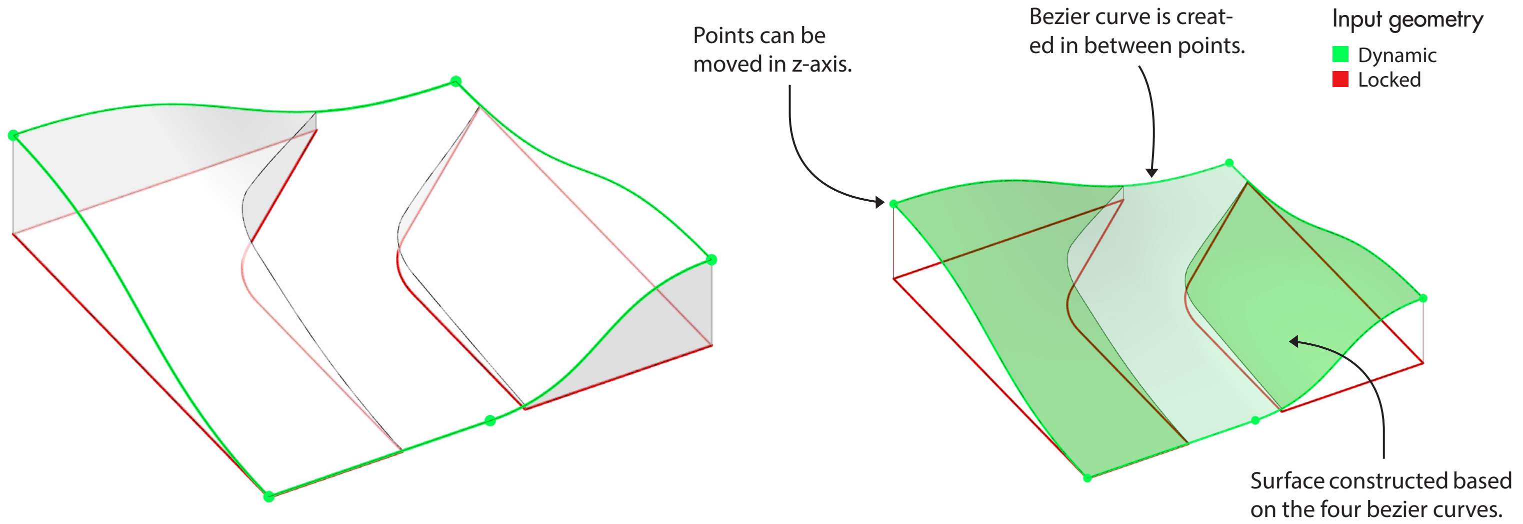
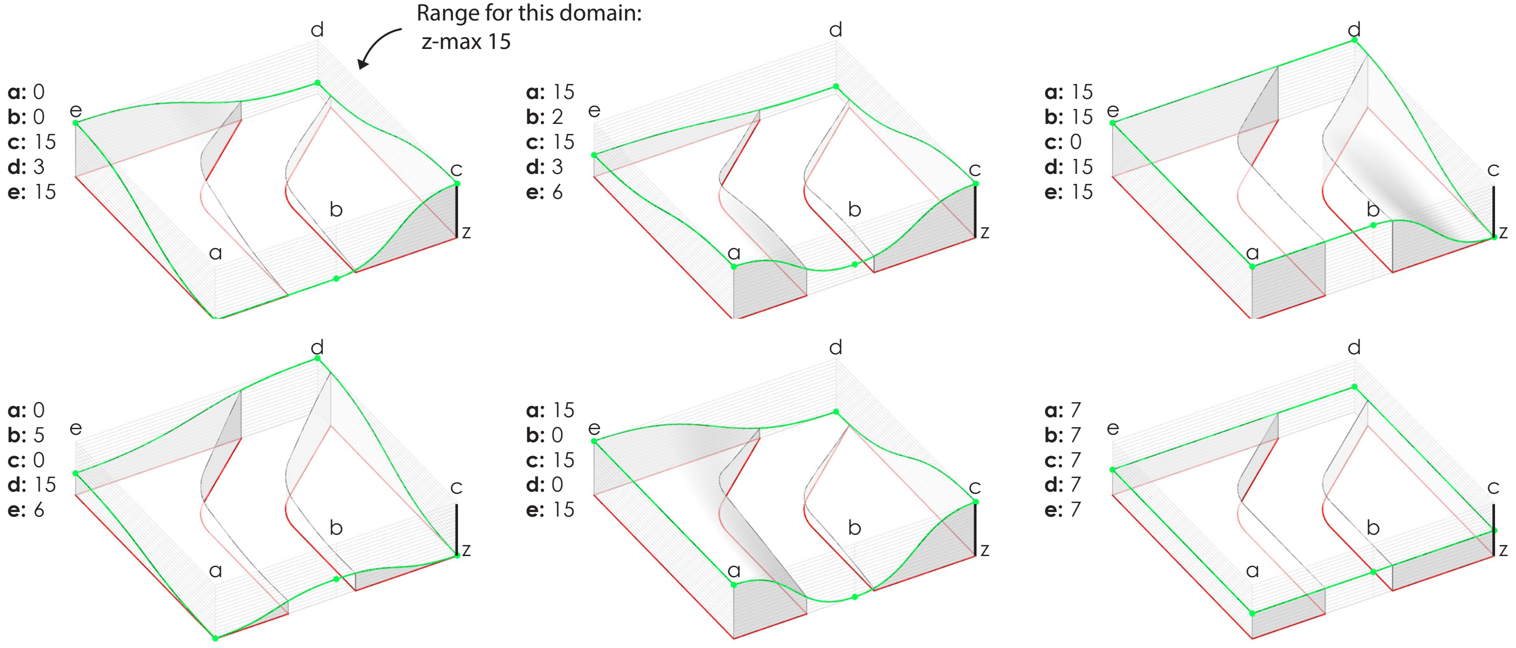


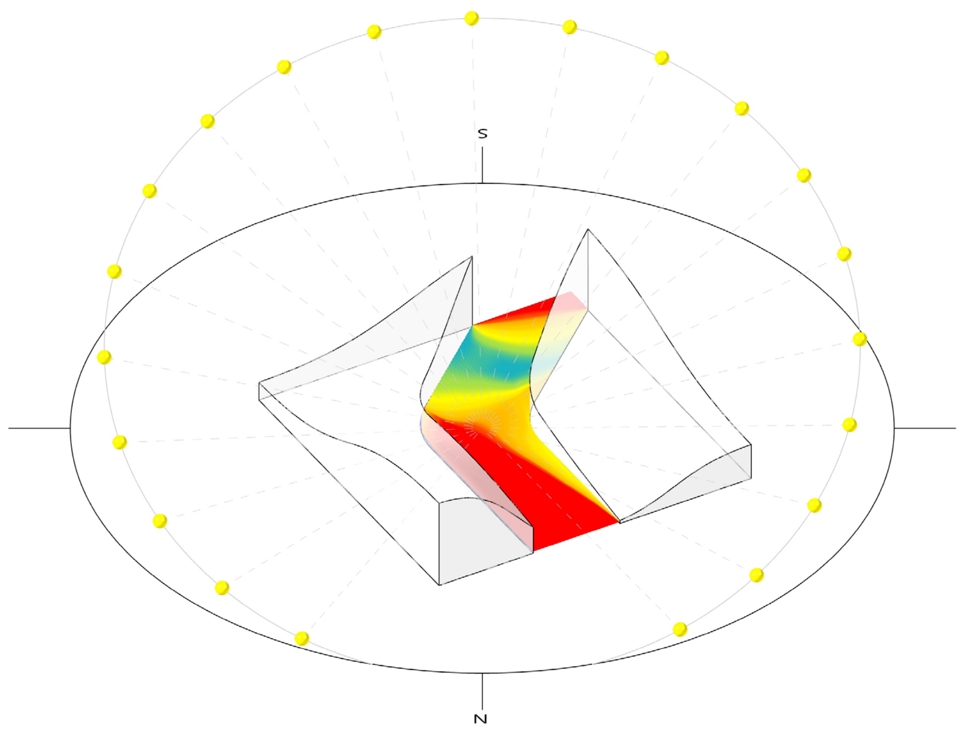
Landscape B



Movement



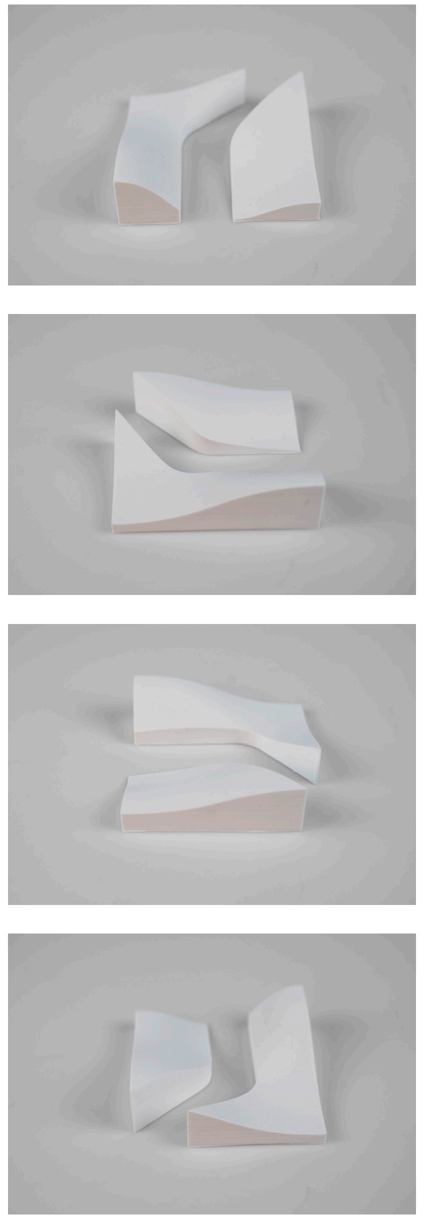
Direct sun analysis



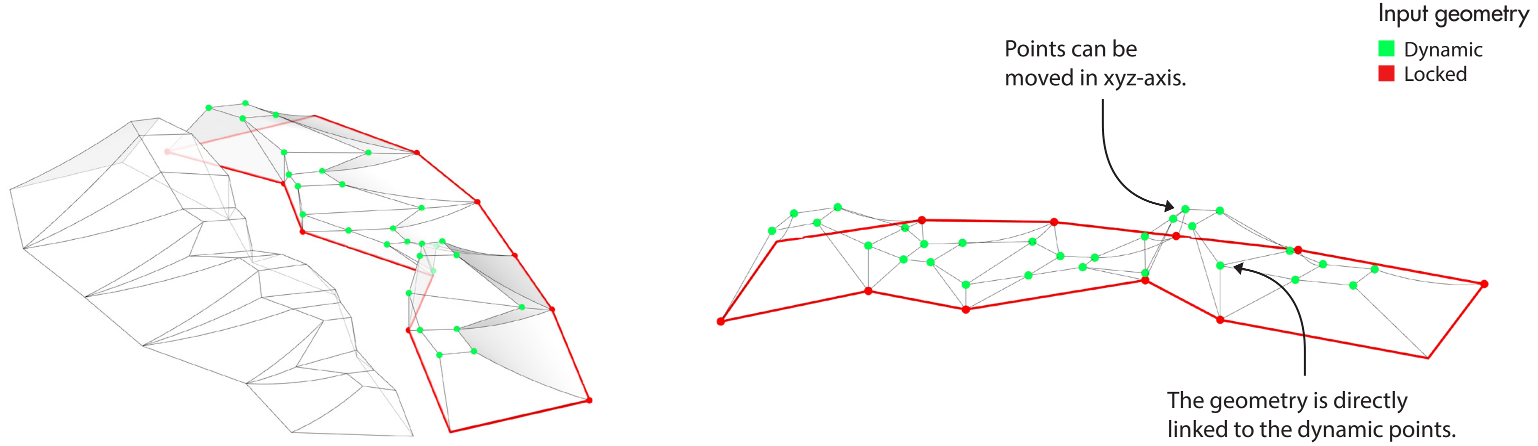
Solar hours (hr)

0	1	2	3	4	5	6	7	8	9	10	11	12

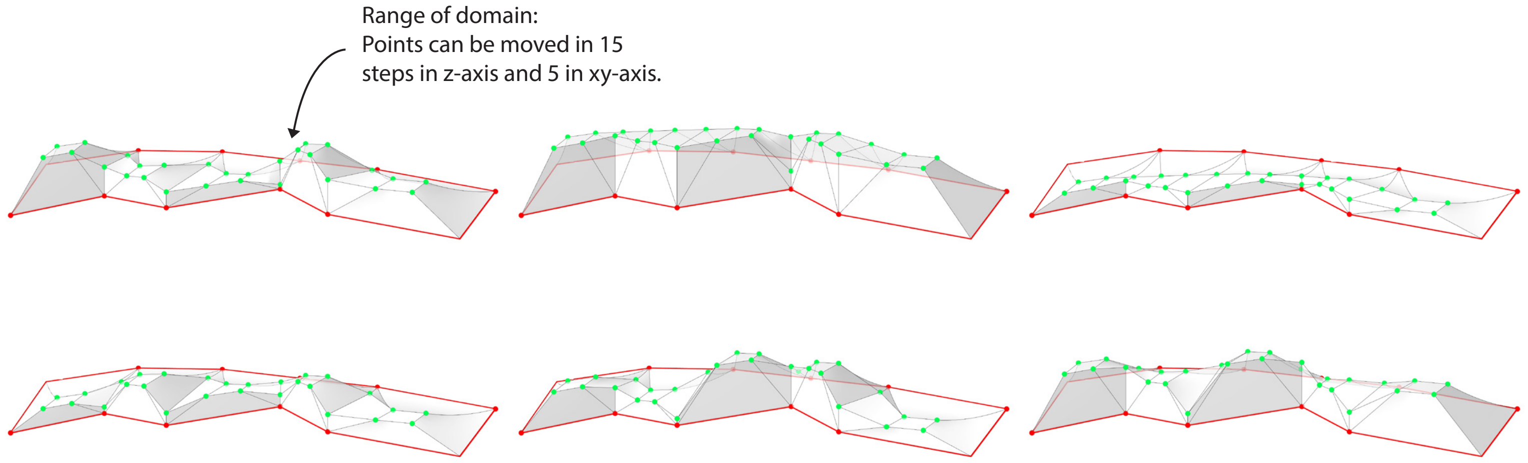
3D - Print



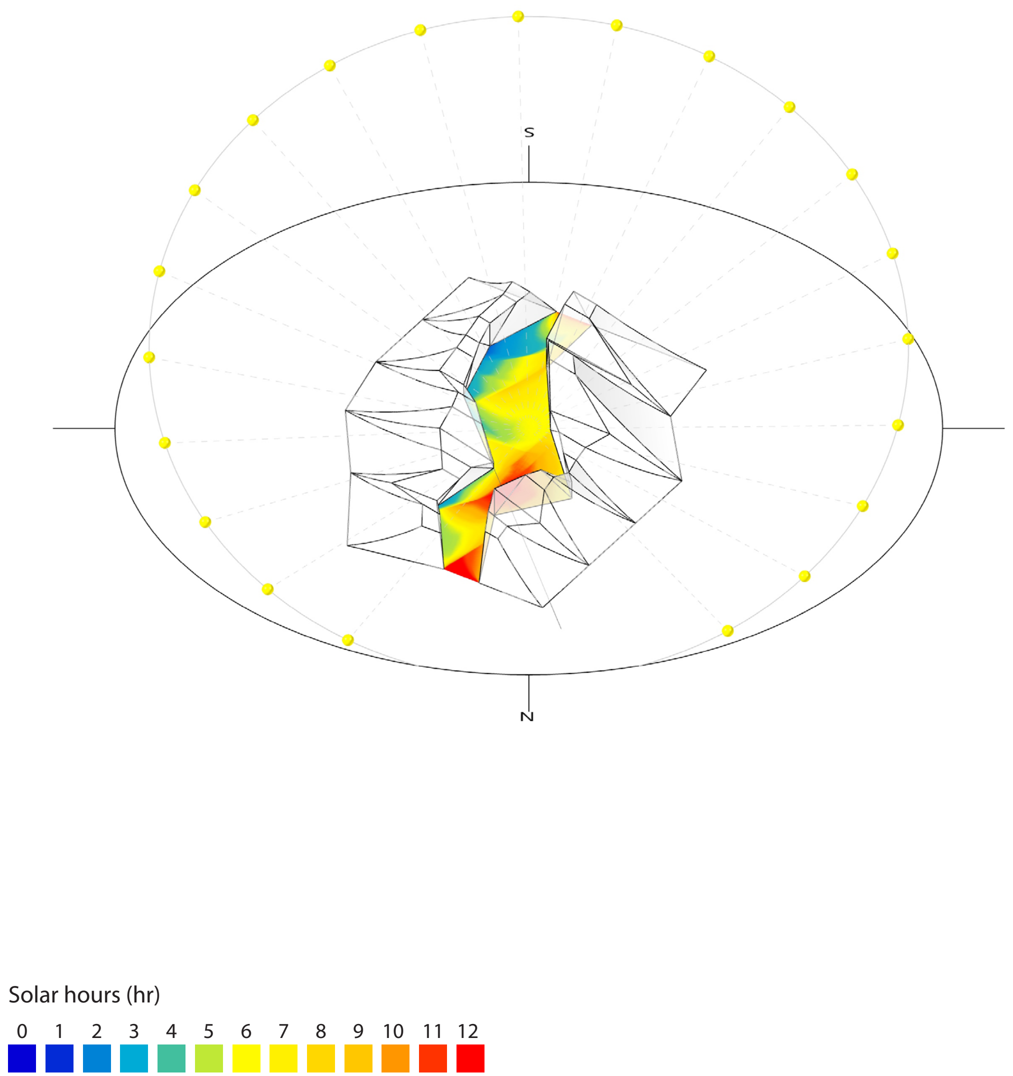
Landscape C



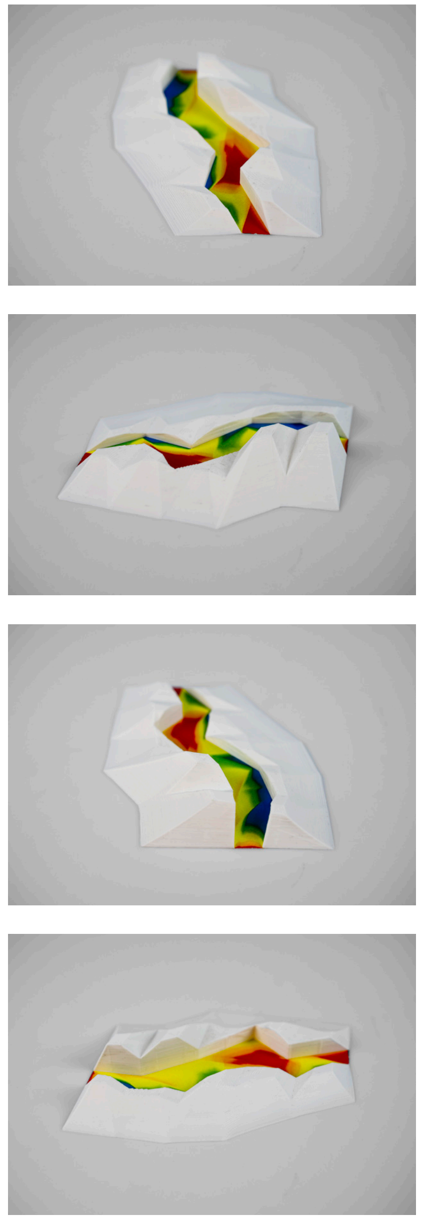
Movement



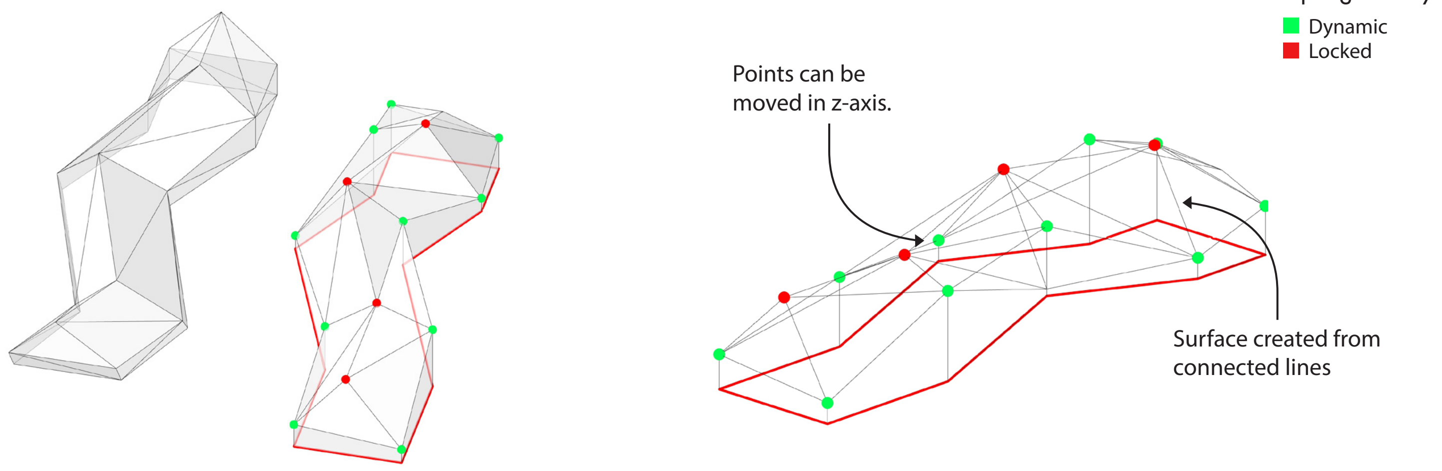
Direct sun analysis



3D - Print



Parametric box A



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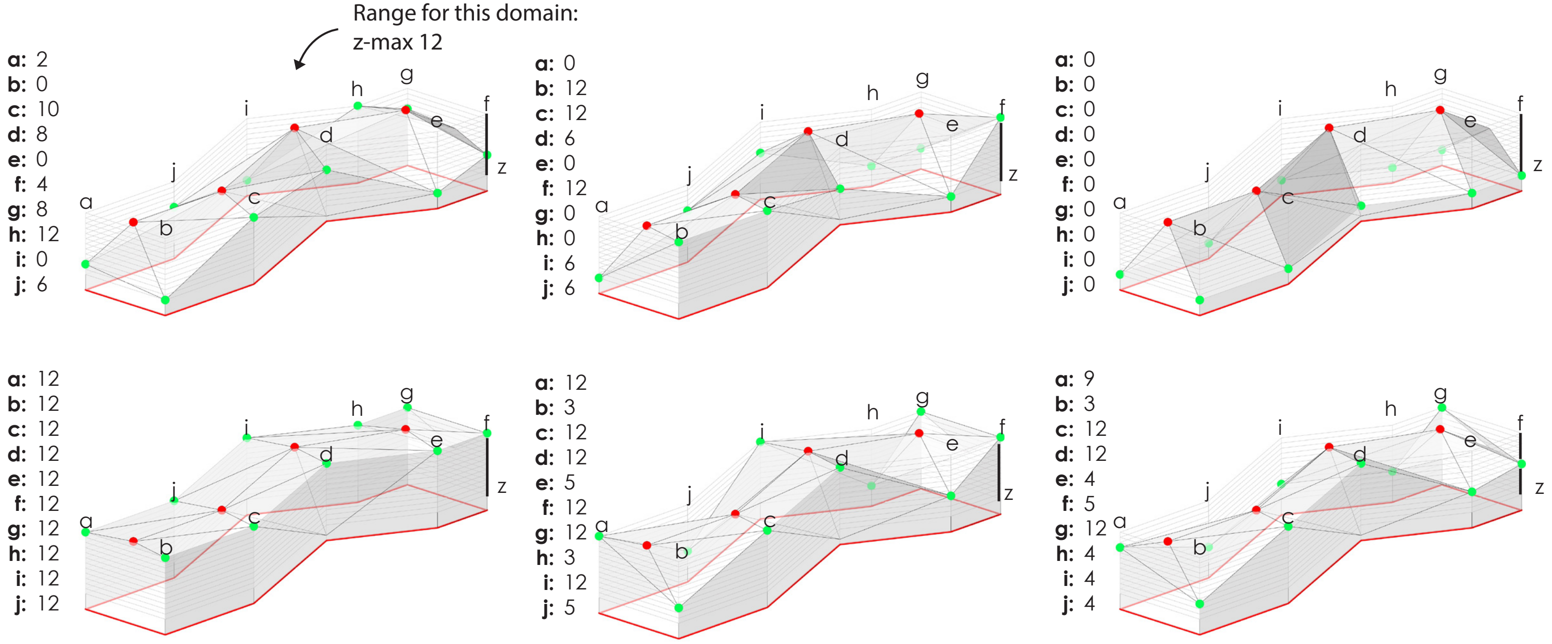

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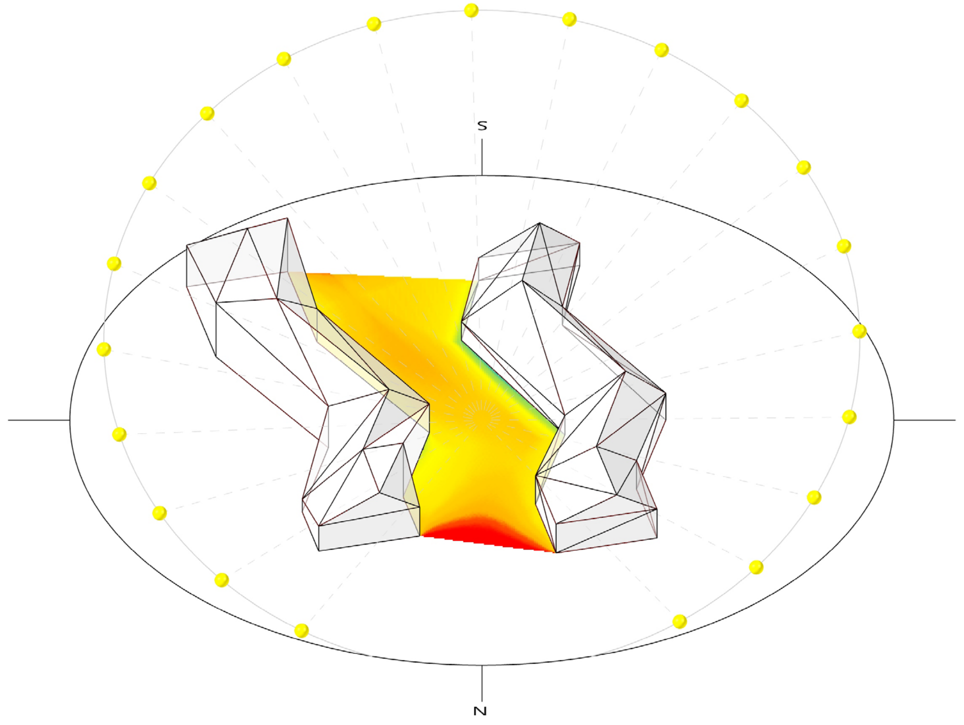

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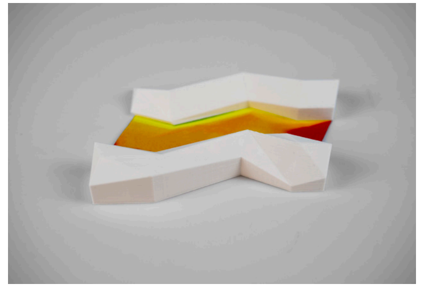
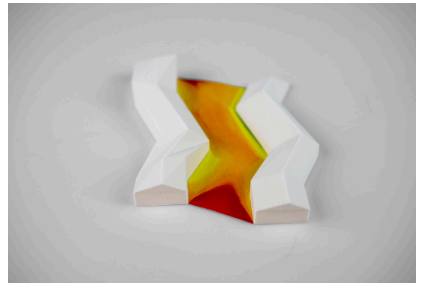
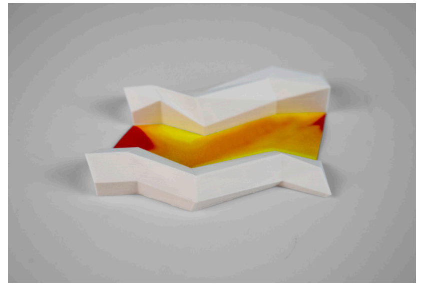
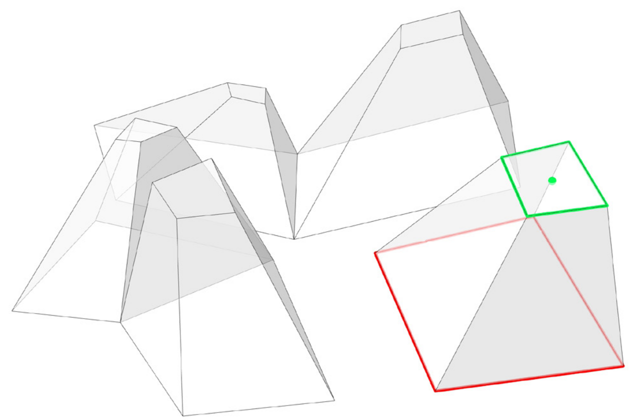
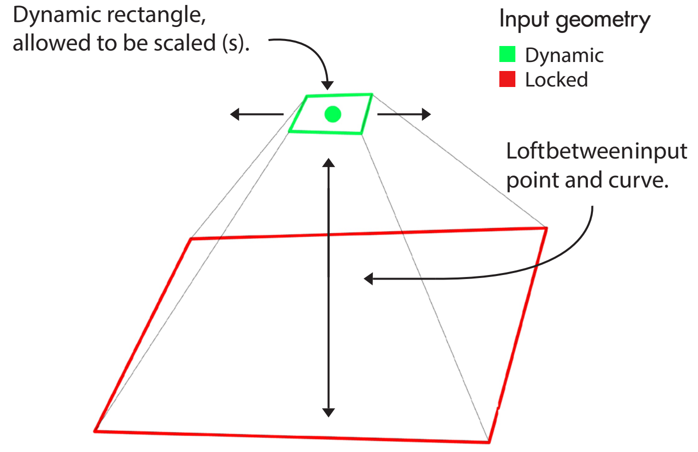




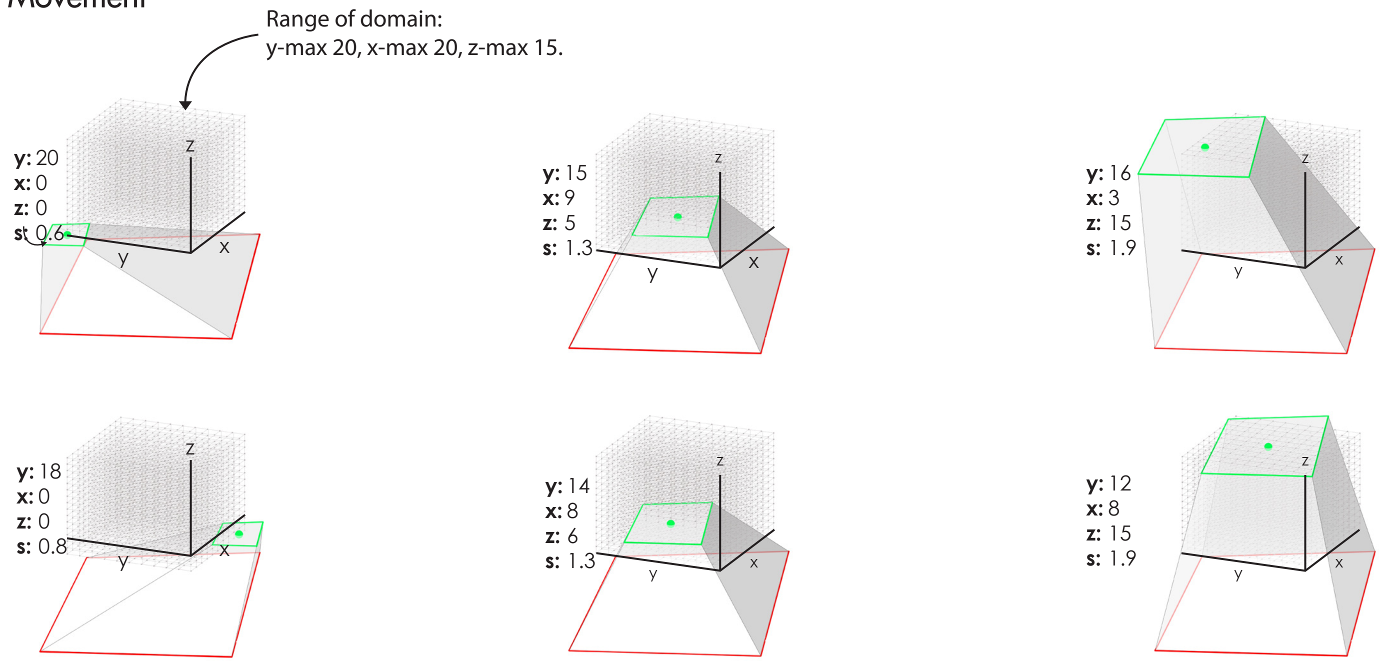


Parametric box B

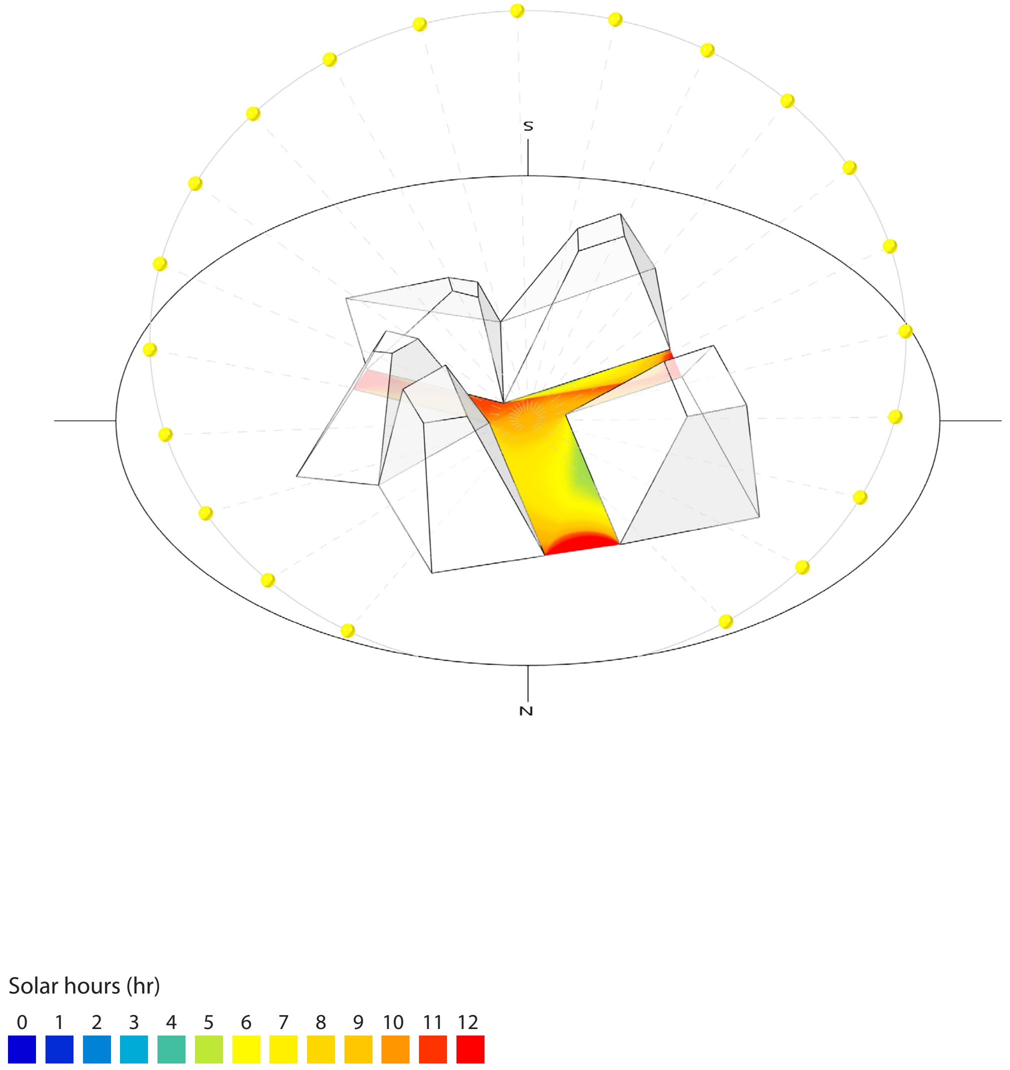




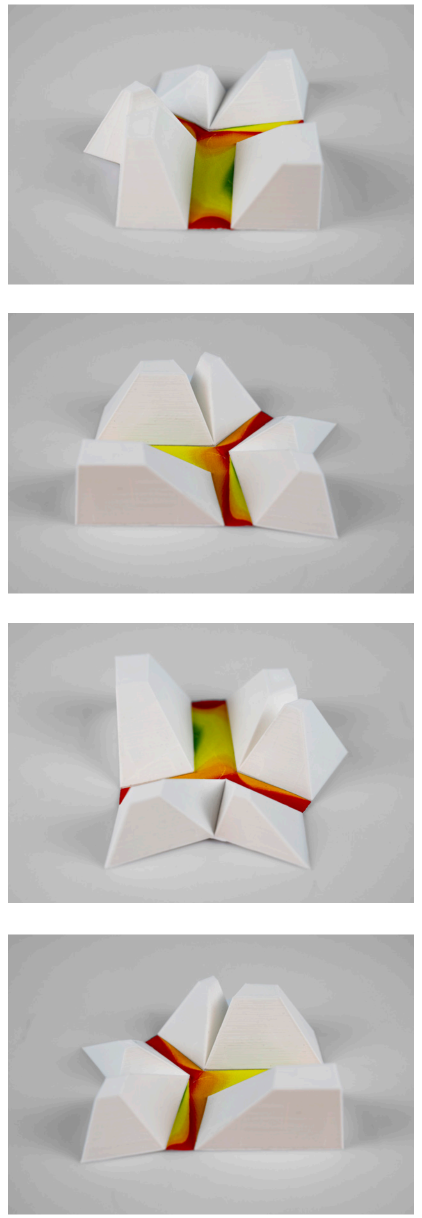
Movement



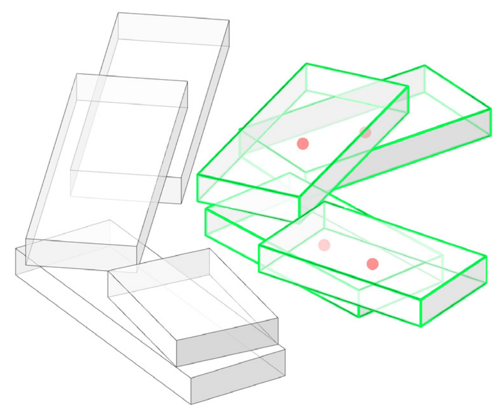
Direct sun analysis

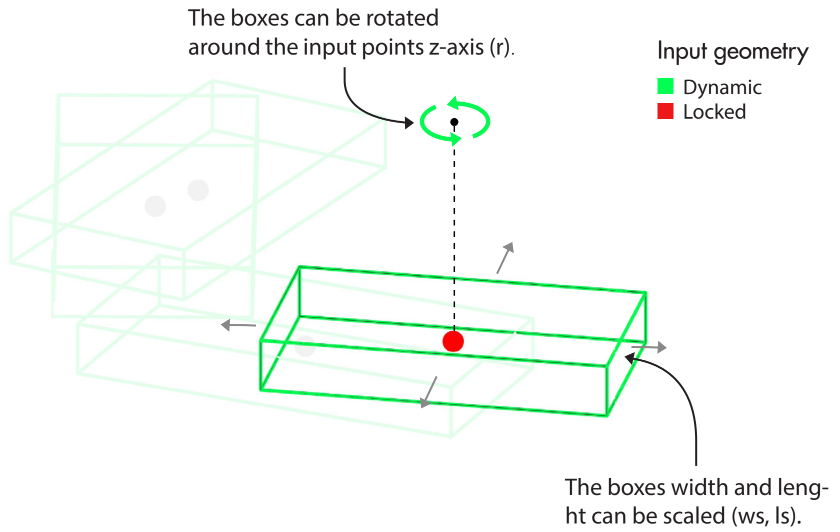


3D - Print

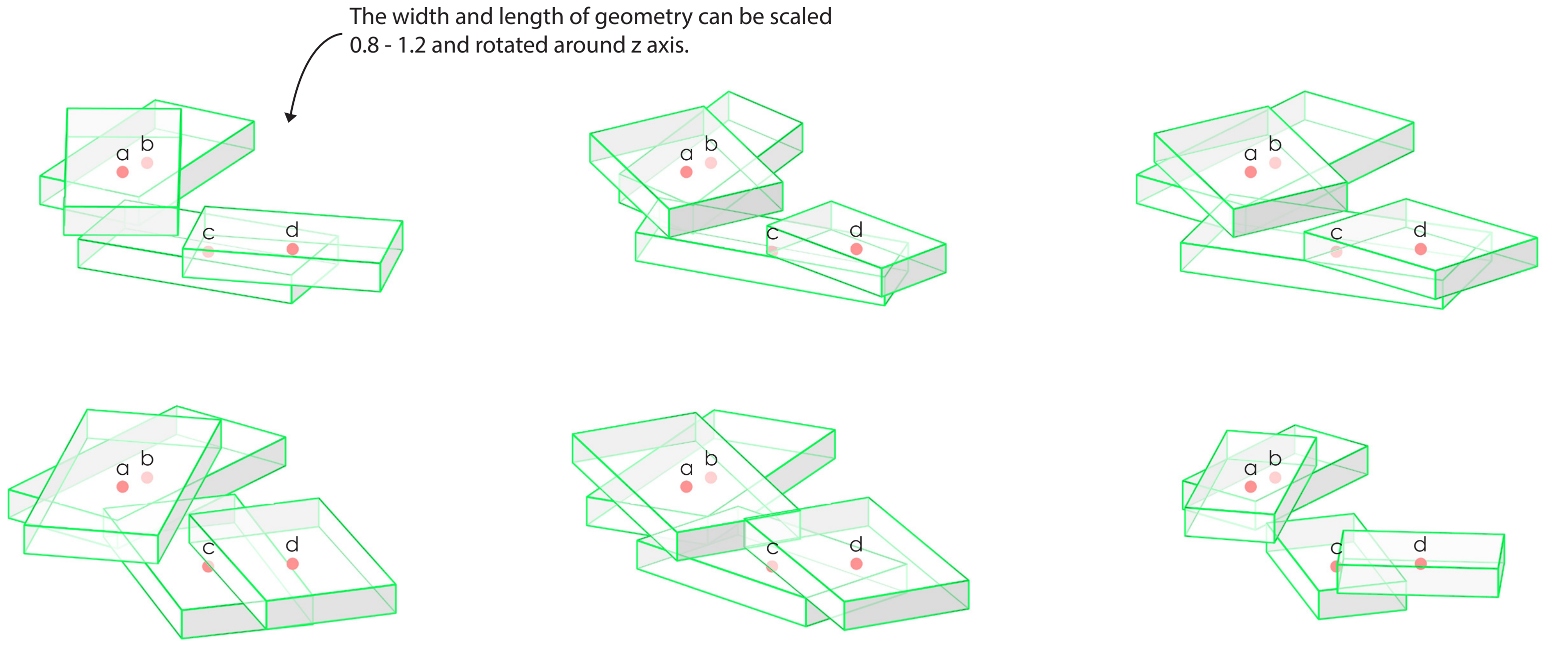


Parametric box C

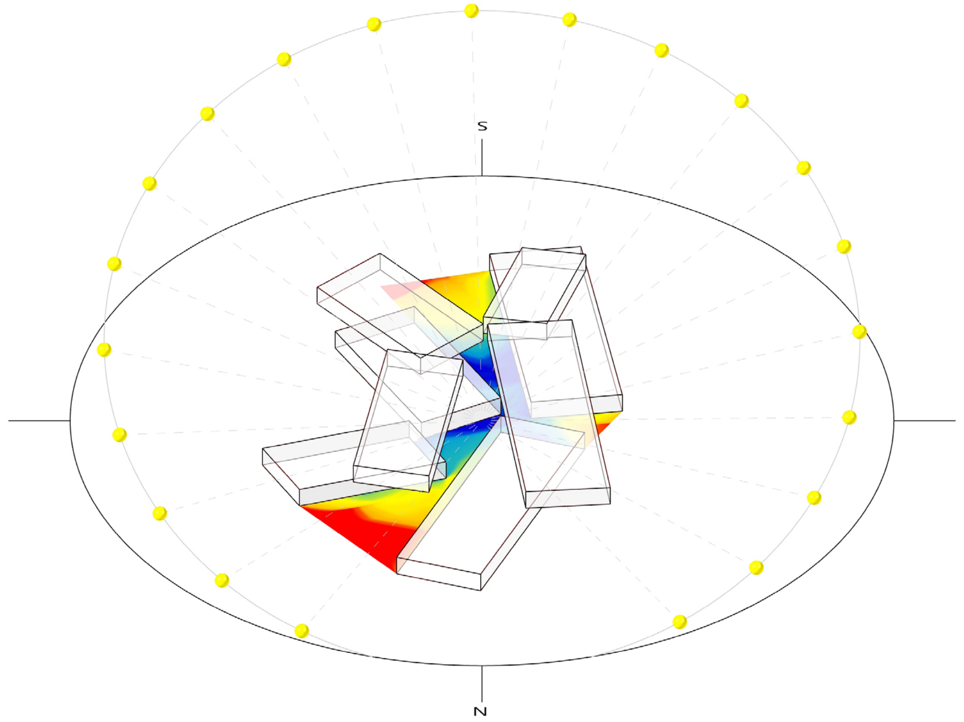




Movement

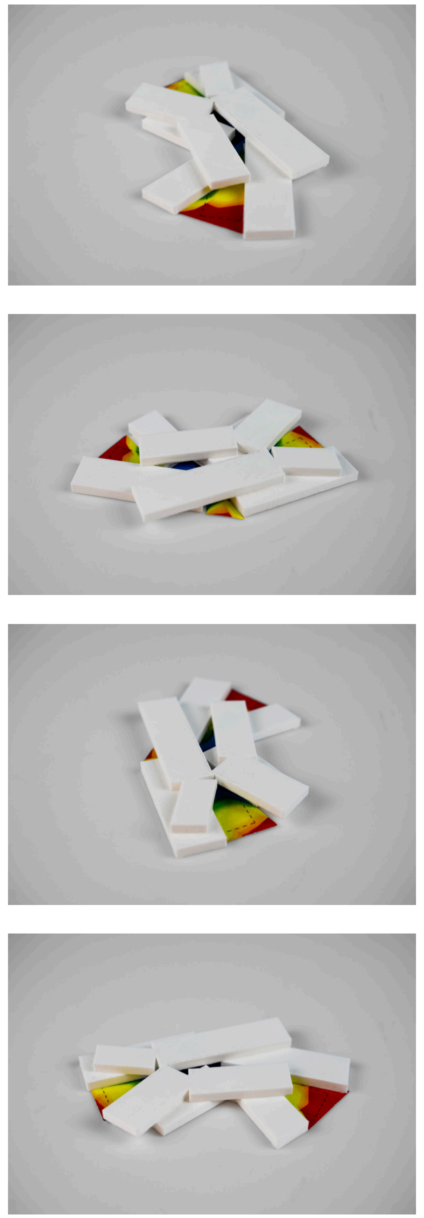


Direct sun analysis

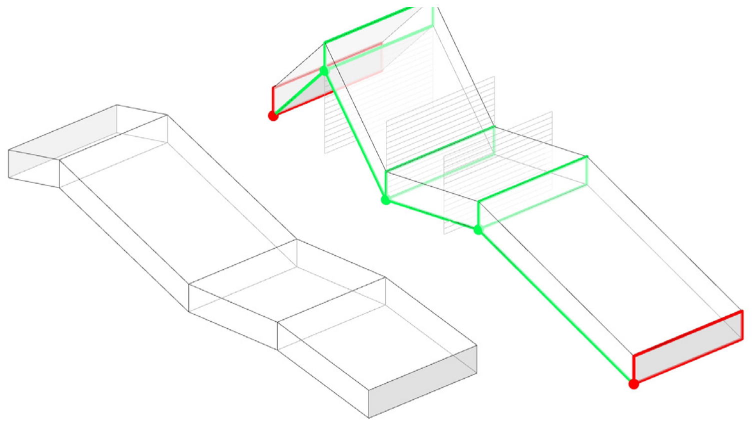


Solar hours (hr)

3D - Print

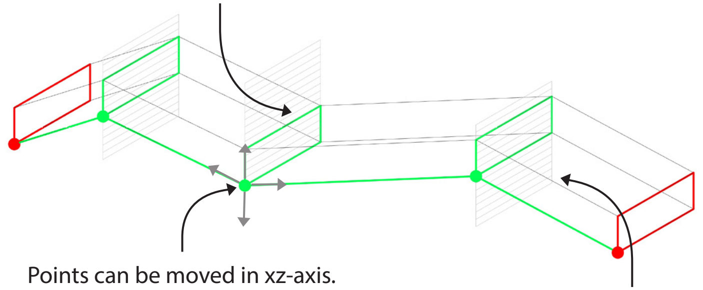


Parametric box D

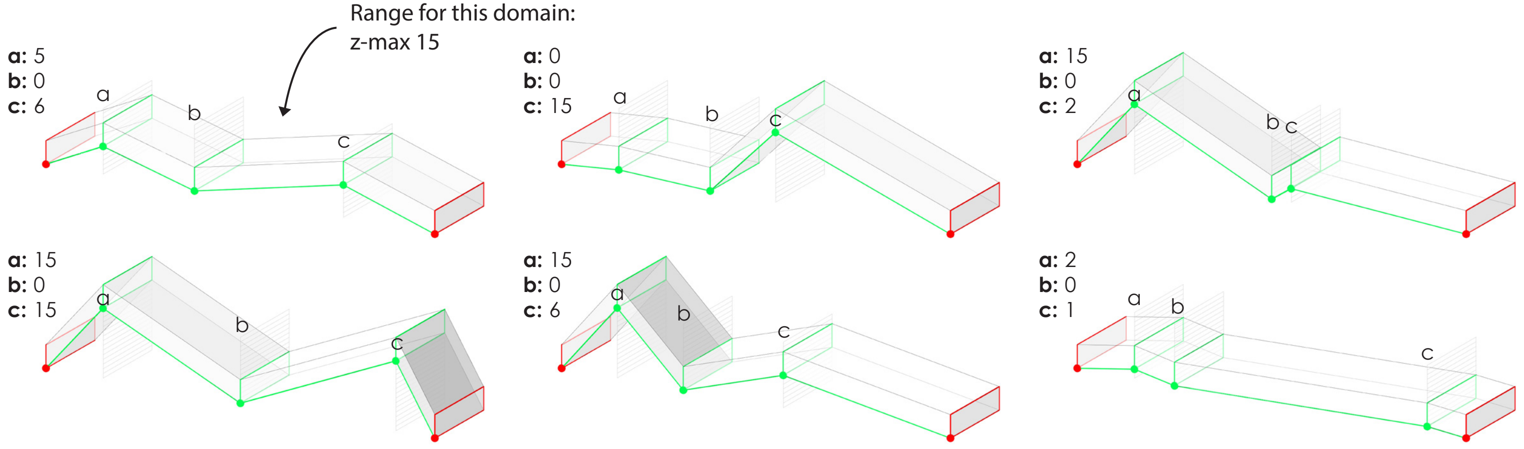


Input geometry

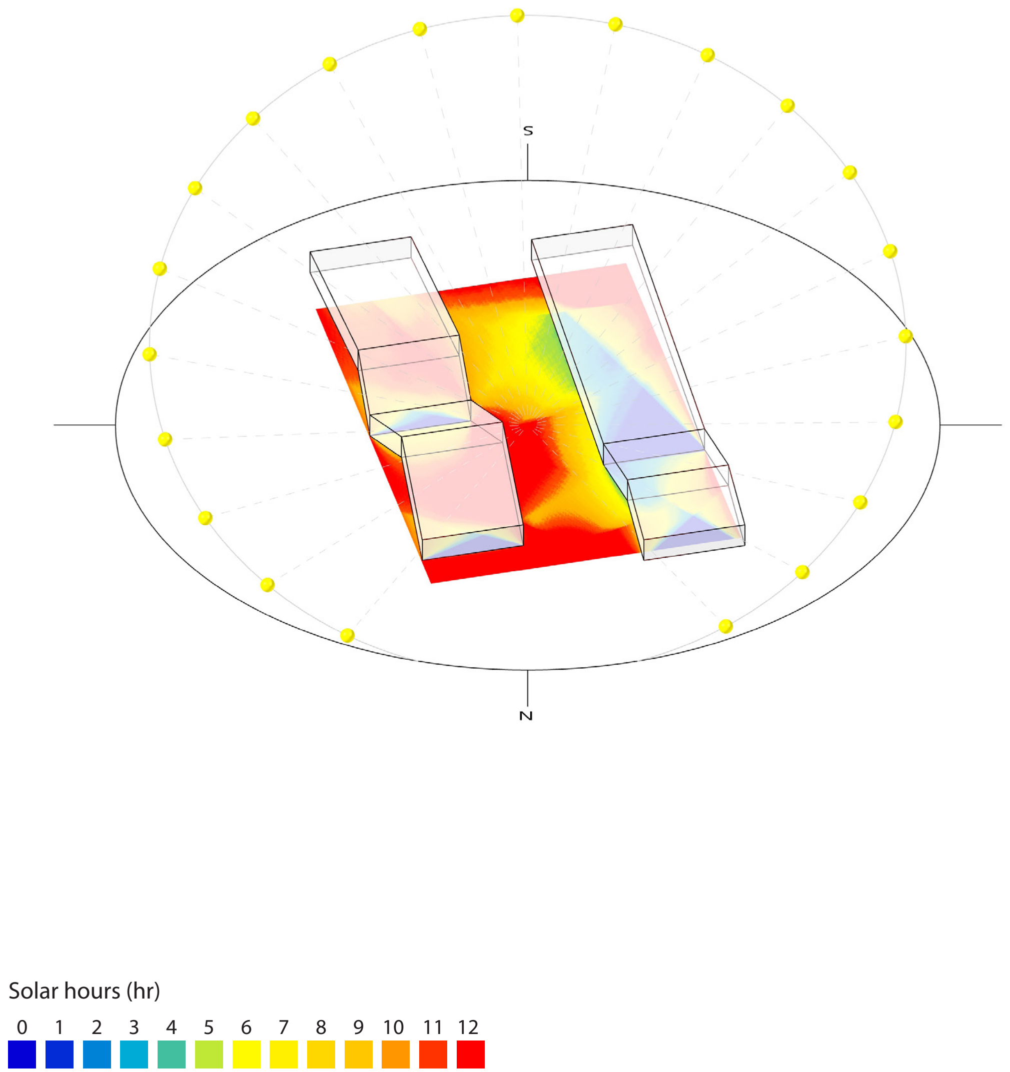
- Dynamic
- Locked



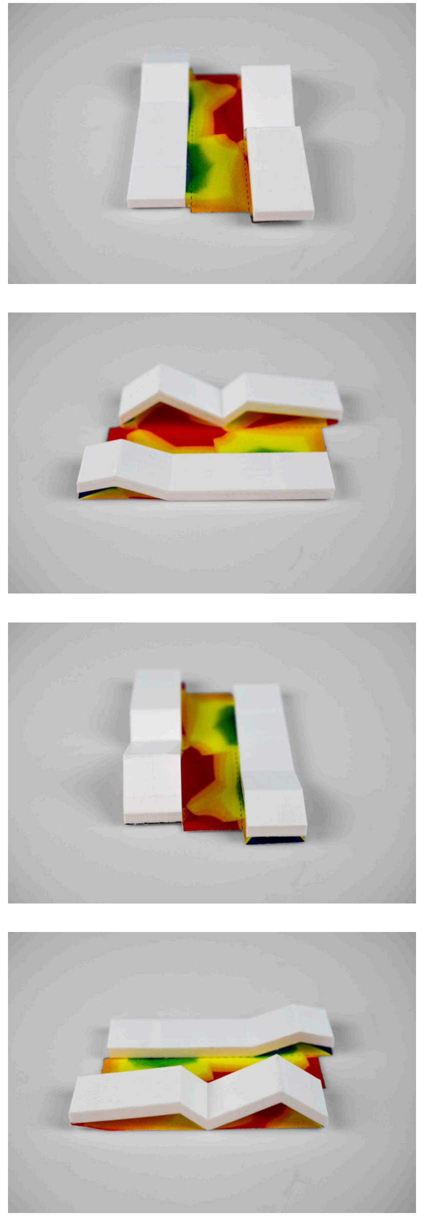
Movement



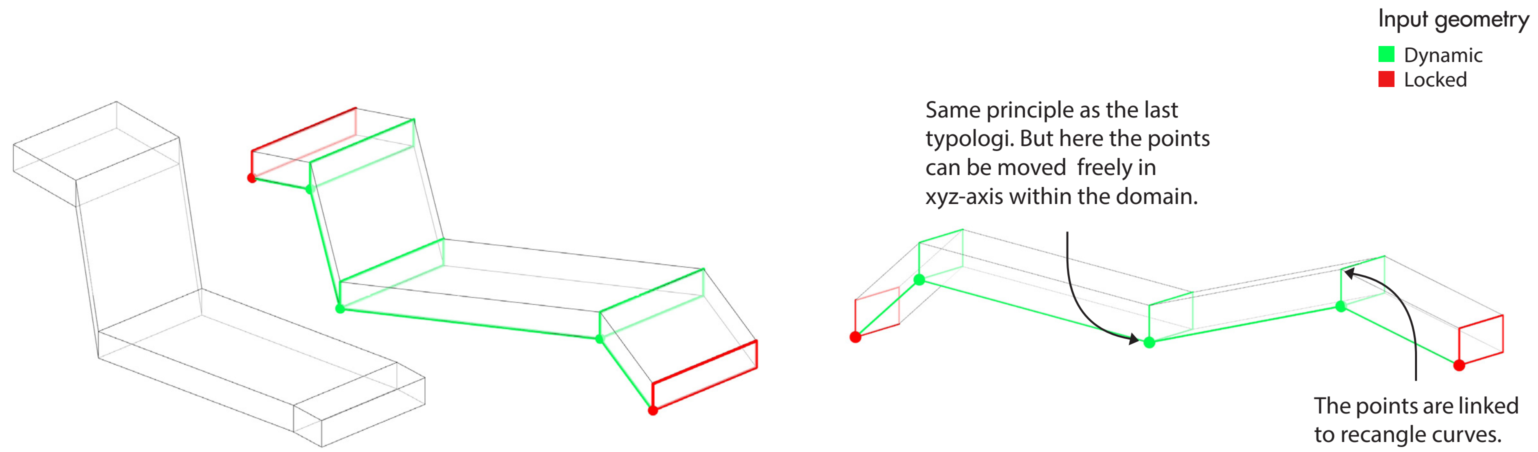
Direct sun analysis



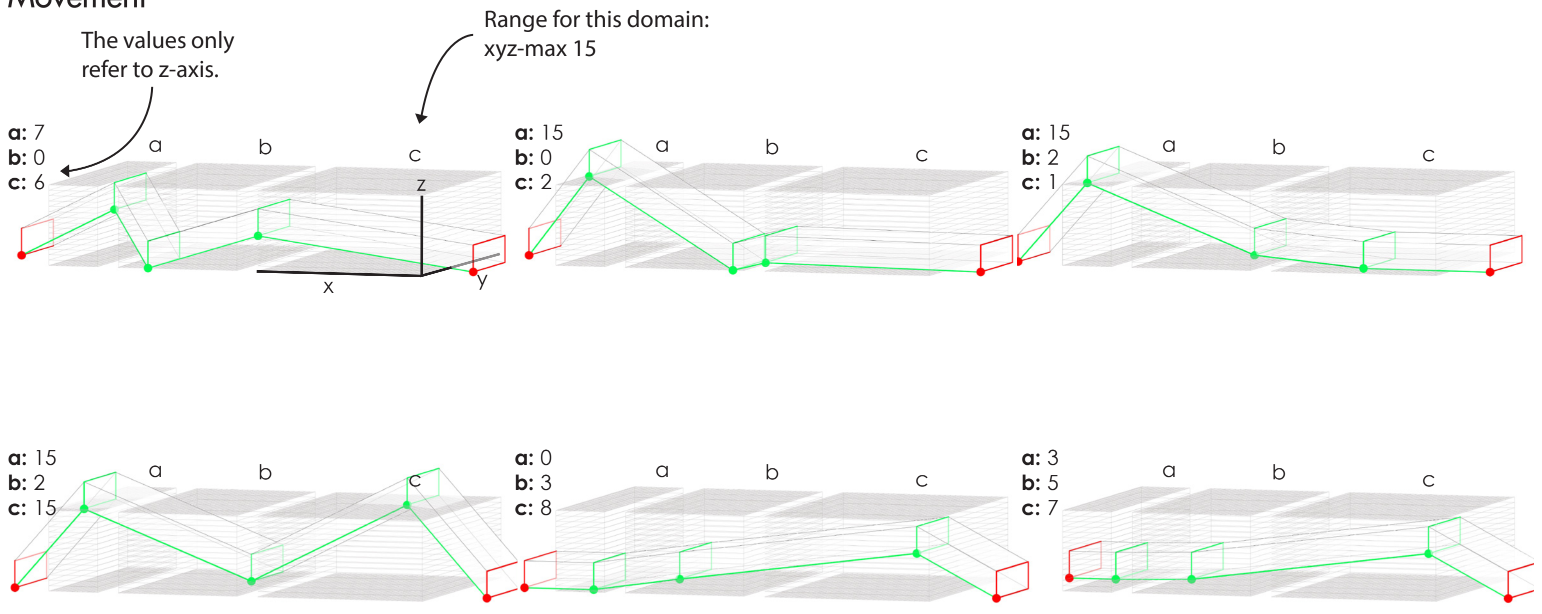
3D - Print



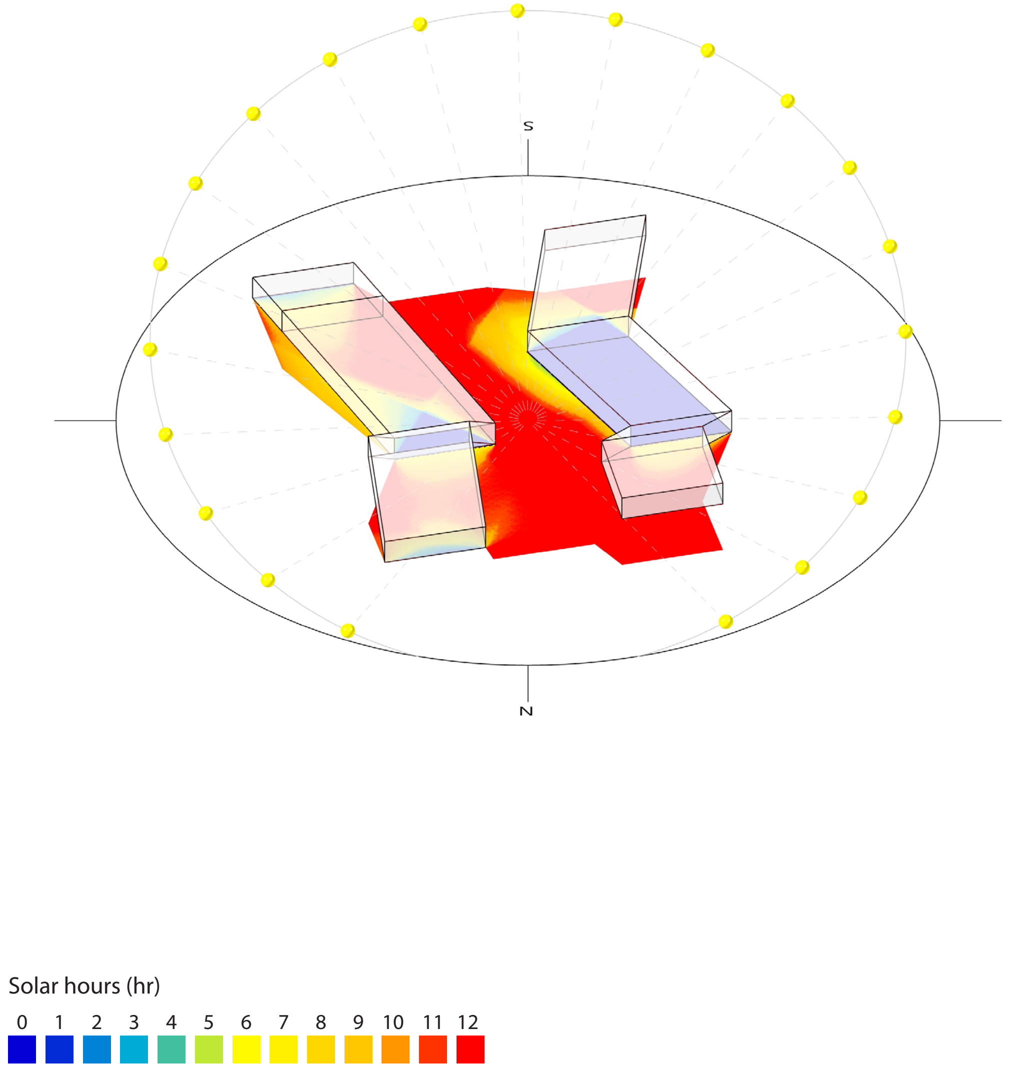
Parametric box E



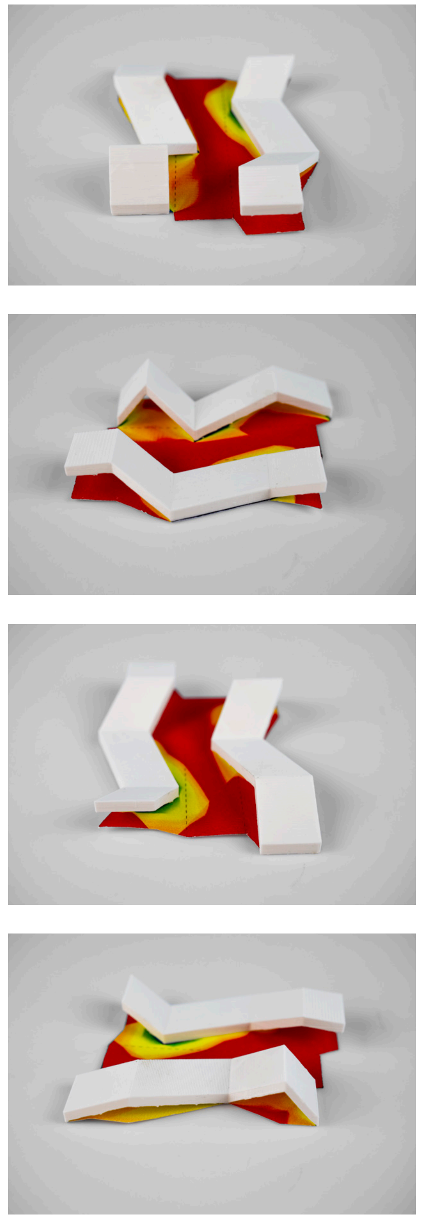
Movement



Direct sun analysis



3D - Print



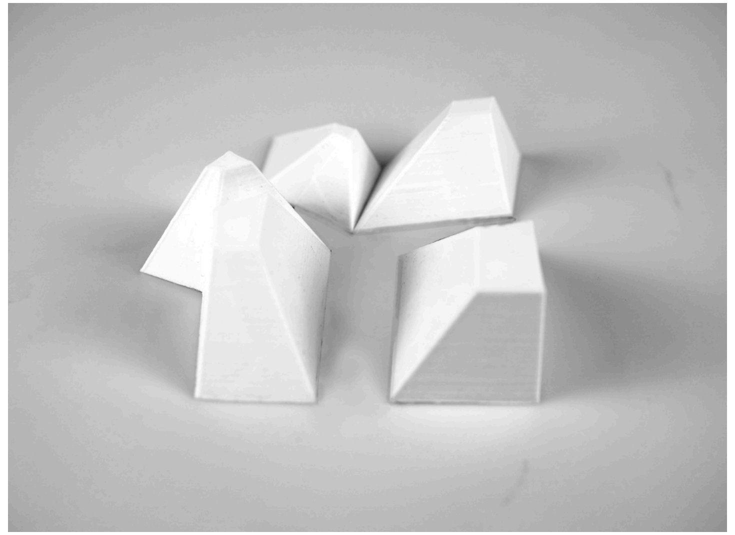
Selection

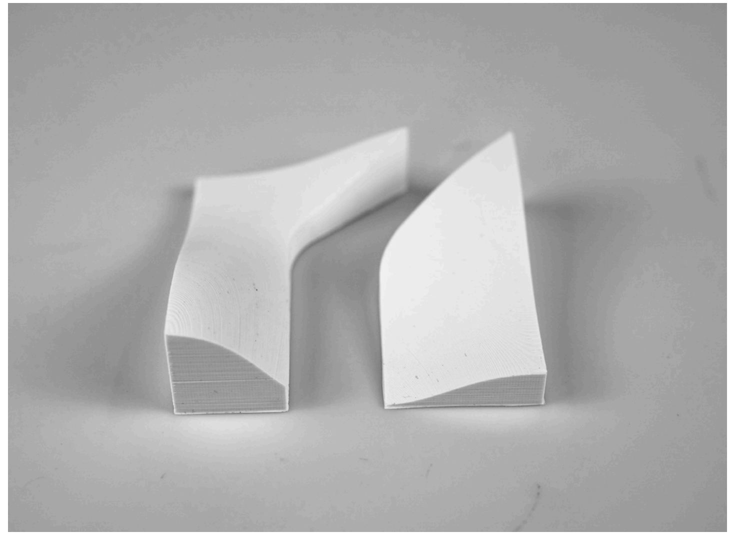
We considered these four iterations to be the most successful. Therefore, they qualified for the next phase.

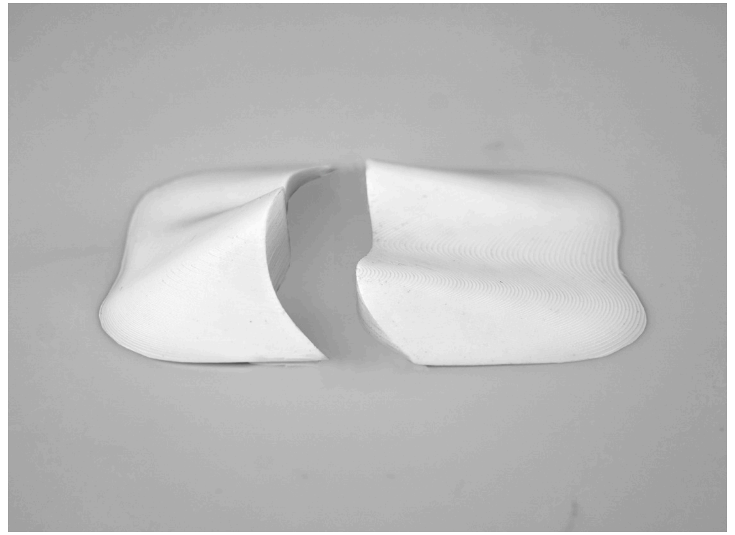
In addition to analyzing the typologies based on performance, an awareness of the upcoming competition started to emerge. We wanted to find a typology that suited the narrative of the project. Based on the dramatic landscape on the site, we started to play with the notion of using this as an expression. From here on, we conceived the iterations more as building volumes than abstract forms. The next step was to analyze visual connectivity to the context and the daylight conditions.

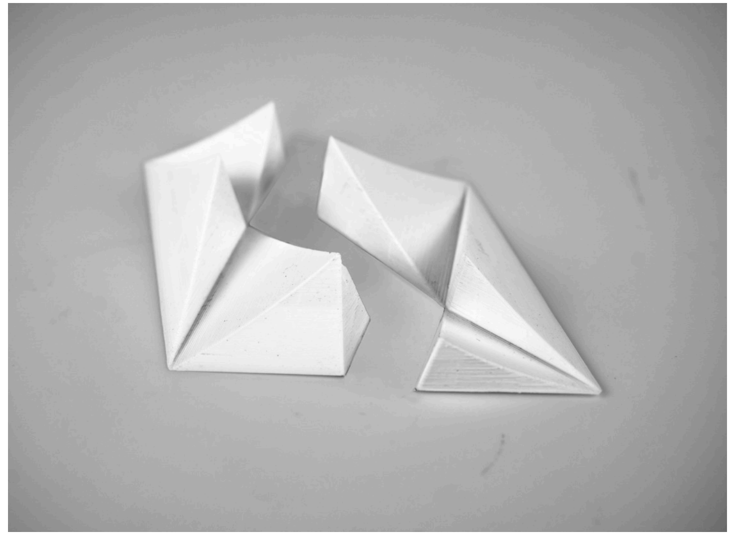
The museum and its geological context.

The concept of aesthetics and narrative is something that the computer can not optimize (depending on what you constitute as aesthetics and narrative, of course). It was therefore up to us as conscious architects to come up with the realization of the visual adaption of the geolocical context.





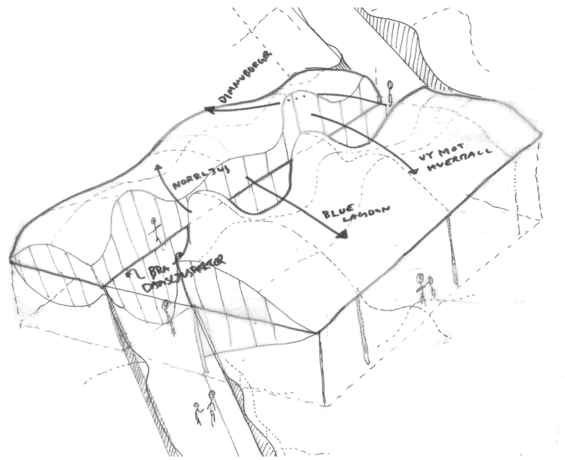




Most successful iterations

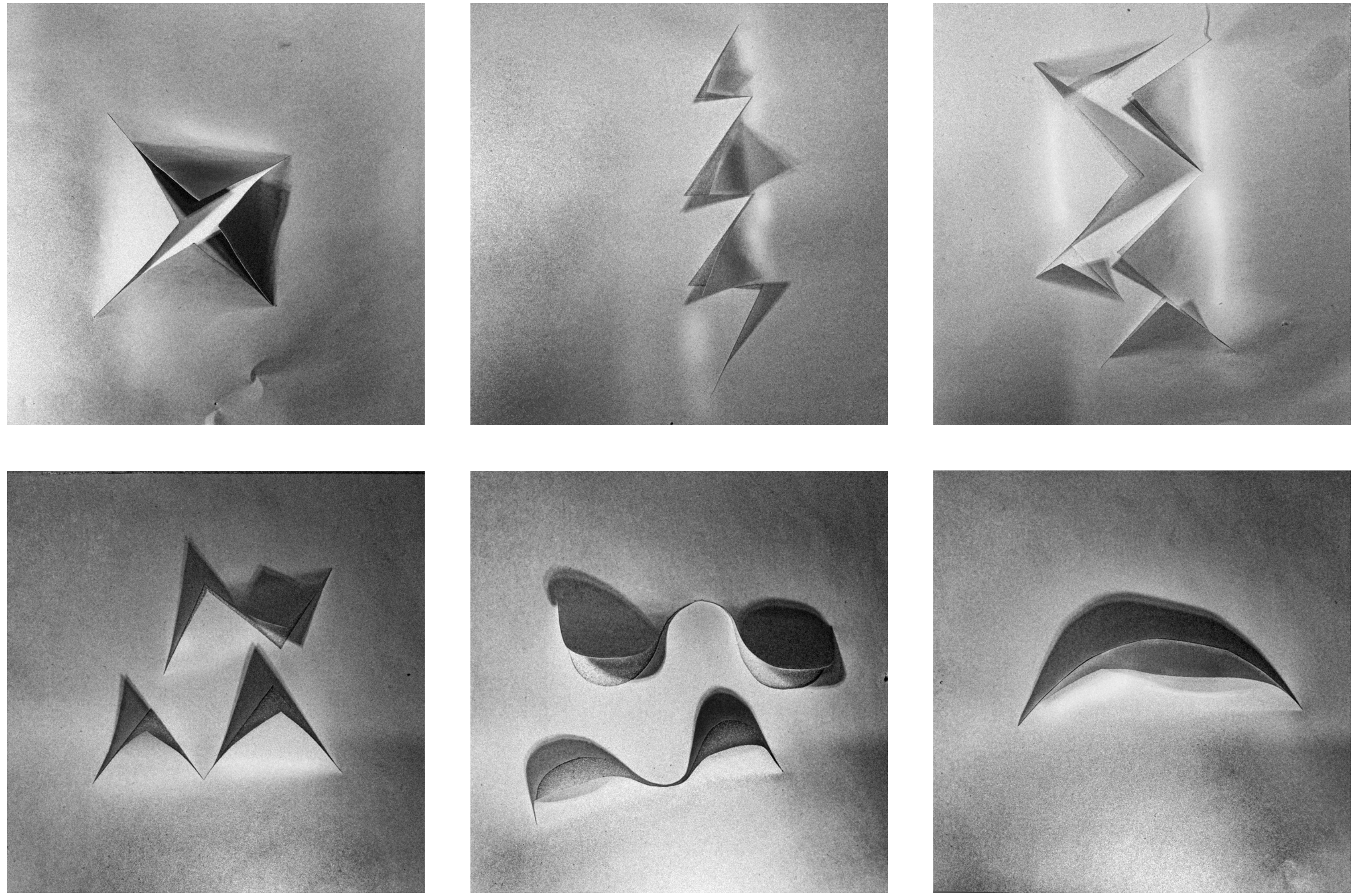
Physical vs. Digital

In parallel with the digital process, we worked with physical sketches as a complement. Both in the form of pre-digital sketches and post-digital 3D prints. The analog sketches helped us to understand the narrative more clearly while the physical 3D prints facilitated the evaluation process. Instead of just looking at a computer screen, we gained more information by actively looking and touching a physical object. We also found that physical sketches can act as an efficient conversation tool in the design phase.



Physical sketch as conversation tool.

We saw this as an opportunity to investigate a hybrid methodology where you can use both analogue and digital methods together. This also proved to create a couple of challanges that we will elaborate more detailed in our evaluation.

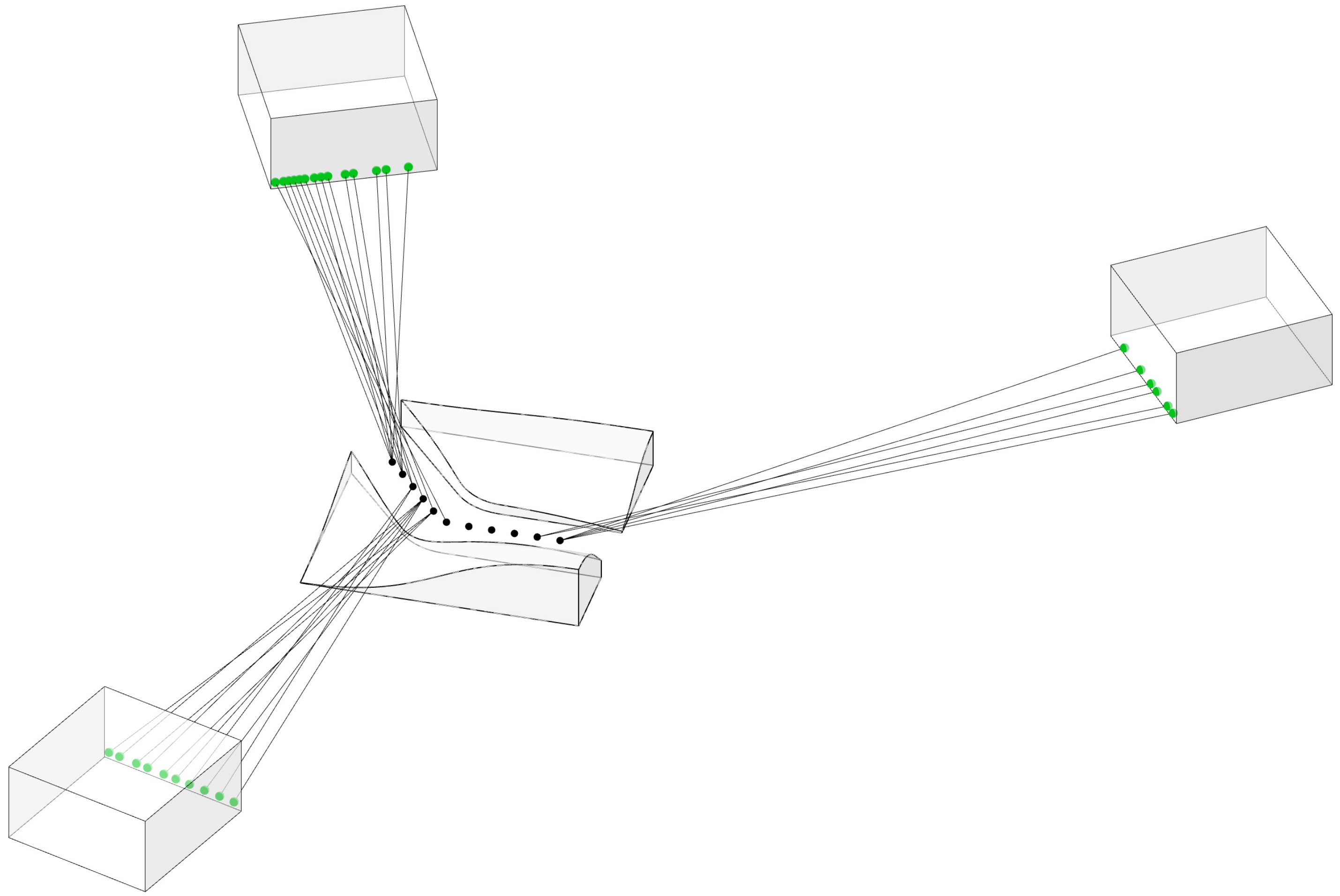


Paper sketch models

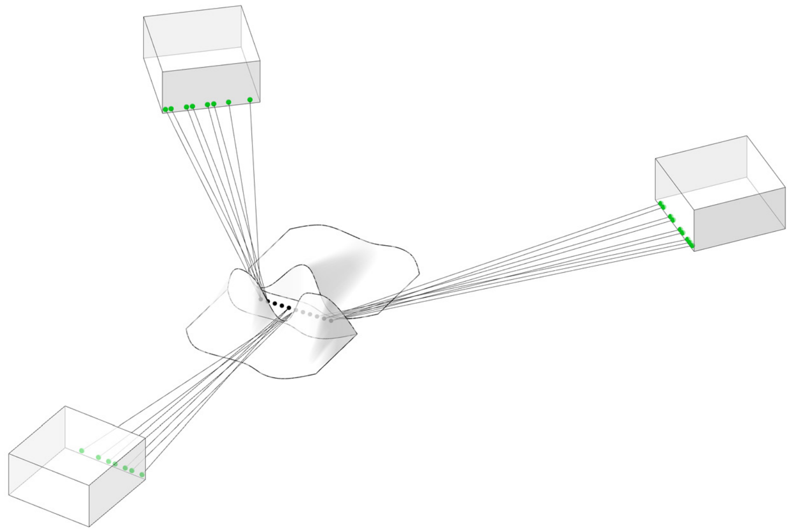
Workshop 2: Visual connectivety

The focus of this experiment was on developing an algorithm that optimized the visual contact with the volcanoes around the site. We created geometrical representations of the volcanoes in the form of boxes and placed a set of points between the two volumes in the typology. The points represent human views by projecting vectors in all directions, from the height of a human eye. The goal of the algorithm is to optimize the visual connectivity between the boxes and the points by manipulating the building mass so that the vectors are not blocked by any volume, and hit the boxes that function as the targets for the vectors. We also set up a scoring system where the computer was rewarded if it hit more than one box to create an extra incentive. Again, we added a contradiction for the algorithm to maximize the volume to force creative solutions.

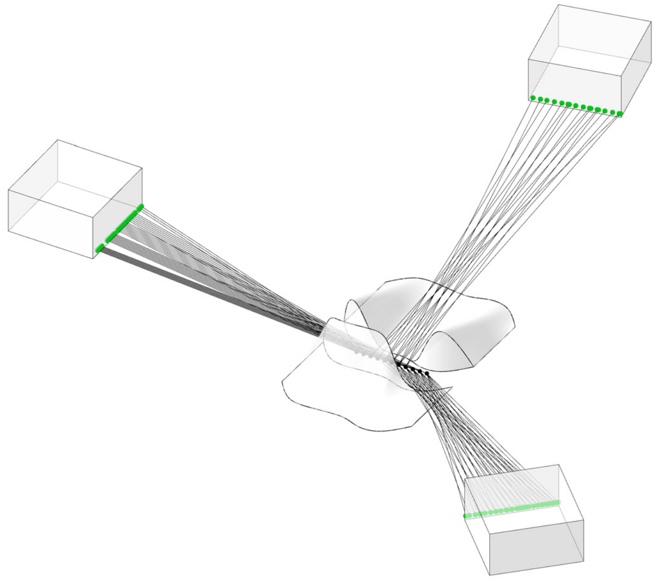
When we introduced a new objective, it was possible to distinguish which typologies were adaptable and which were too limited in their structure to deal with several objectives at the same time.



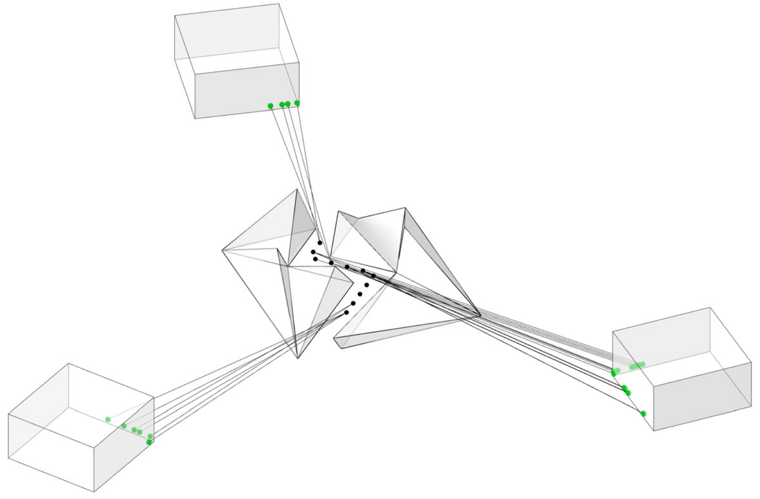
Example of visual connectivity simulation



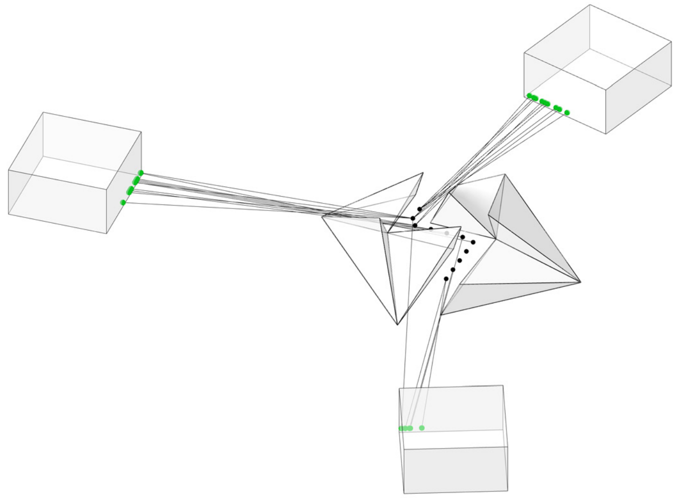
Typology 1



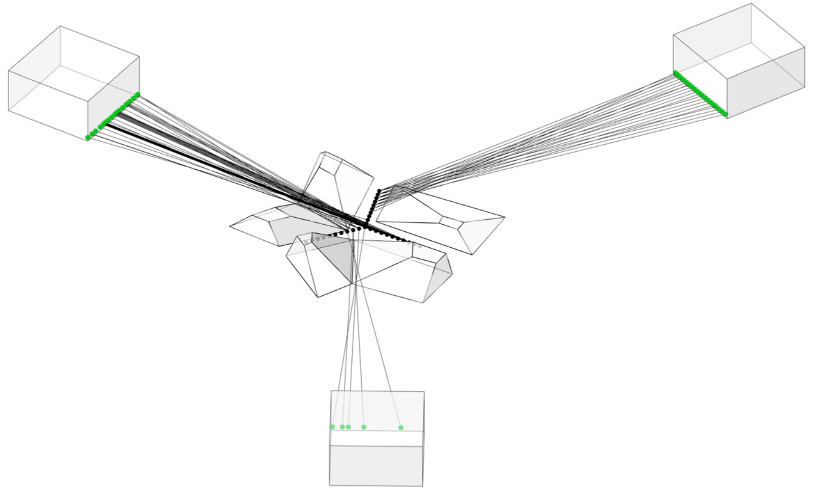
The mass of the typology is manipulated when
we move the boxes (or volcanoes).



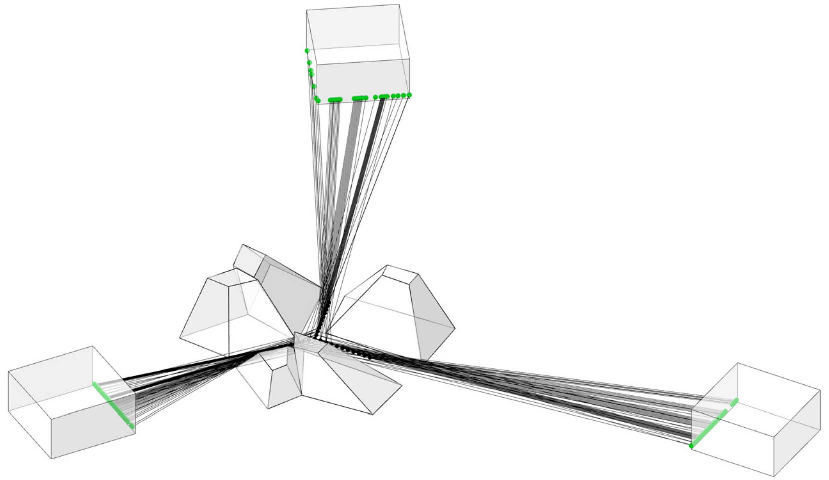
Typology 2



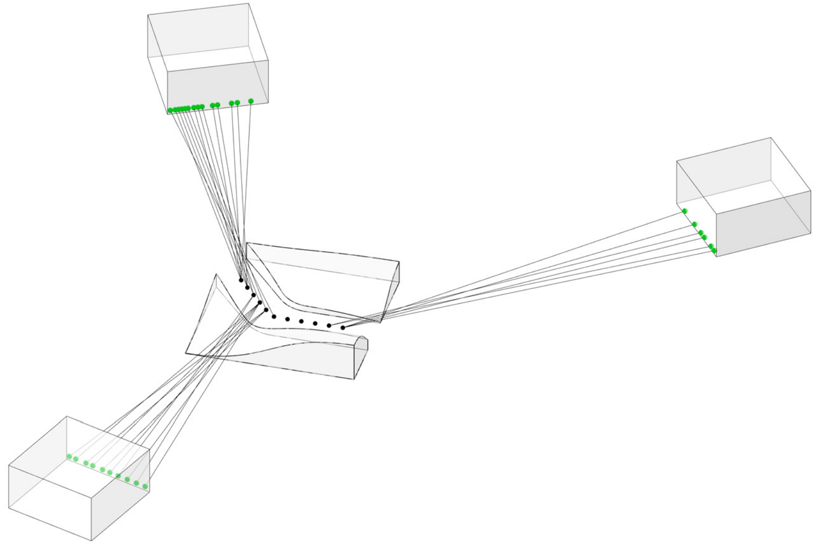
The structure of typology 2 is less flexible than typology 1.



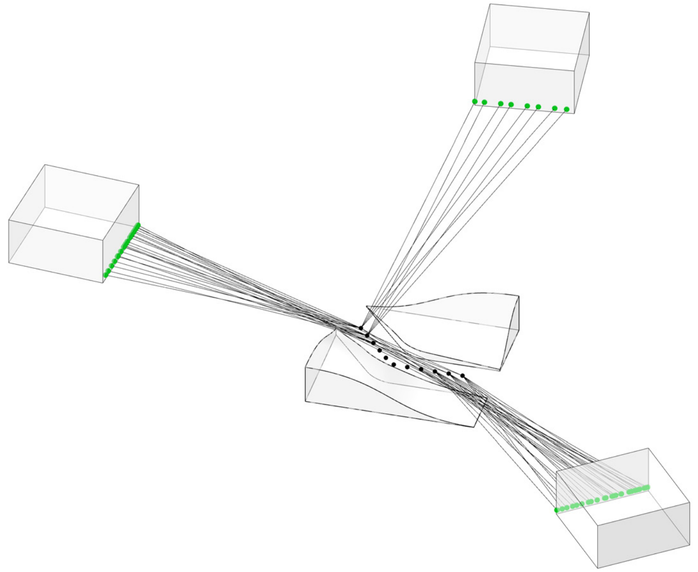
Typology 3



The visual connectivity got restricted to the 'courtyard'.



Typology 4



This typology allows the sightlines to penetrate the volumes, not just the courtyard.

Workshop 3: Minimize glare

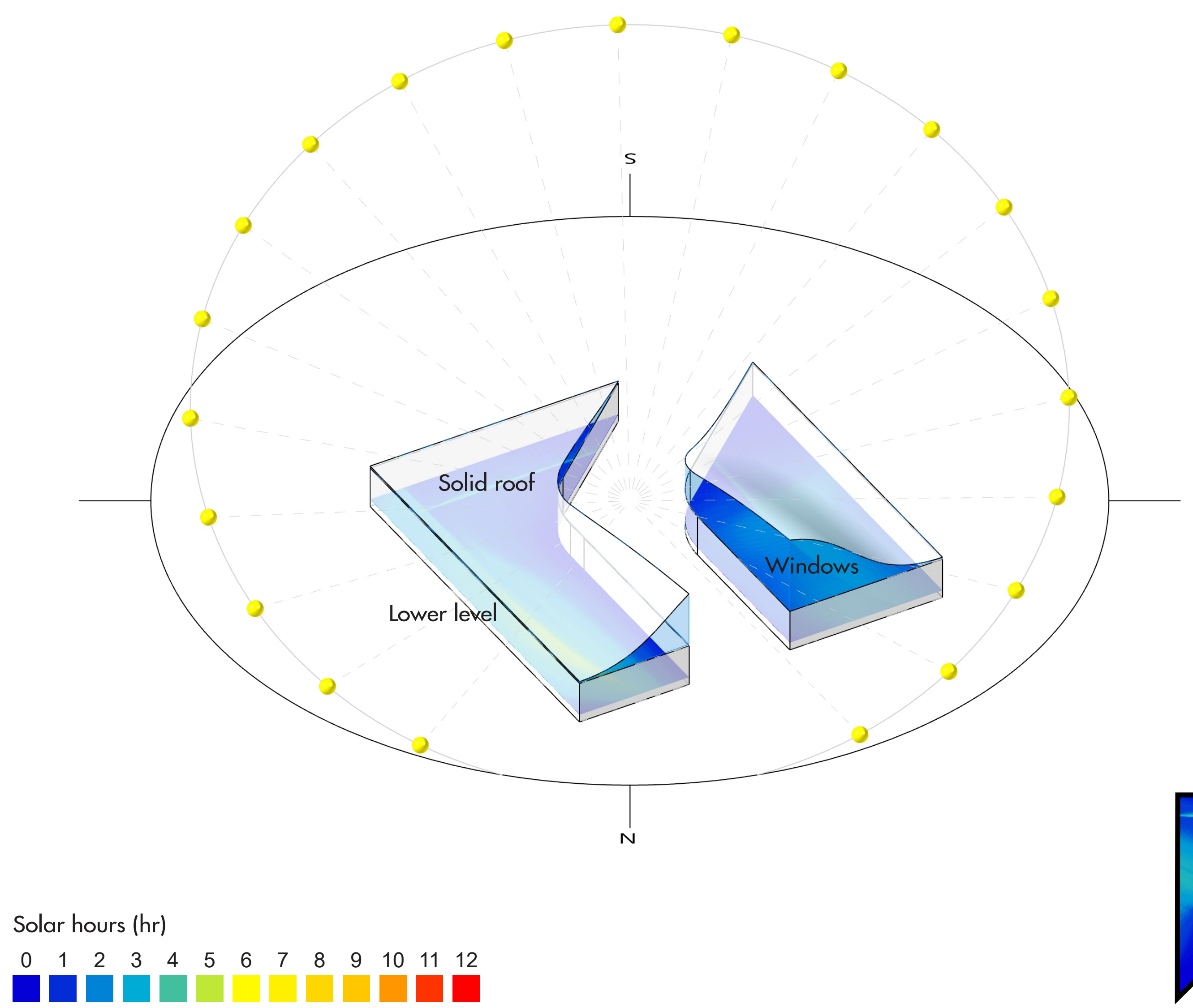
In order to analyze the glare and daylight of the building volumes, we had to define what was the window and wall/ ceiling in the building. We wanted all tests to be analyzed on the same premise. The windows were consistently placed on the sides facing the pathway. The contradiction was to maximize daylight and minimize glare.

We noted that the two volumes in each typology strived to reach the same height. The algorithm thus found the solution to maximize the window area, and thereby maximizing daylight, while at the same time blocking the direct sun for the opposite volume, which ultimately minimized the glare.

The geometry in these simulations consists of solid roofs, transparent windows, and a lower level that wants to get as much light as possible while at the same time minimize the glare.

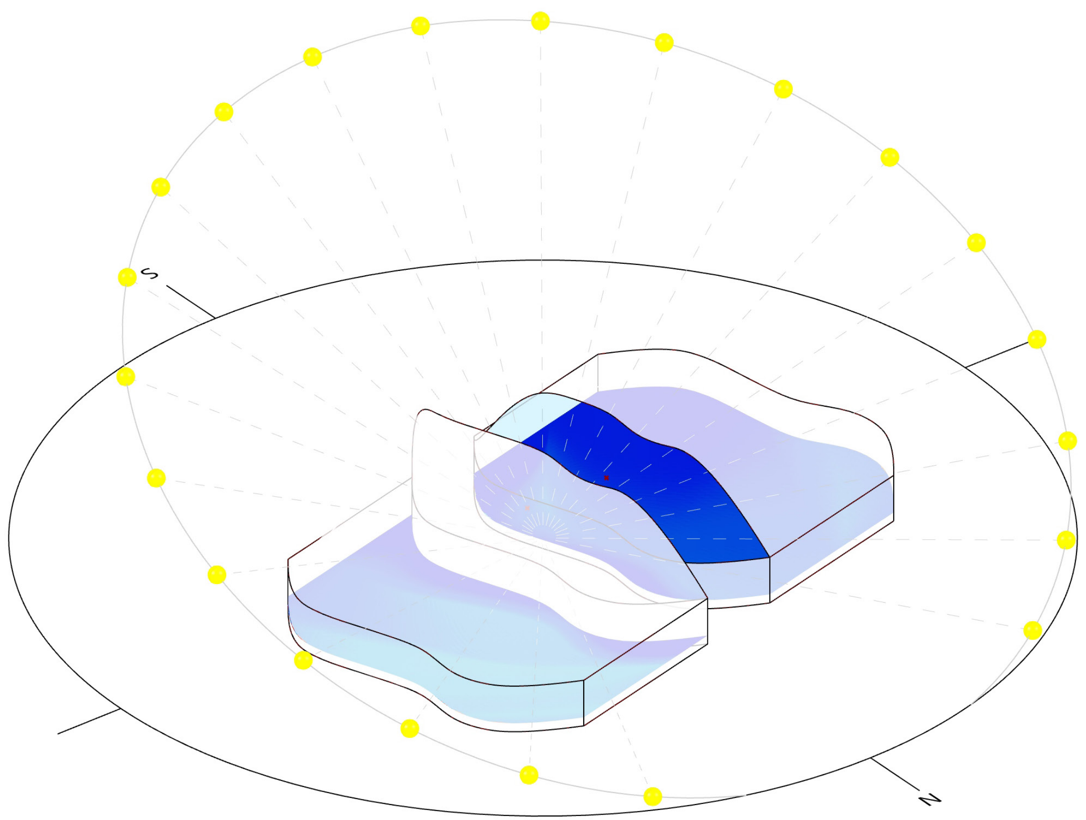
We still used the same types of geometries that we found the most succesful in the previous experiments.

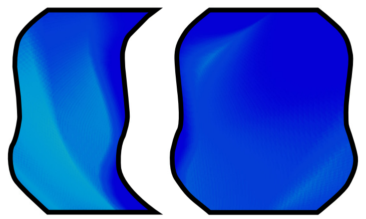
Example of a glare simulation.



Top view

Minimize glare simulation



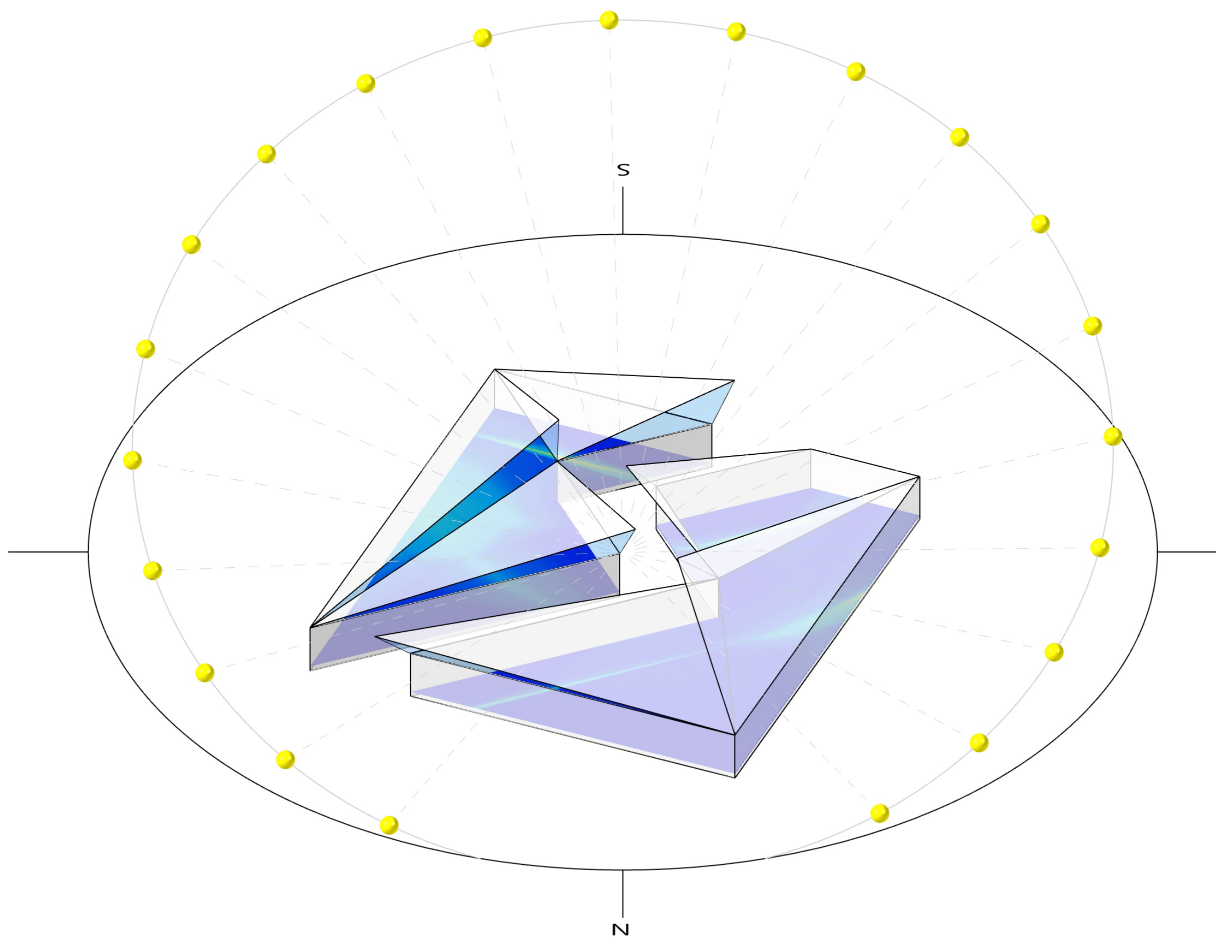


Top view

Solar hours (hr)

0 1 2 3 4 5 6 7 8 9 10 11 12

Minimize glare simulation

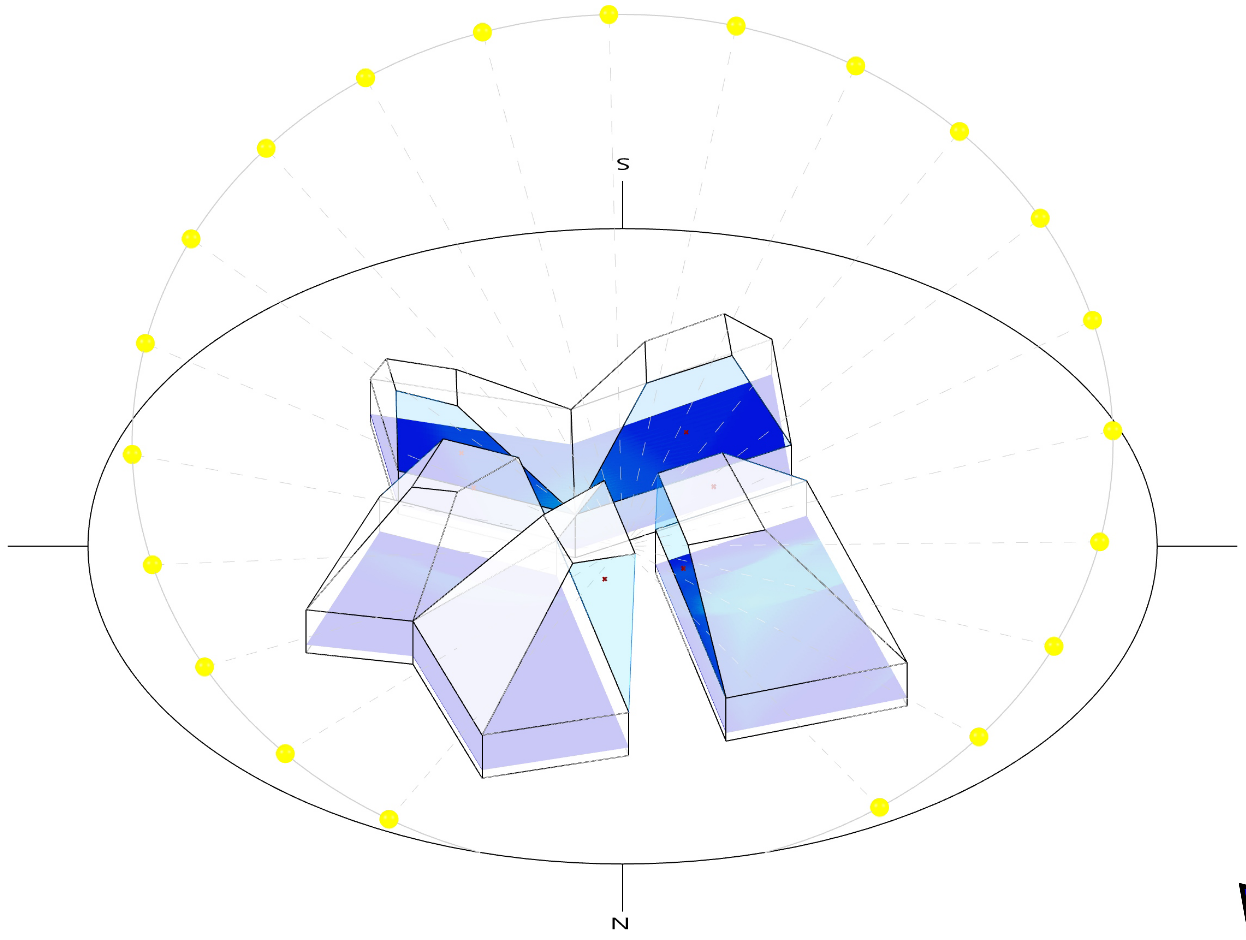


Top view

Solar hours (hr)

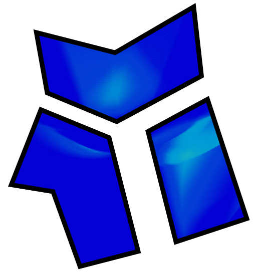
0 1 2 3 4 5 6 7 8 9 10 11 12

Minimize glare simulation



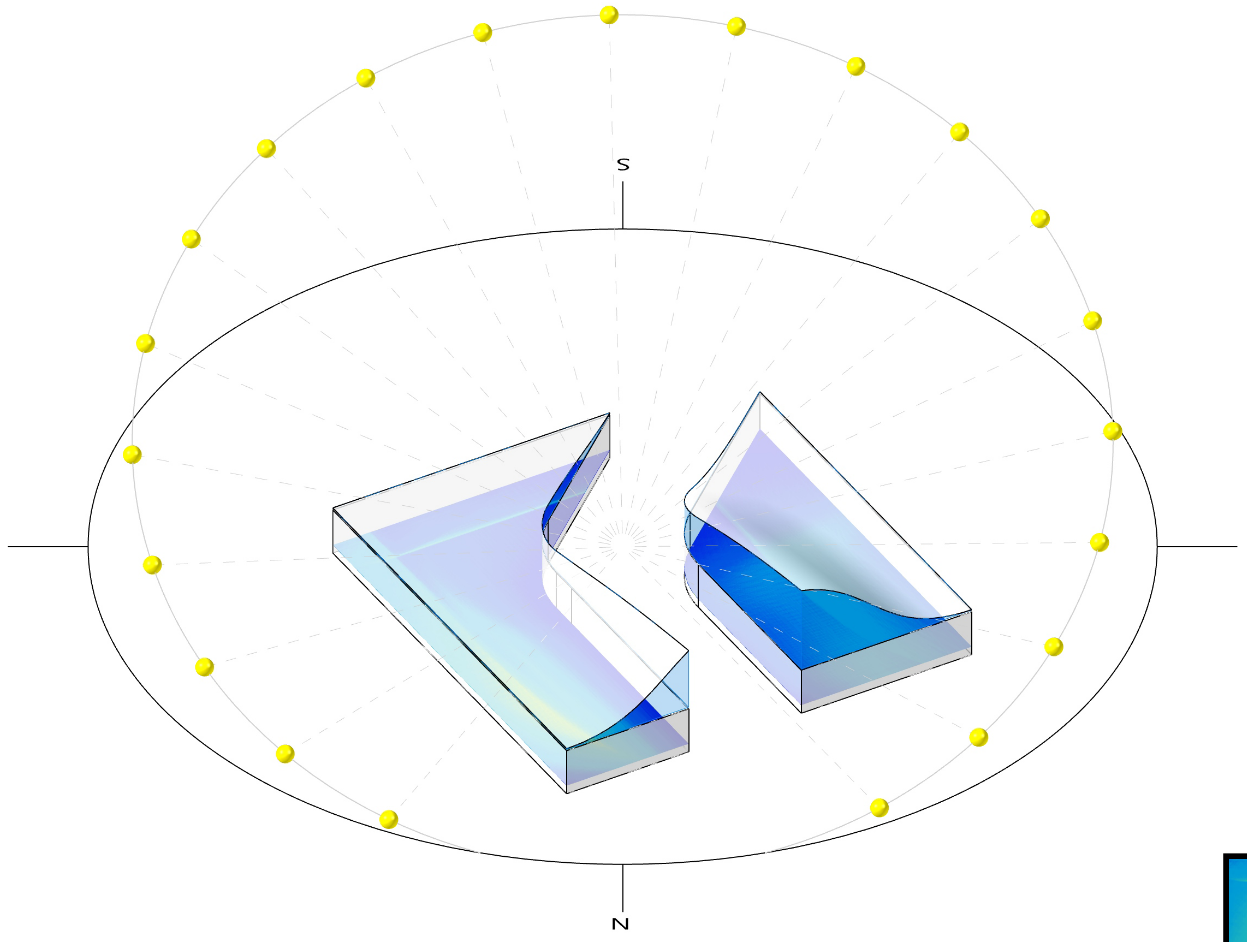
Solar hours (hr)

0 1 2 3 4 5 6 7 8 9 10 11 12



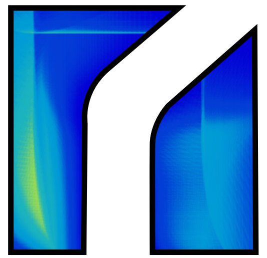
Top view

Minimize glare simulation



Solar hours (hr)

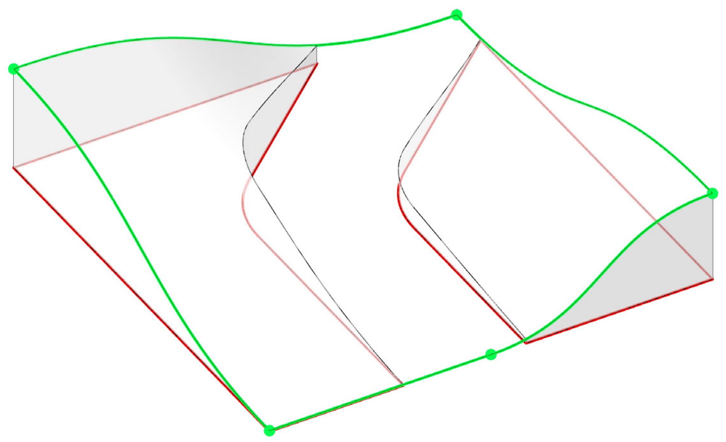
0 1 2 3 4 5 6 7 8 9 10 11 12



Top view

The selected typology

After the experiments, we analyzed the results of our studies and used the following typology in the competition. The decision was based on a collective amount of parameters. Maybe it was not always the best technically performing typology - but its expression and flexibility compensated for that. For us, it was important not only to optimize the technical aspects - but also to create aesthetic and functional architecture.



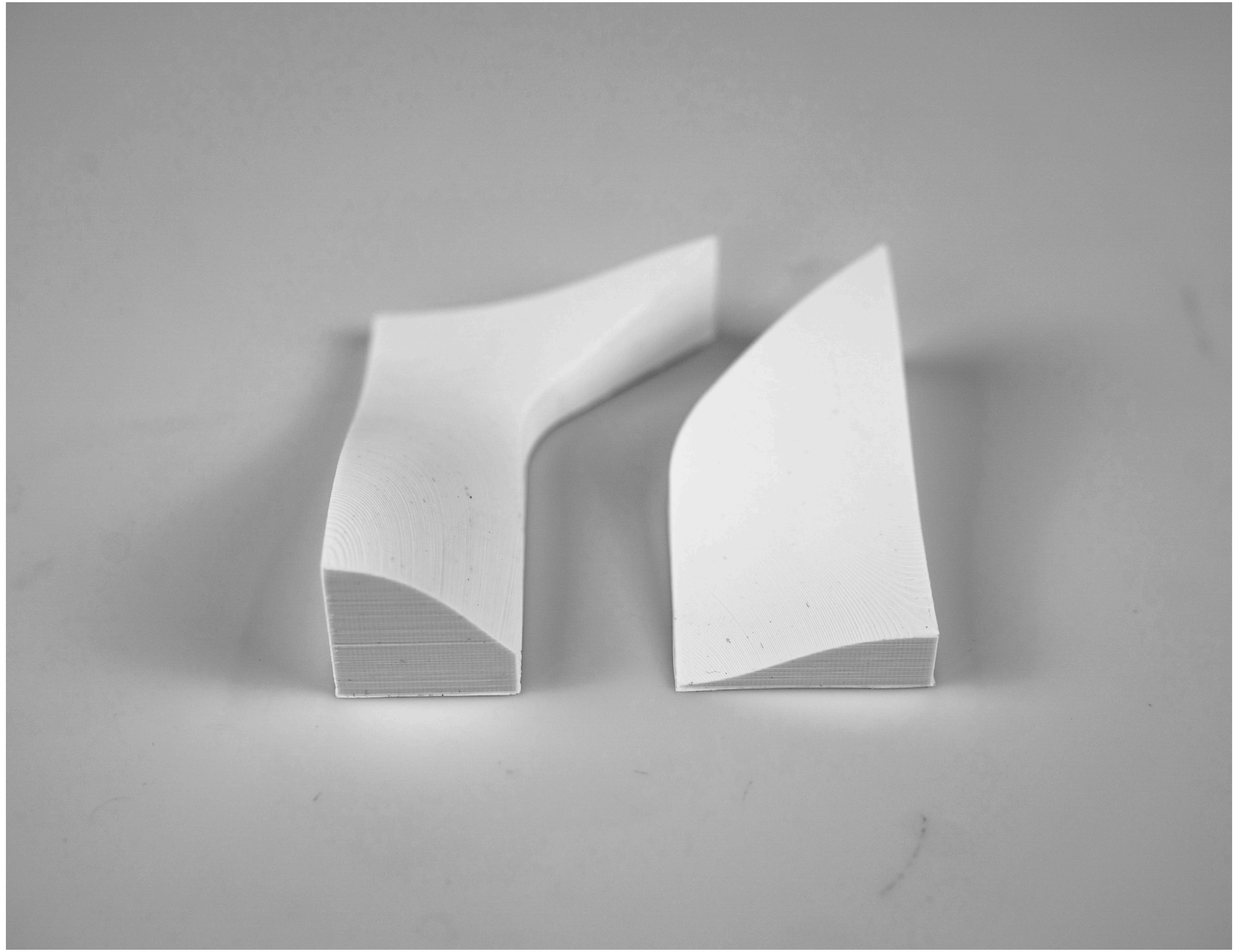
Parametric framework of the selected iteration.

The curating process was interestingly not necessarily technical and computational. We rather subconsciously had a feeling of what would work and what would not. We felt that this iteration resembled the Icelandic landscape, and would in that way fit into the context. When using this generative design-methodology, you constantly negotiate the different objectives against each other. Maybe you want a lot of solar radiation on in one volume, and lesser views. In another volume, it might be a completely different scenario, dependent on what the actual program that the volume exhibits requires.

But as we slowly discovered - you also negotiate the technical aspects with the aesthetic and contextual aspects. With generative design, which is a kind of primitive version of artificial intelligence, the software mimics a conscious AI. In a very rational way, it understands what its role is and what it is expected to optimize. But architecture is not only about rationality. Architecture is also about the subjective and the relative. How can somebody define exactly how to express something specifically Icelandic? Maybe the Icelandic is different and subjective to each and every one. And maybe there's a specific factor of that culture that we would like to enhance in this project.

Generative design simply can not offer us any solution for this. Therefore, we had to be included in the algorithm, and constantly steer the narrative to fit our purpose.

This means that you do not only negotiate between different fitness goals, you also negotiate between fitness goals and subjective factors such as narrative. Maybe a very technically optimal solution does not give rise to any cultural connotations? With more advanced AI, it is possible to let the computer come up with these subjective ideas. We will discuss how to theoretically use these technologies in our last chapter.



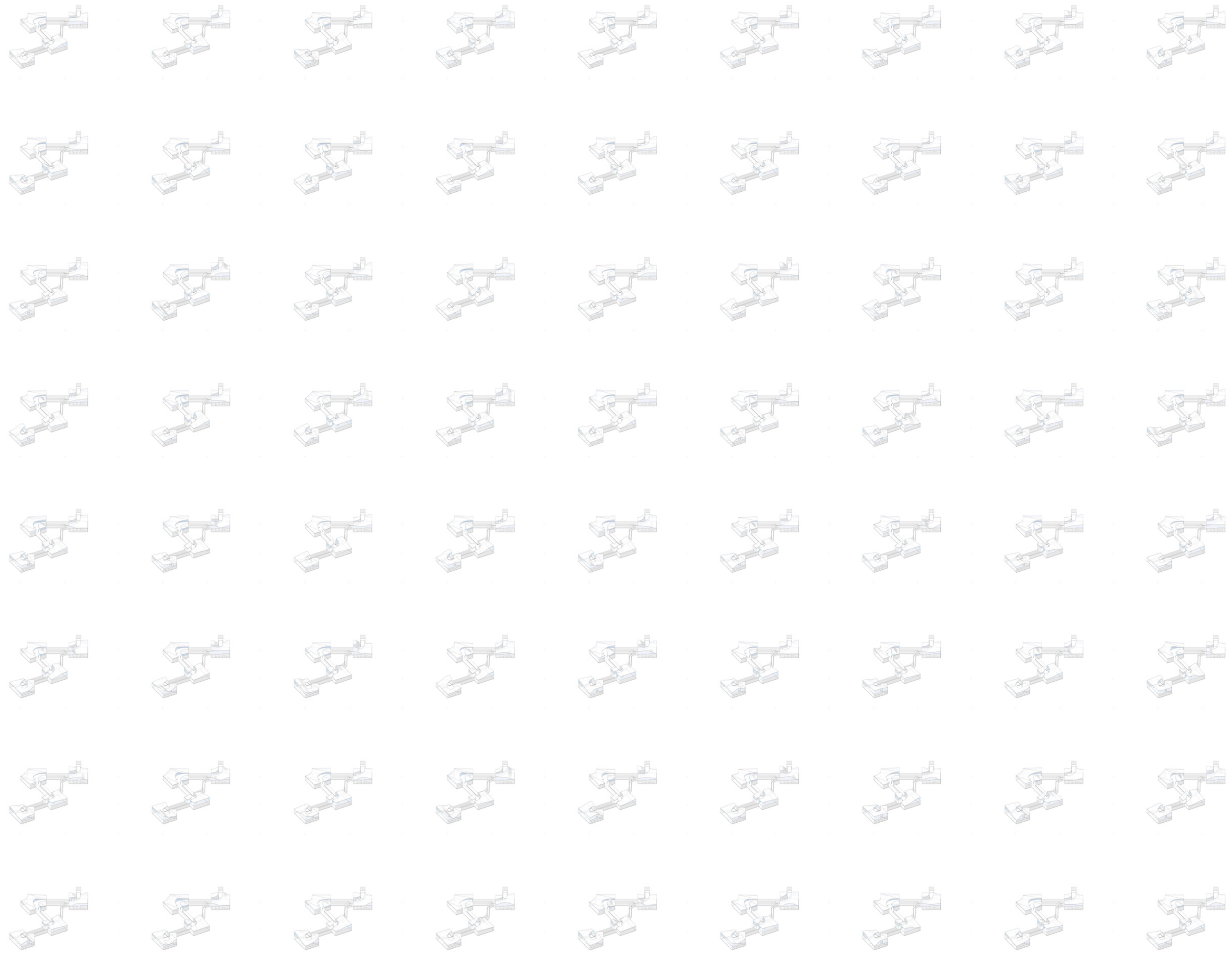
3D-print of the selected iteration.

Architecture with a digital approach

After the initial studies, it was now time to implement the methodology on an architectural project. We chose to participate in Bee Breeders competition for a volcano museum on Iceland. The reason for choosing to participate in a competition was that it would give us a framework to operate in, and to see how far we could take the methodology within an architectural context.

We now spent a period of time defining the narrative, the program and the plan for the museum and classified them as locked. By clearly defining locked and unlocked parameters for the project, we were able to constrain the algorithm to fit our purpose. The task of the algorithm was to optimize the configuration of the roof. Interesting objectives were interior lighting conditions, exterior micro-climate on the courtyards, and the visual connectivity with the volcano.

We will in a later chapter discuss the opportunities and obstacles that arose by locking the plan and focusing on the roof structure.



Iterations of the museum.

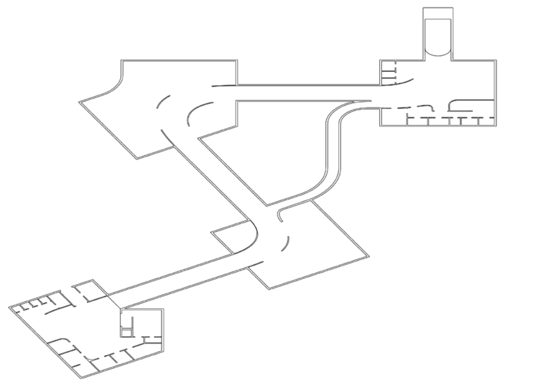
Software to elevate the plan

To generate the building volumes we used Wallacei, which is a plugin for Grasshopper. Like Galapagos, Wallacei's algorithm is based on evolutionary principles. The difference is that Wallacei is developed with the intention to use more objectives at the same time. Galapagos can only optimize one objective at a time.

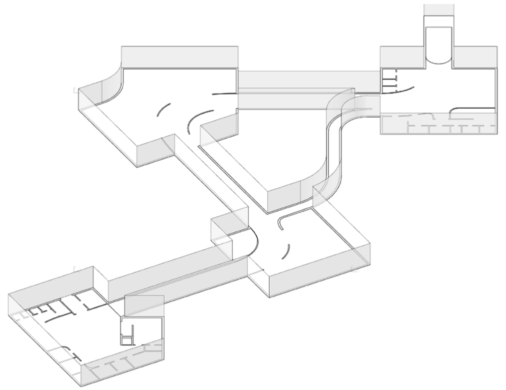
In the previous experiments, we solved this by formulating an equation outside Galapagos where the two objectives could compete with each other. This was far from optimal, as the result was directly linked to the formulation of the equation.

In Wallecei, we combined the algorithms we developed in the previous experiments and were, therefore, able to simulate all three objectives at the same time. The task of the computer is to try to find solutions that meet all three goals at the same time.

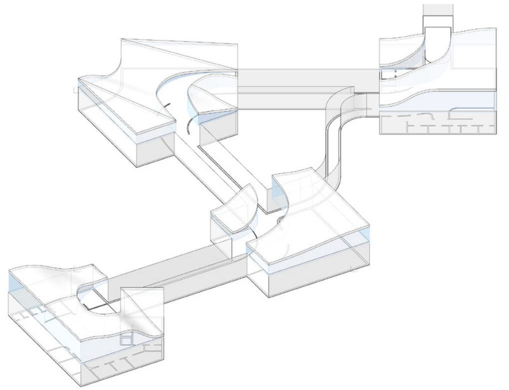
Wallecei also provides a user-friendly interface where you can effectively sort the iterations based on their rankings and get statistics which facilitates the process of negotiation between different objectives.



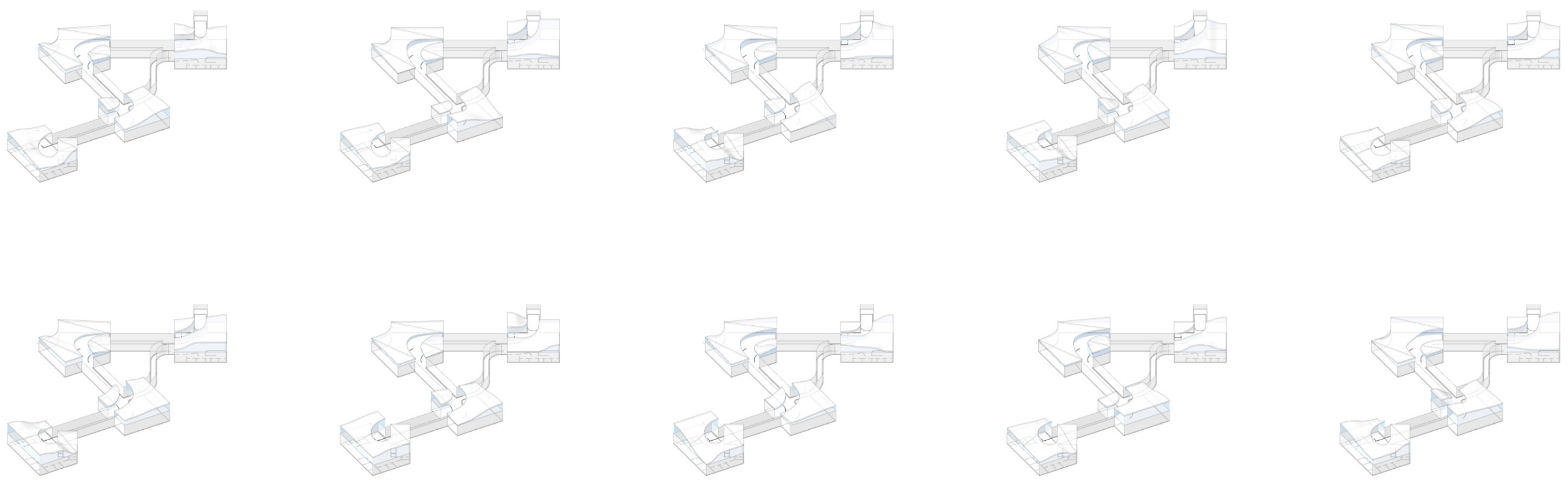
Plan



Extruded walls



Parametric roof



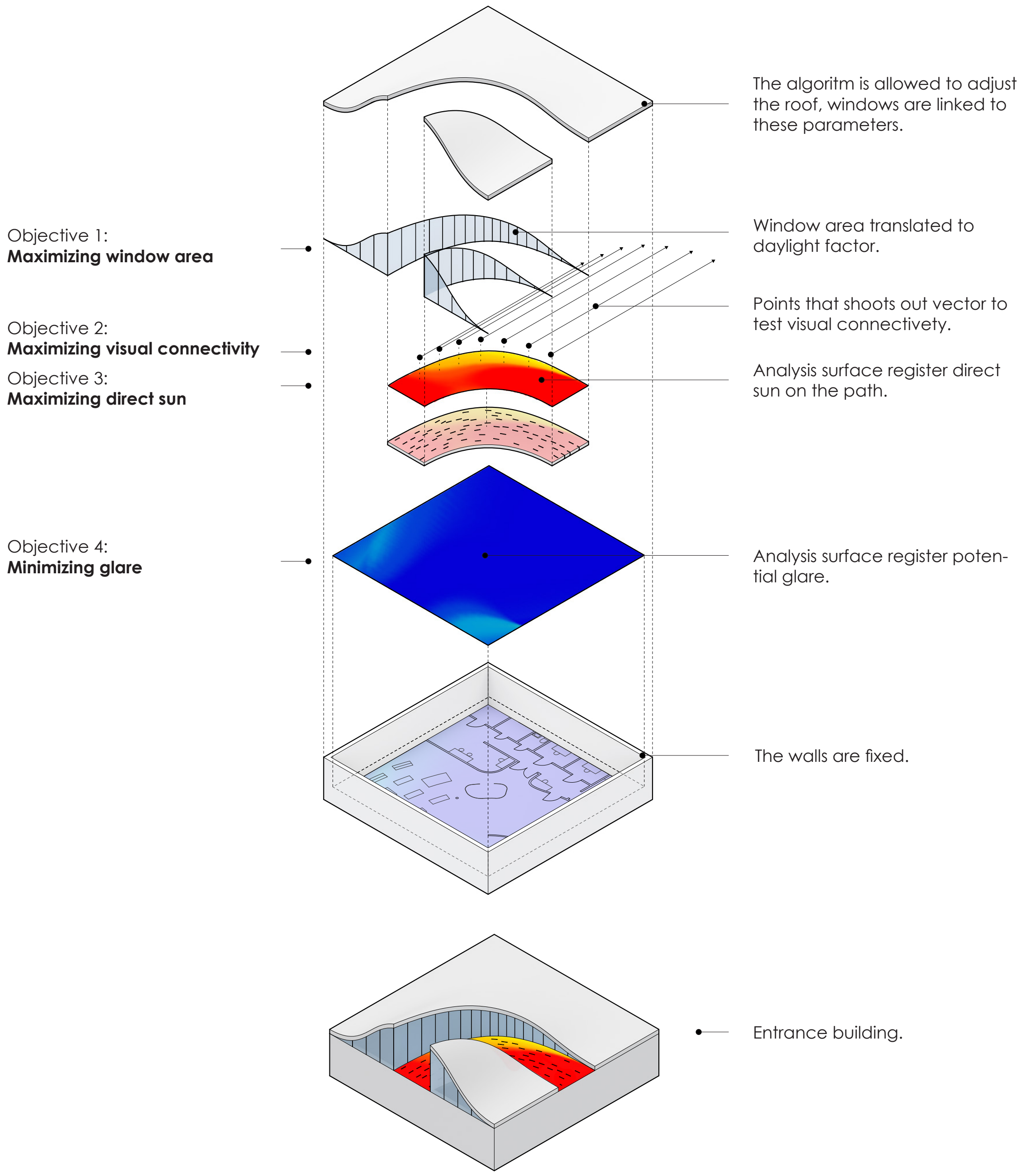
Roof iterations

Negotiation of objectives

This diagram illustrates how we negotiated the four different objectives. It was important for us to create pedagogic and communicative diagrams in order to fully understand the various results. This meant that we could both compare the fitness charts (in numbers), but also look at the more intuitive color schemes of the diagrams to take quick decisions.

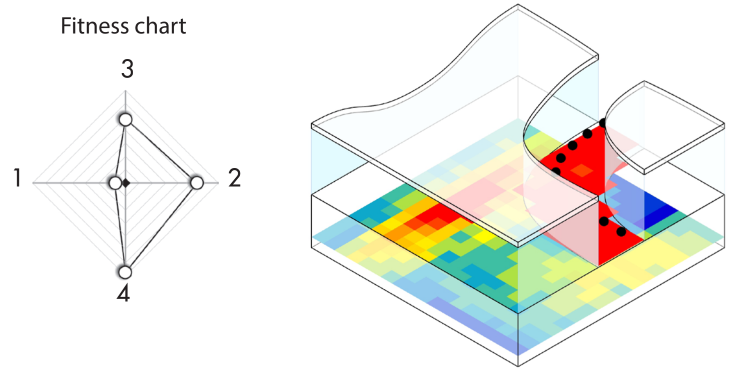
We seperated the building into four volumes to rationalize the process, but also because we thought that it was an interesting architectonic idea. Each volume required a specific set of prioritized objectives. By letting the software generate thousands of iterations, we simply followed the process and stopped it when we were pleased with the result.

The opposite page illustrates an example of how the volume would turn out for each objective. The diagrams show the best scoring iterations for each individual objective. The task for Wallacei was to then find interesting hybrids between the four objectives.

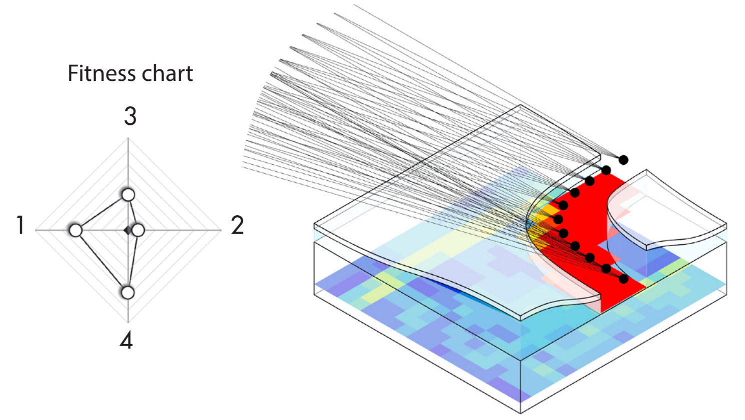


Exploded isometric illustrating the four objectives.

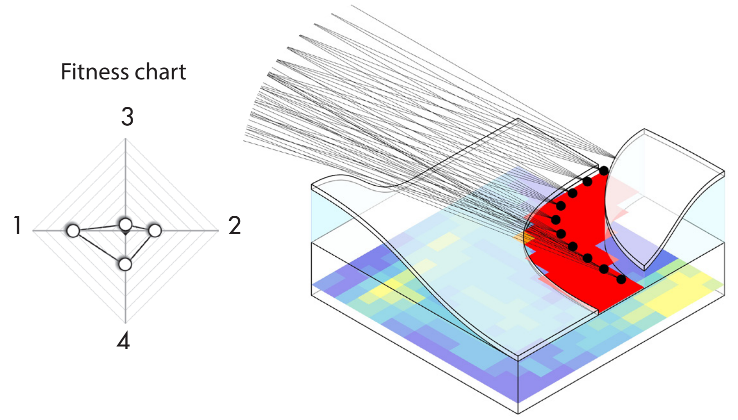
Objective 1: Maximizing window area
Generation: 96 Individual: 3



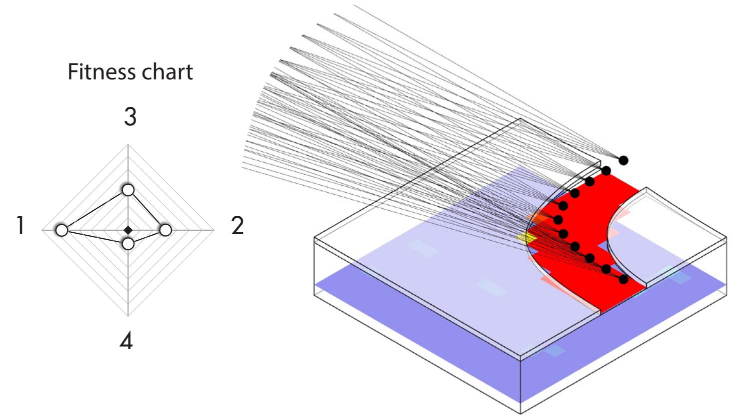
Objective 2: Maximizing visual connectivity
Generation: 74 Individual: 8

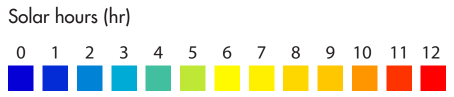


Objective 3: Maximizing direct sun
Generation: 96 Individual: 3



Objective 4: Minimizing glare
Generation: 96 Individual: 3





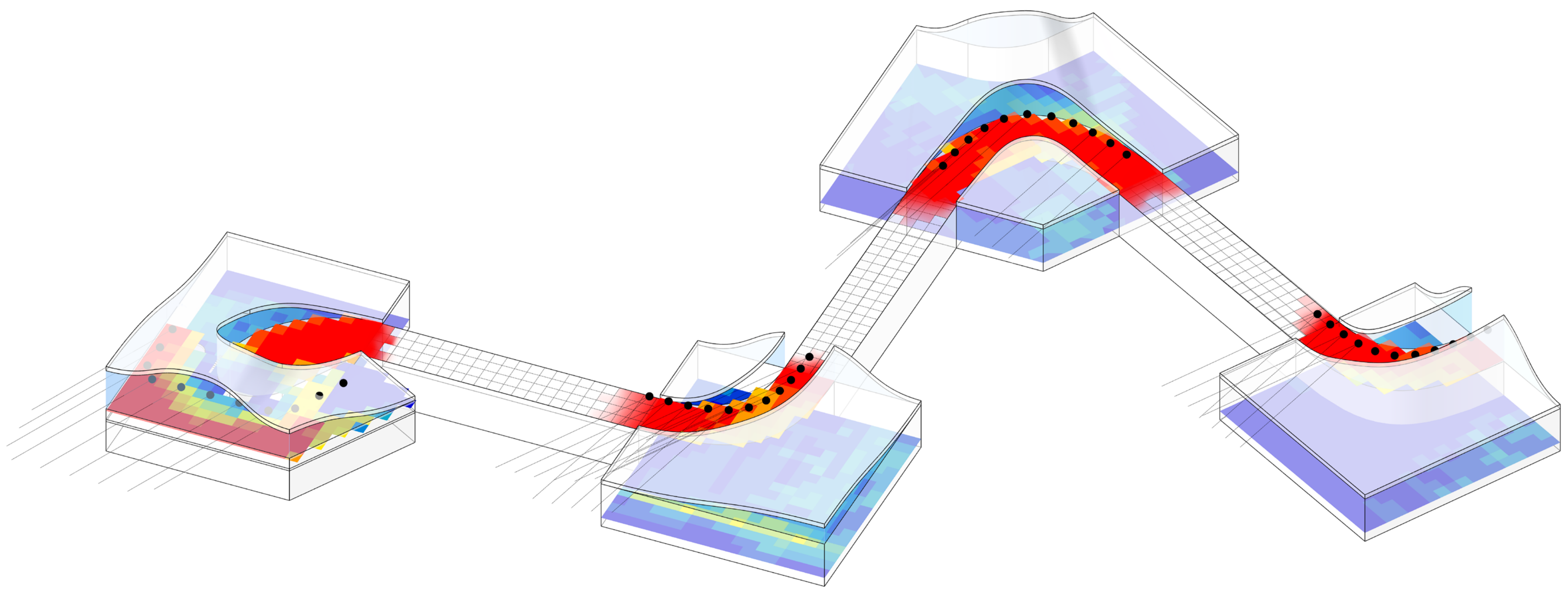
Fittness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare

Interaction of volumes

Ideally, we would include all the four volumes in the algorithm at the same time. This would mean that they would take each others forms into consideration. Unfortunately, this operation required too much computer power, and we had to deal with the volumes seperately. The diagram shows how the generated volumes looks together.

From this point and on, it was simply a game of running the algorithm for each building volume. We started out with the first volume, which is the entrance building. After that, we went on to the next volume, which is exhibition hall 1. If we would discover an interesting form in exhibition hall 1, that did not match with the established volume for the entrance building, we would then go back and run the simulation for that volume to see if we would find a more suitable form. This back-and-forth process continued until we were overall happy with the building as a whole.

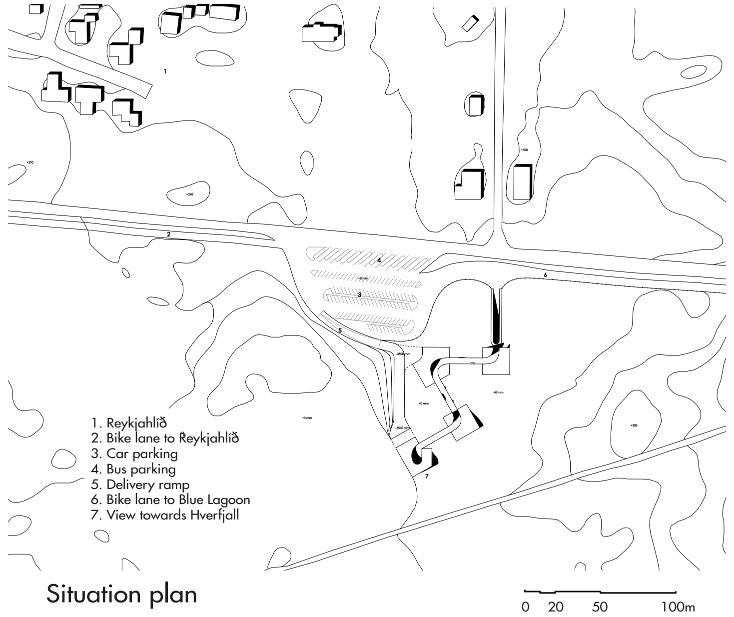
From the next page and forward, we will present how we used the methodology for each individual building volume. We will describe what fitness goals we prioritized, but also show how important we thought that the narrative would be. Moreover, we will include the presentation drawings and renderings in this chapter.



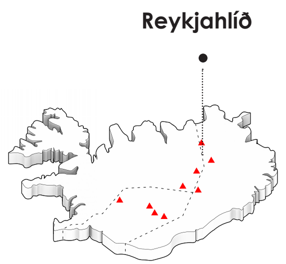
The four volumes together.

Context, narrative and aesthetics

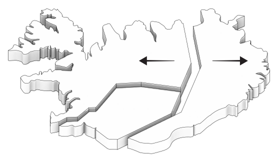
As previously stated, it was important for us to find a strong narrative that suited the context. But also as a way of acting as a constraint for the algorithm. When researching the site, we found that the site is located on a crack that separates Iceland in two. It is this crack that gives rise to the volcanoes. We wanted to enhance this experience, by placing the program along an artificial crack. We then let the computer generate forms that resembled volcanoes along the crack.



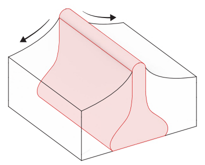
Situation plan



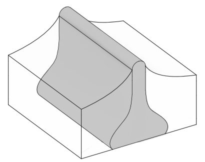
The site is ocated in the intersection between two continental plates.



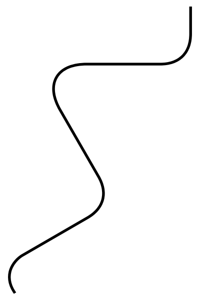
The plates are slowly drifting apart.



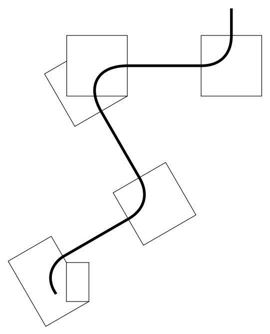
The separating plates enable magma to erupt.



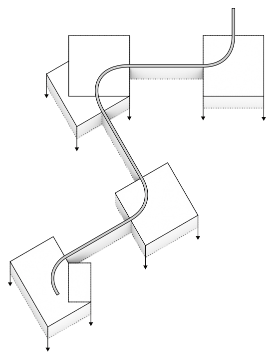
Magma solidifies and volcanoes are formed.



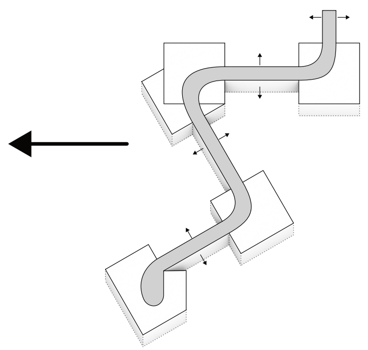
Artificial crack based on site analysis.



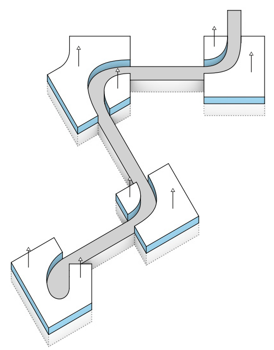
Arrayed program along the crack.



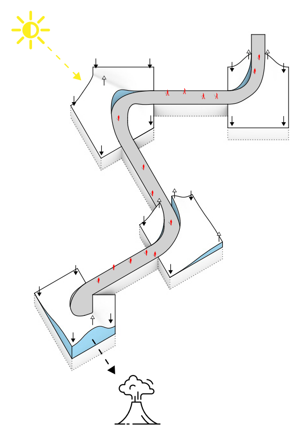
Program extruded down, creating volumes.



The crack drifts apart and widens.



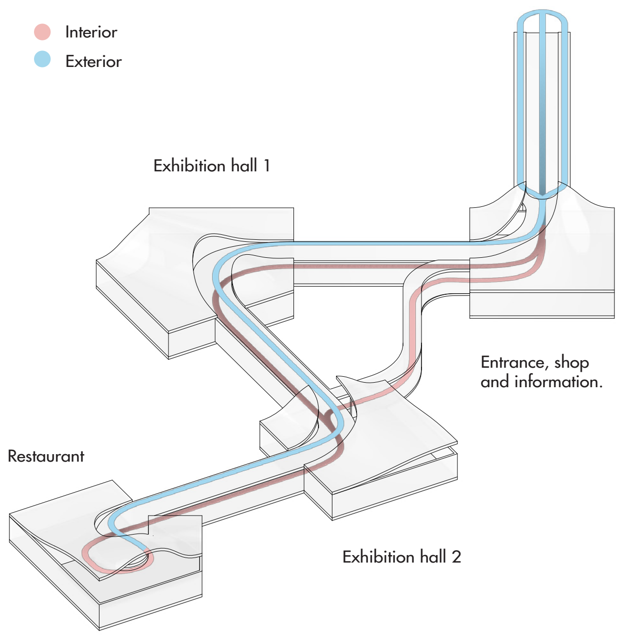
Volumes reacts and erupts.



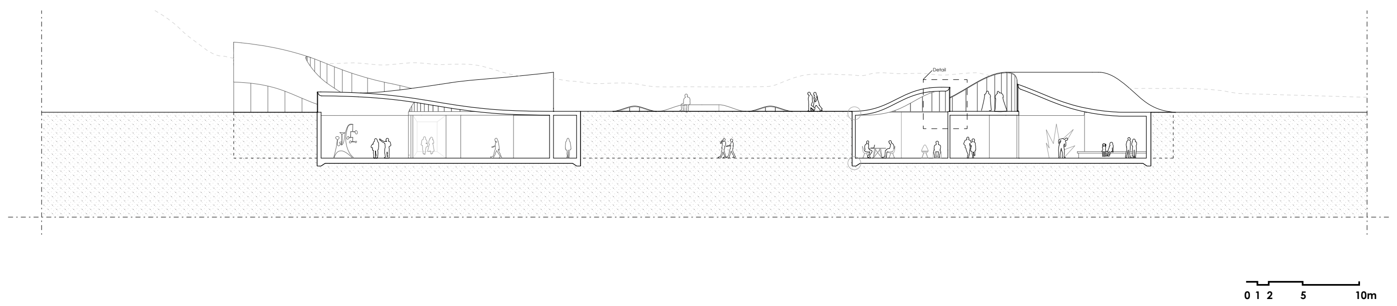
The roof structure and window openings are optimized for natural light and views.

The program informed and shaped large parts of the building. By dividing the program into different volumes, the roofs could be optimized for specific purposes, giving the volumes different expressions.

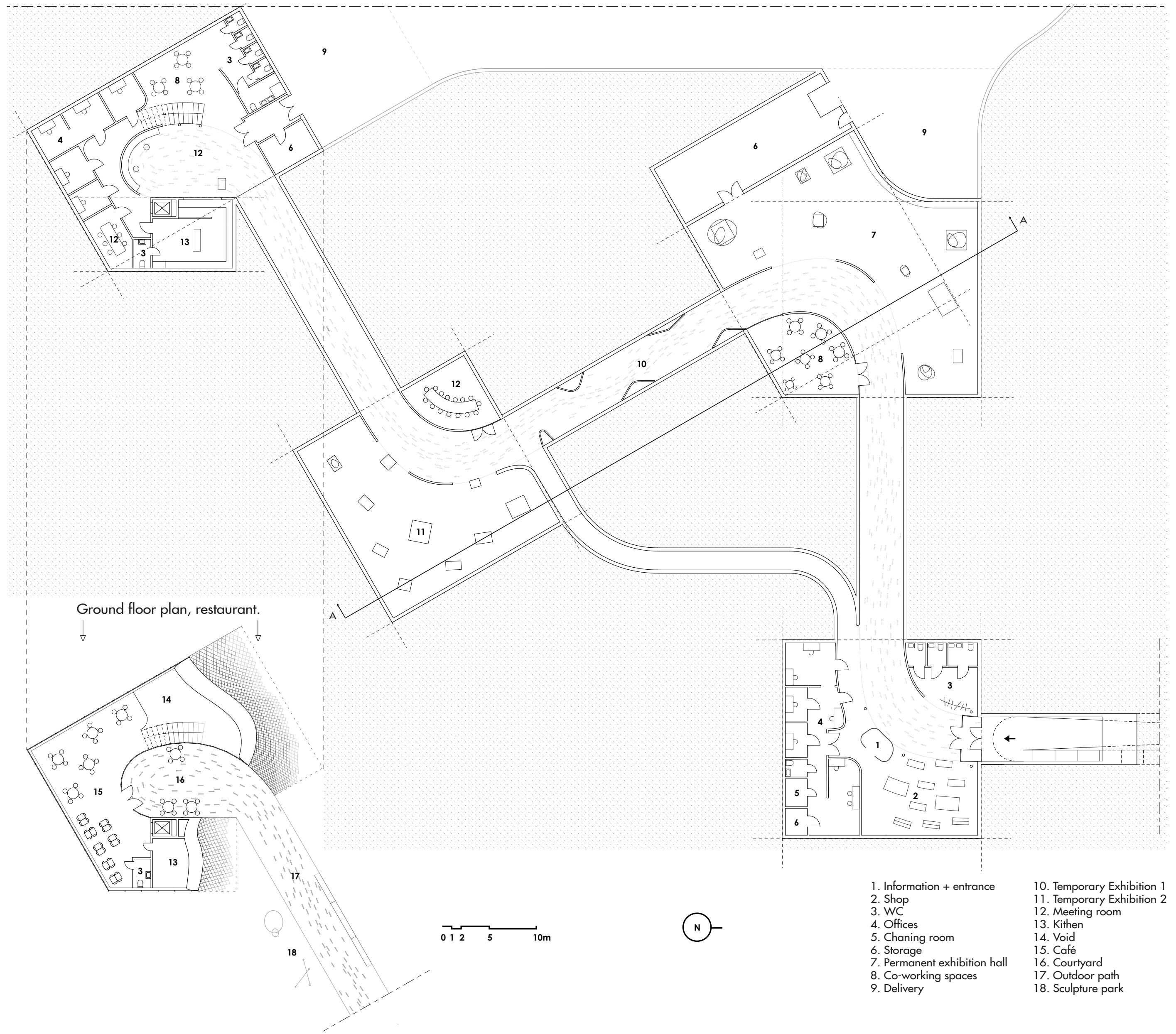
The Volcano Museum lends from Icelandic vernacular architecture by digging itself down. This improves thermal heating and wall area for exhibitions. The windows act as both lanterns and viewfinders towards the Icelandic sky. This principle also prevents visitors from interacting with the nearby volcano Hverfjall until finally revealed in the very last room.



Circulation and program.



Section A-A



Plan: Lower level + ground floor of the restaurant.

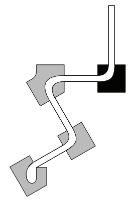
The entrance

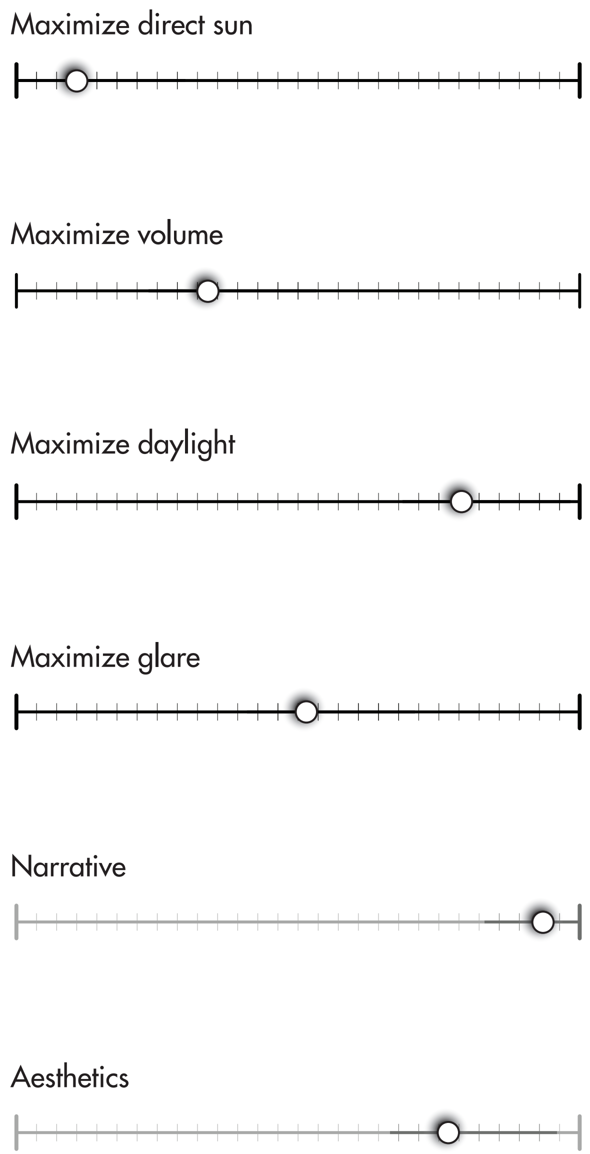
The Volcano Museums' entrance building is very much about the atmosphere and narrative. It is the first building volume that the visitors encounter, and we wanted them to get the impression that they were delving down into the inner core of the volcano. Defining that as an objective in an algorithm was impossible, therefore it was important that we as curators were active and not just chose the most optimized based on performance.

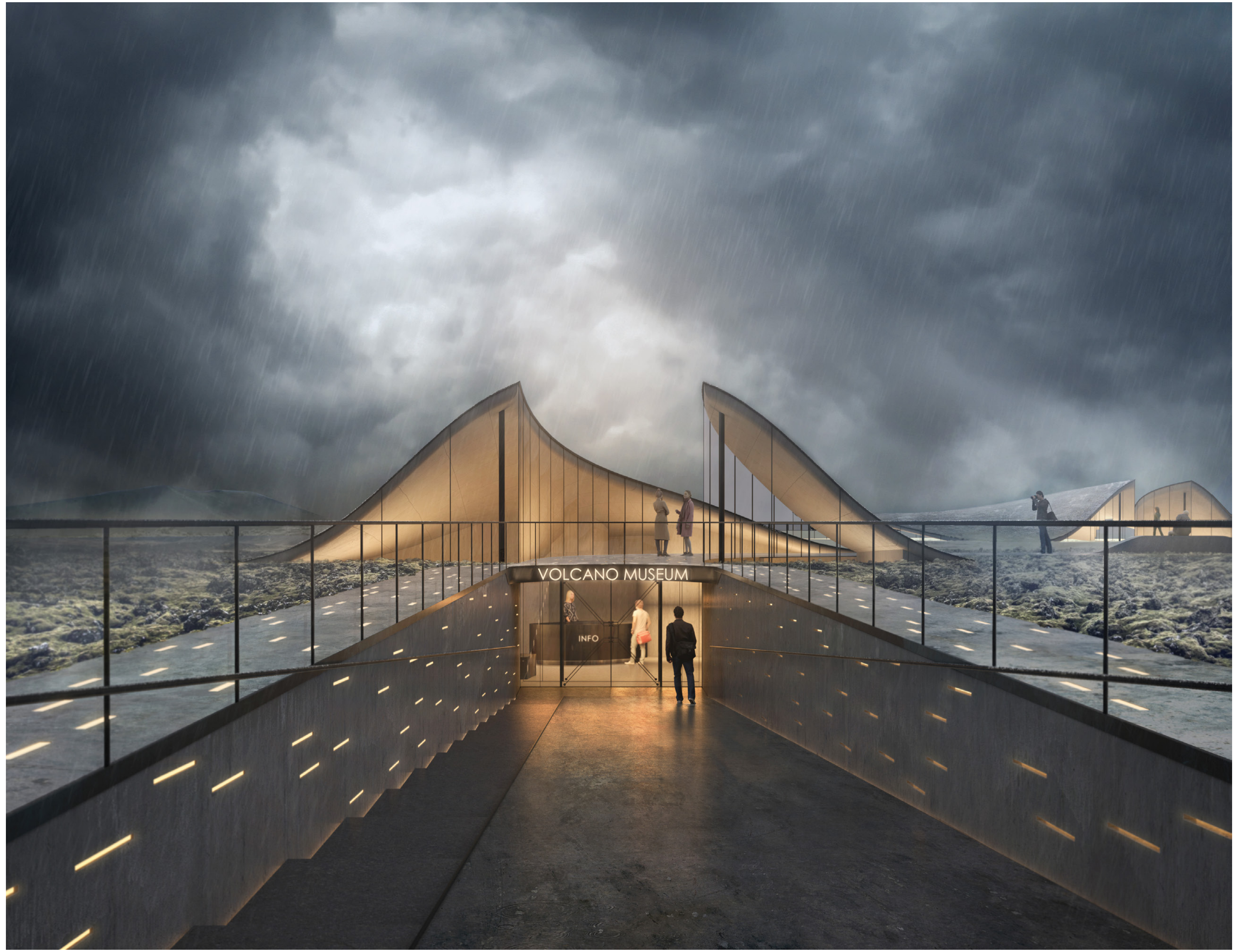
The building also holds other functions. For example, the offices require a good daylight factor and a minimum amount of glare. The process primarily focus was about getting a good symbiosis between the narrative and the performative objectives.

Since the large volcano is constantly present in the flat landscape, we wanted to hide it as the visitors approached the entrance, to then slowly be revealed. This resulted in a roof shape that started out as extruded and successively slanted down towards the ground.

The graph to the right highlights our objectives for this specific volume.



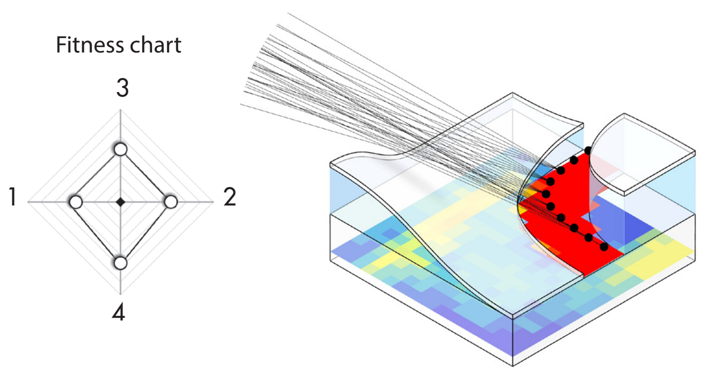




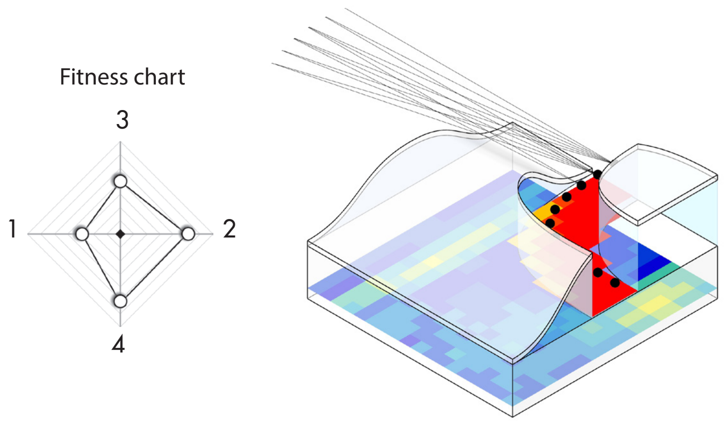
The entrance

Top iterations

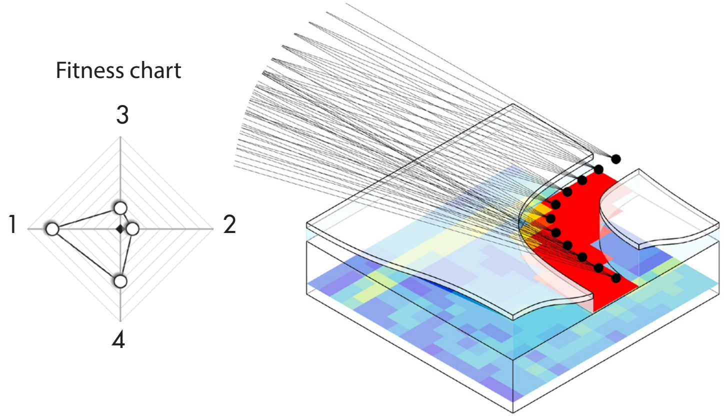
Generation: 99 Individual: 7



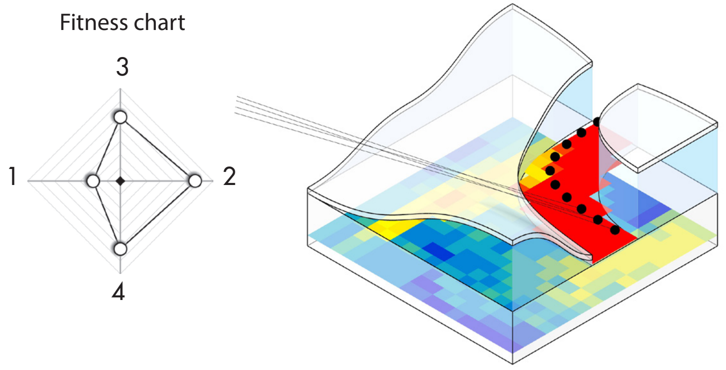
Generation: 89 Individual: 15



Generation: 97 Individual: 19



Generation: 89 Individual: 21

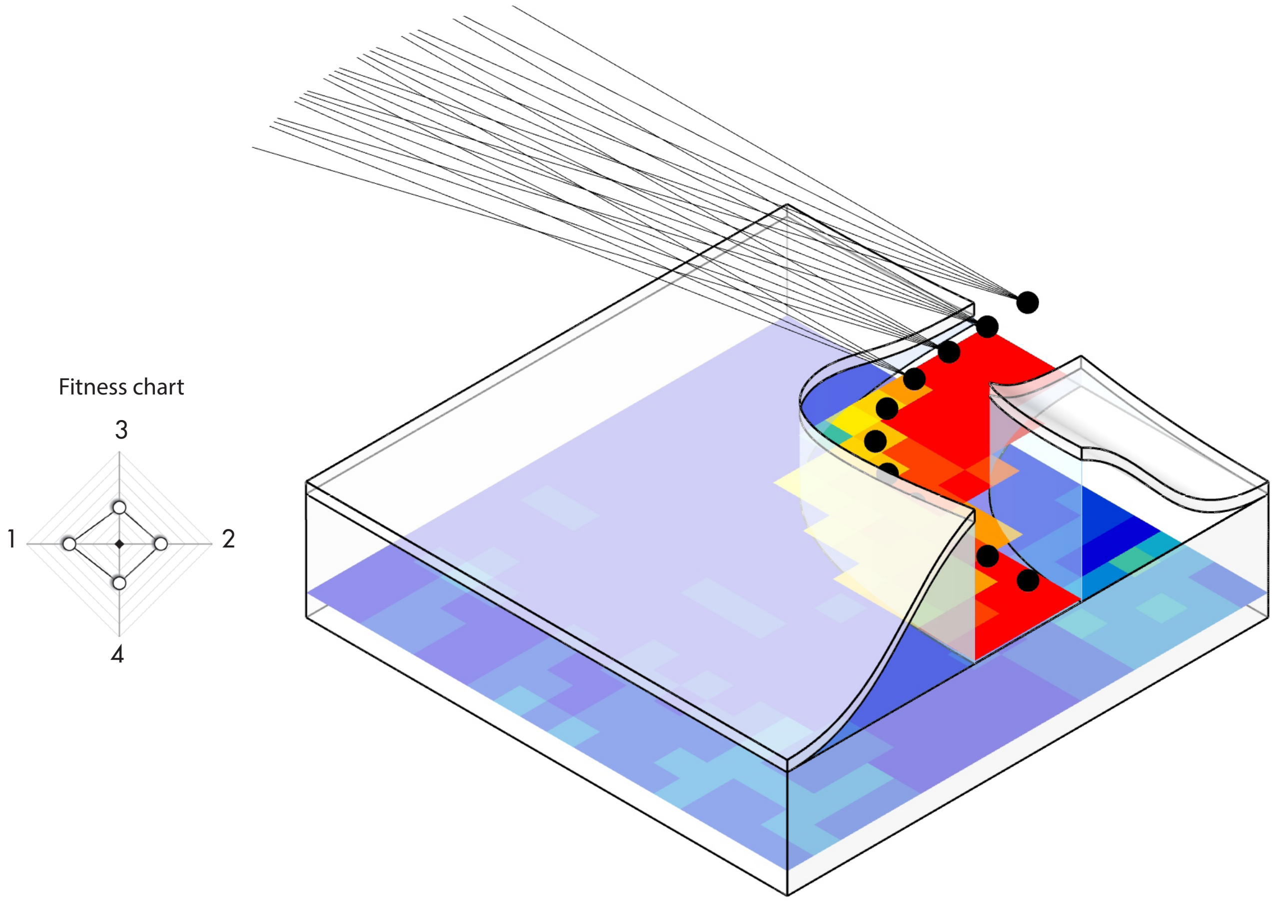


Solar hours (hr)

Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare

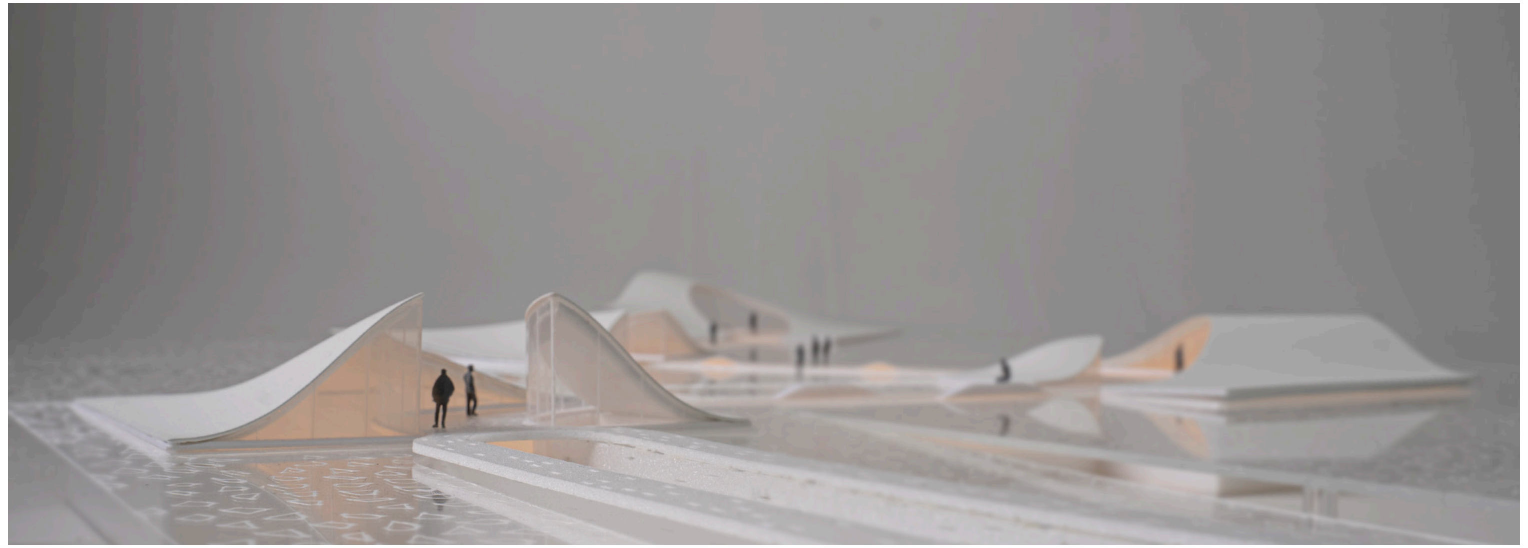
Selected iteration

Generation: 99 Individual: 7



Solar hours (hr)

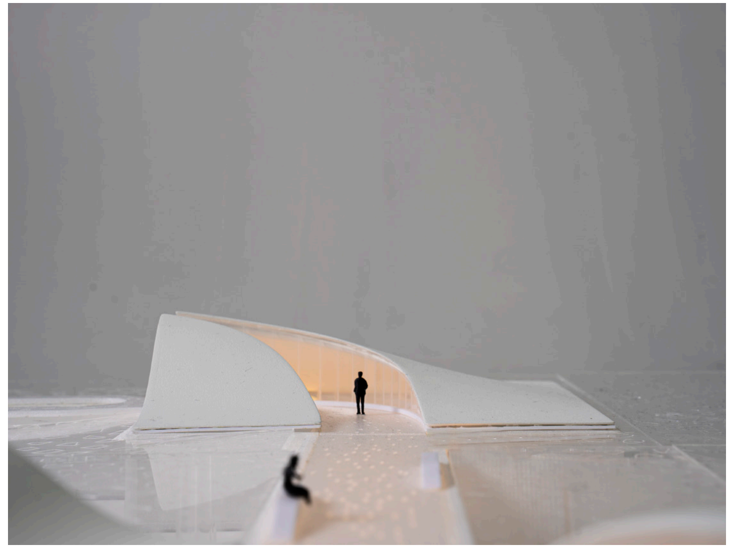
Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare



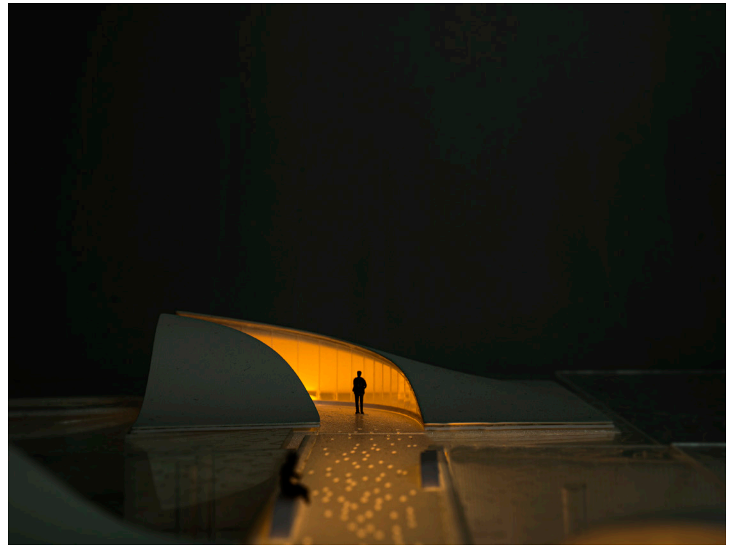
Approaching the entrance.

Analysis

When we evaluated the results of the entrance building, it became clear that many of the iterations did not work with our narrative. Because of this, we actively searched for iterations we thought fit the narrative instead of being the most performatively optimized. We found an iteration that we thought expressed the feeling we wanted to achieve. The selected iteration did not perform so well in the daylight factor, and to some extent shadows the path a bit too much, but it creates a clear gesture towards the visitors, to successfully reveal the volcano in the background. The form also lets in enough light to meet the daylight requirements.



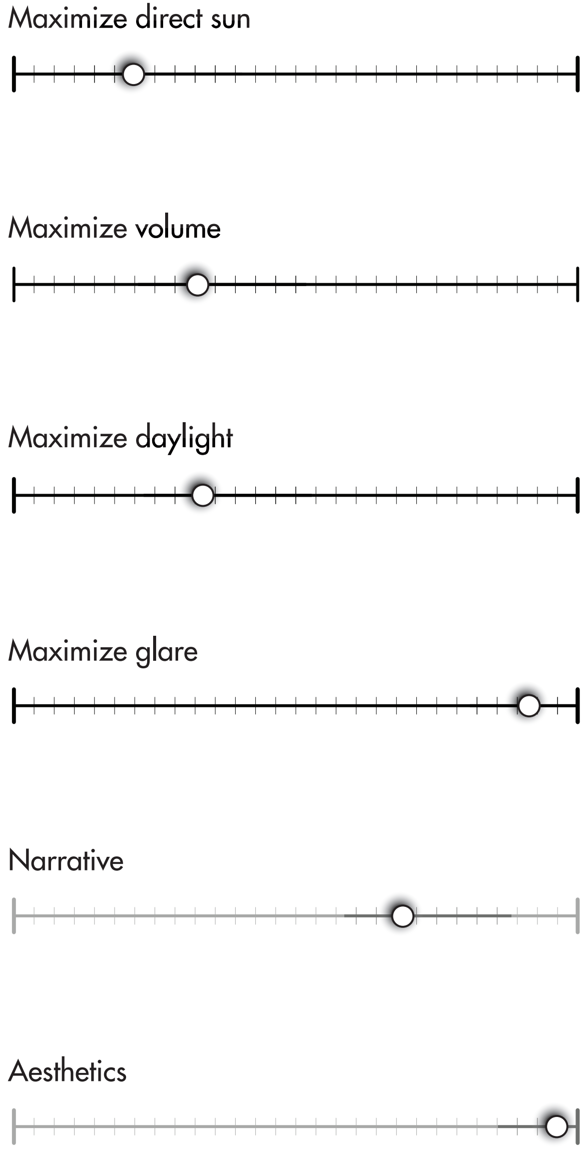
Day photo

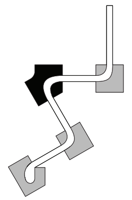


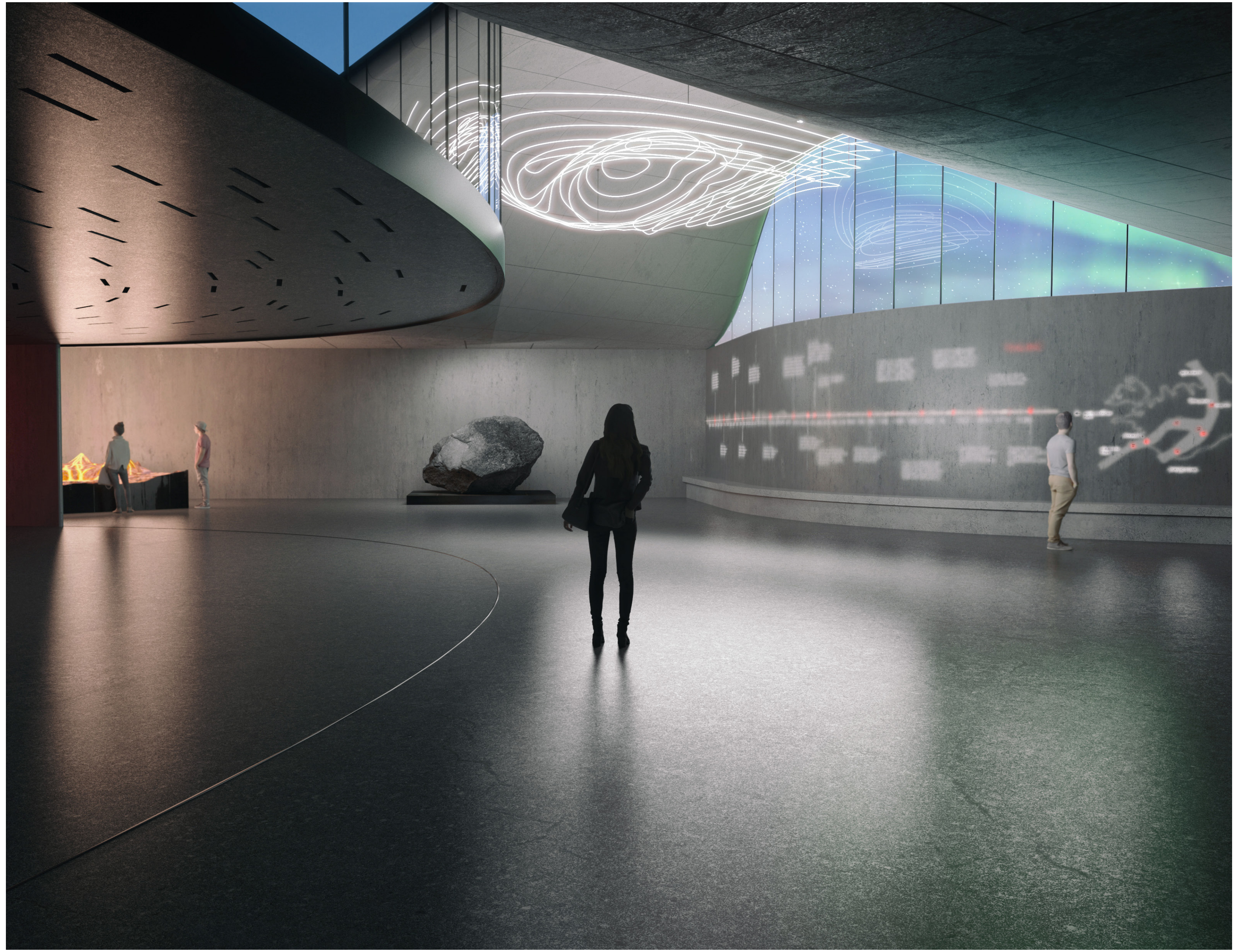
Night photo

Exhibition hall 1

The goal for exhibition hall 1 was to create a contrast for the visitors as they entered the hall from the narrow and dark pathway. A contrast both in the form of light, but also in spatiality. As a typical exhibition hall, it was important to maximize daylight and minimize glare. The design of the exhibition hall also aimed to strengthen the connection with the neighboring building volumes. Since the plan was symmetrical, we used this symmetry as a constraint.

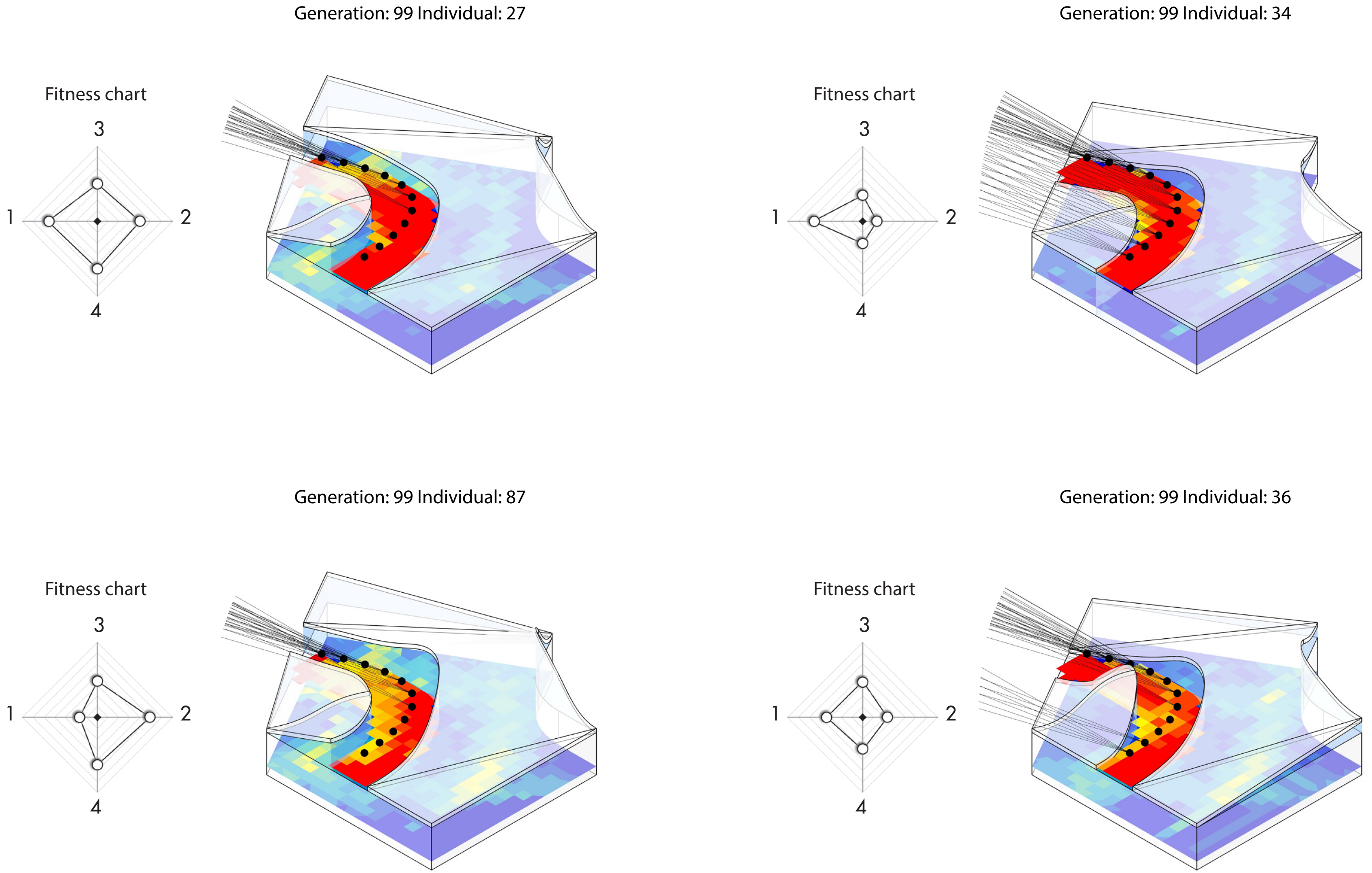


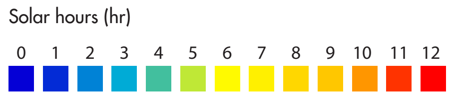




Exhibition hall 1

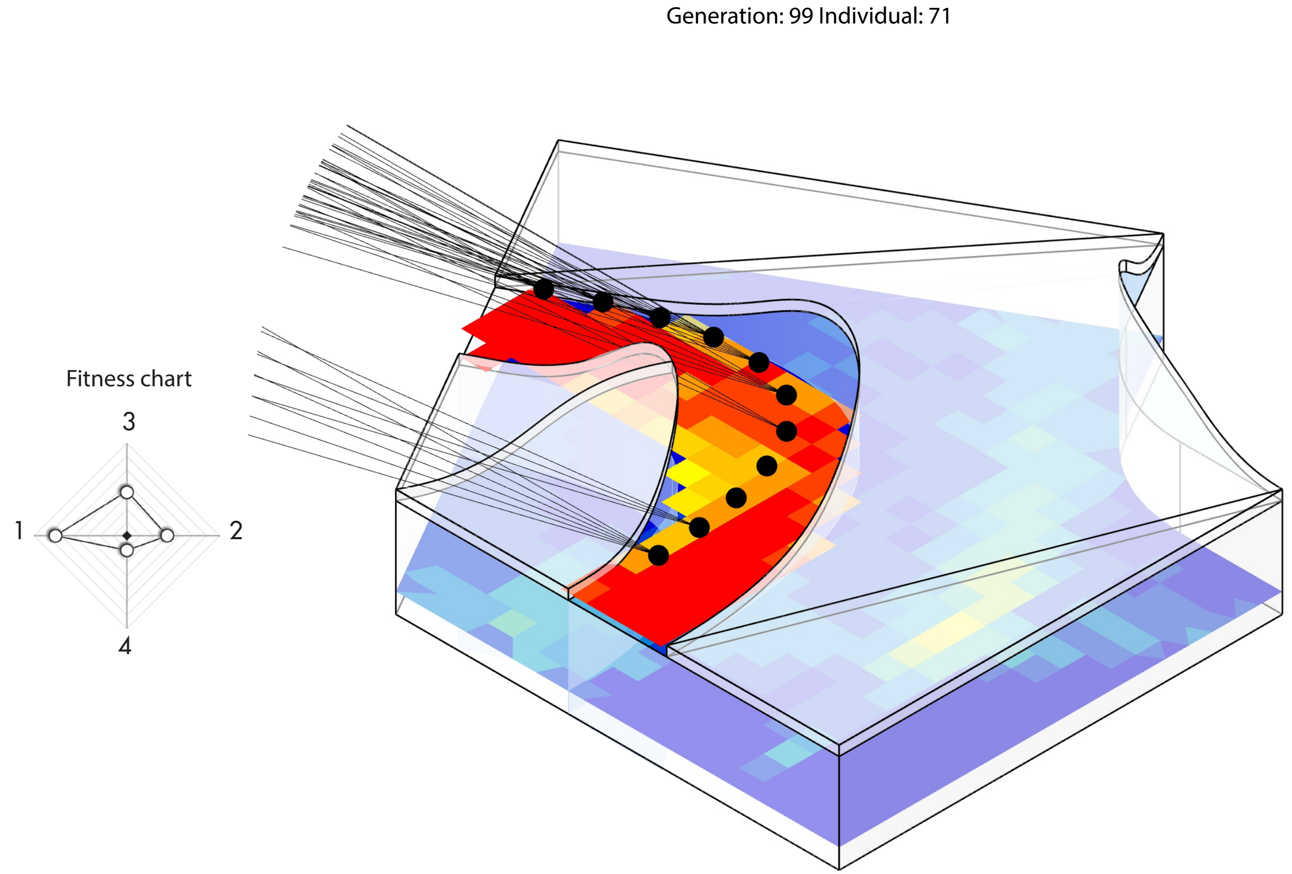
Top iterations





Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare

Selected iteration

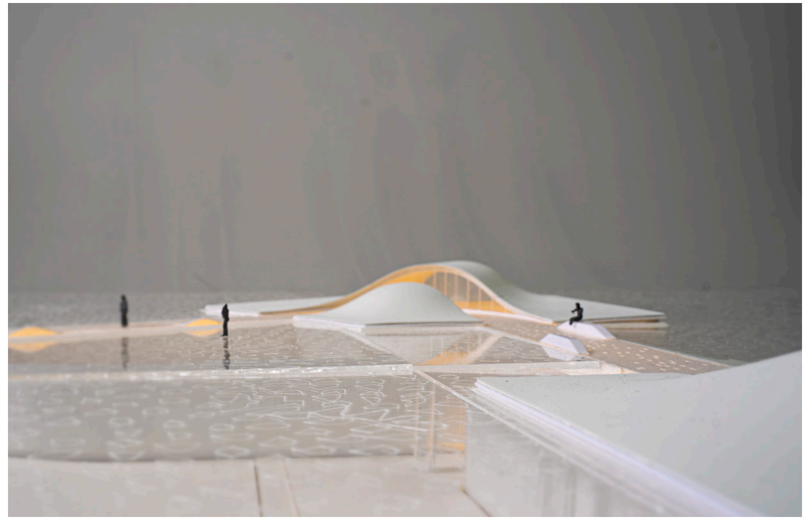


Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare

The intersecting pathway creates pockets of visual connections to the interior spaces.

Night photo from west.

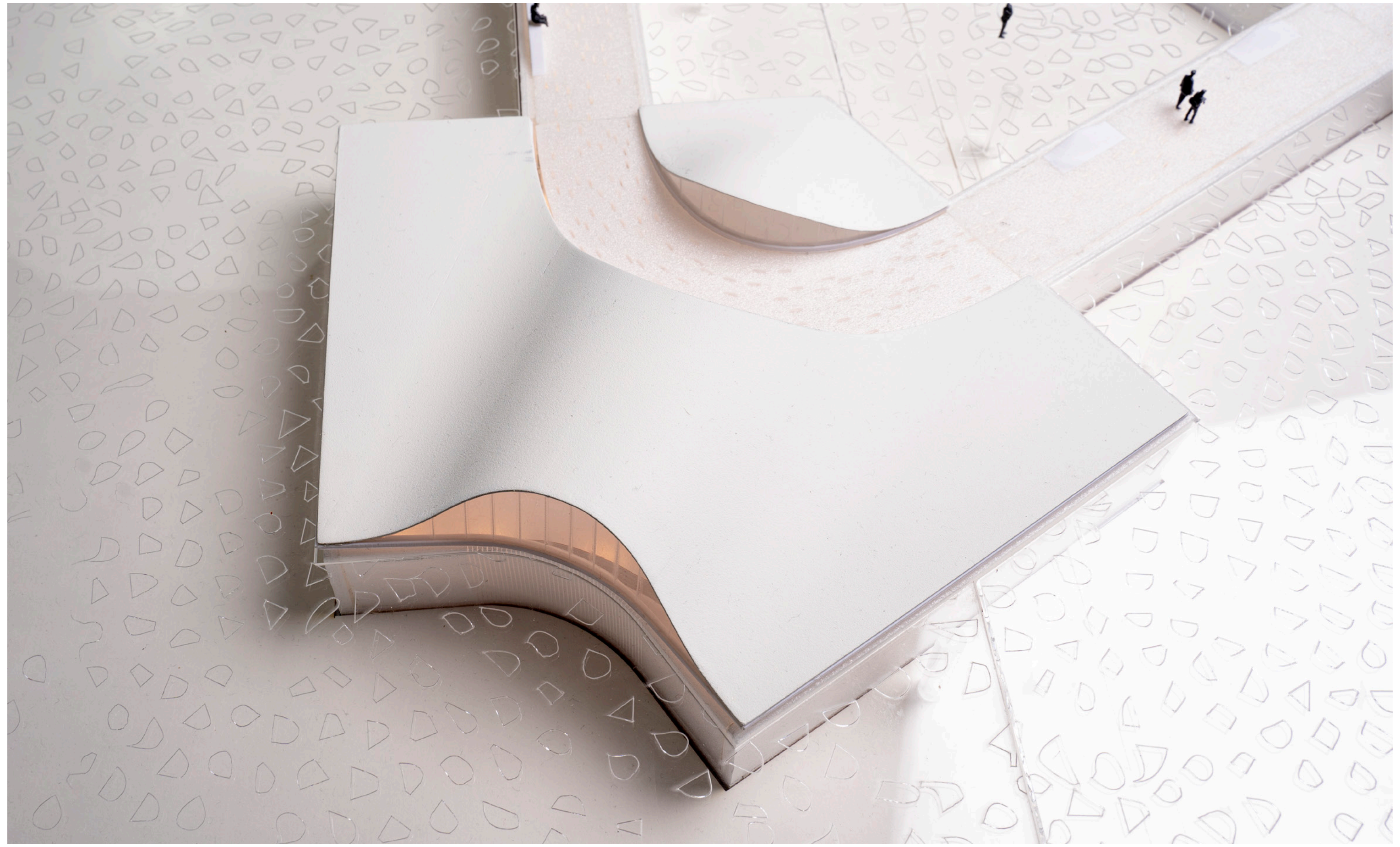
View from nortwest.



View from northeast.

Analysis

By using symmetry as a constraint, we ultimately eliminated large amounts of uninteresting iterations. Wallacei simply could not generate a large amount of iterations that was symmetrical, which was successful. It also eliminated all of the assymetrical iterations, which saved us time in the design process. On the other hand, we might have lost an opportunity to discover something outside of our own creativity. On the technical side, the selected iterations gave the hall plenty of daylight, while the smaller roof lowered to the south, which shields from direct sunlight.

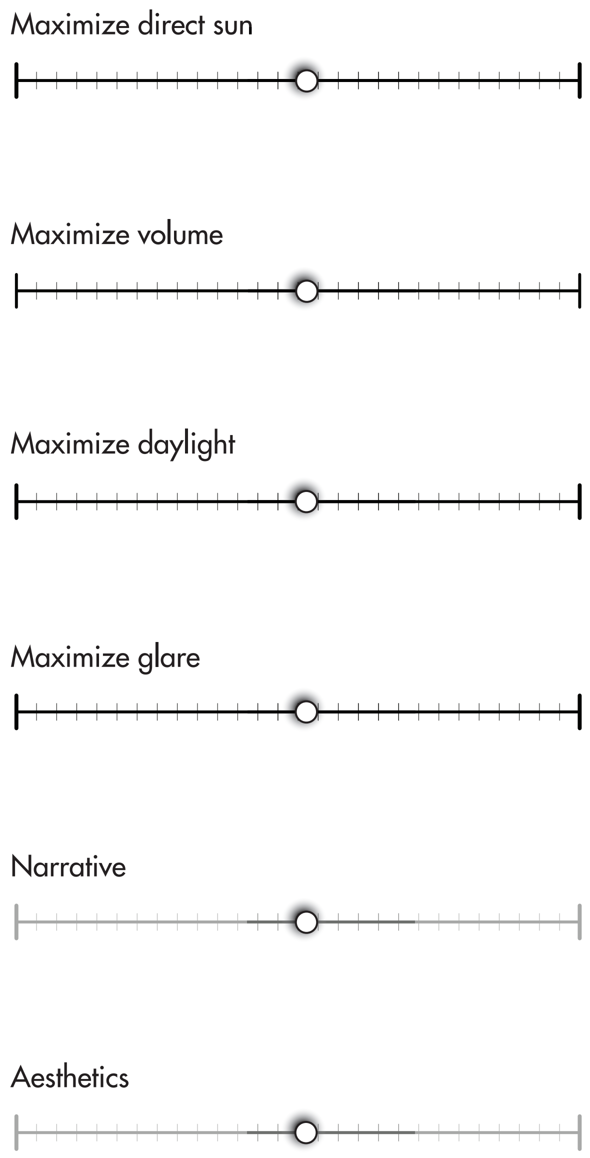


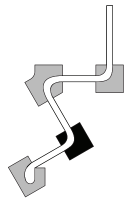
Roof top photo.

Exhibition hall 2

For Exhibition Hall 2, we had no established objective, which meant fewer constraints and our role as curators became more neutral. The roof's algorithm was locked to the footprint of the hall. Other than that, the algorithm could freely generate a diverse amount of iterations.

By giving the algorithm a lot of freedom, we could take a step back in our role as curators and instead be inspired by the generated iterations. The selected form appeared among the highest performing solutions. We were attracted by the fact that it had a similar expression to the entrance but with a slight elevation to the east to let in more daylight.

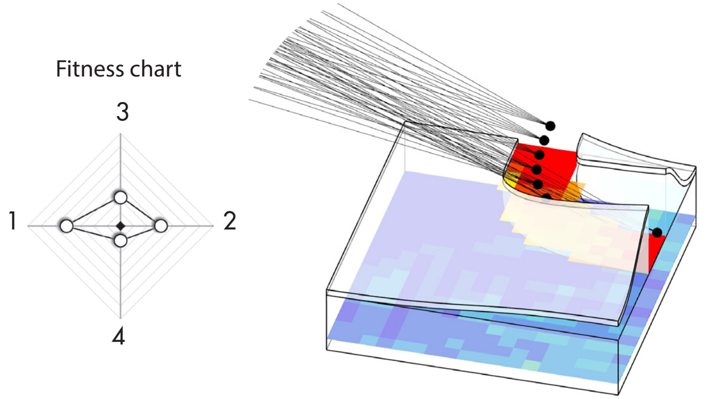




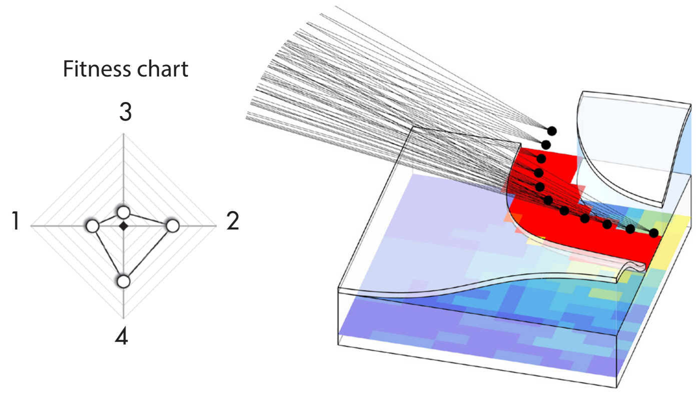
Exhibition hall 2. View from the western exhibition hall.

Top iterations

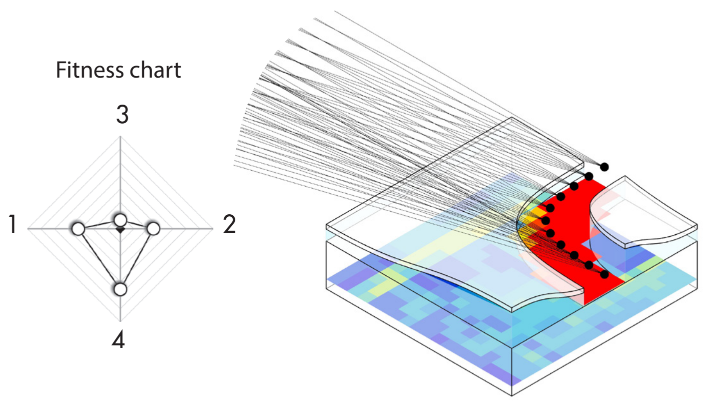
Generation: 99 Individual: 18



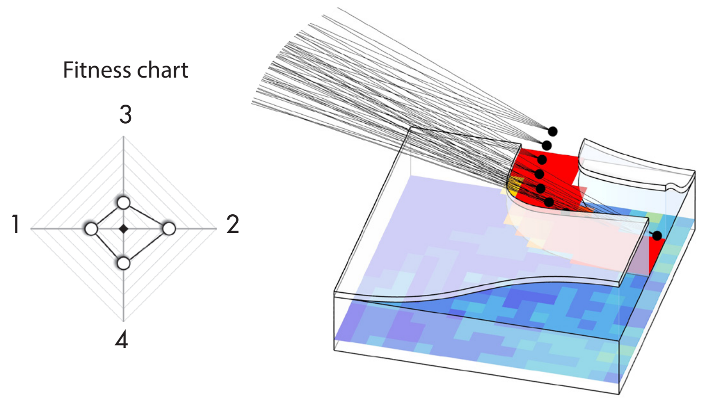
Generation: 99 Individual: 14



Generation: 99 Individual: 54



Generation: 99 Individual: 34

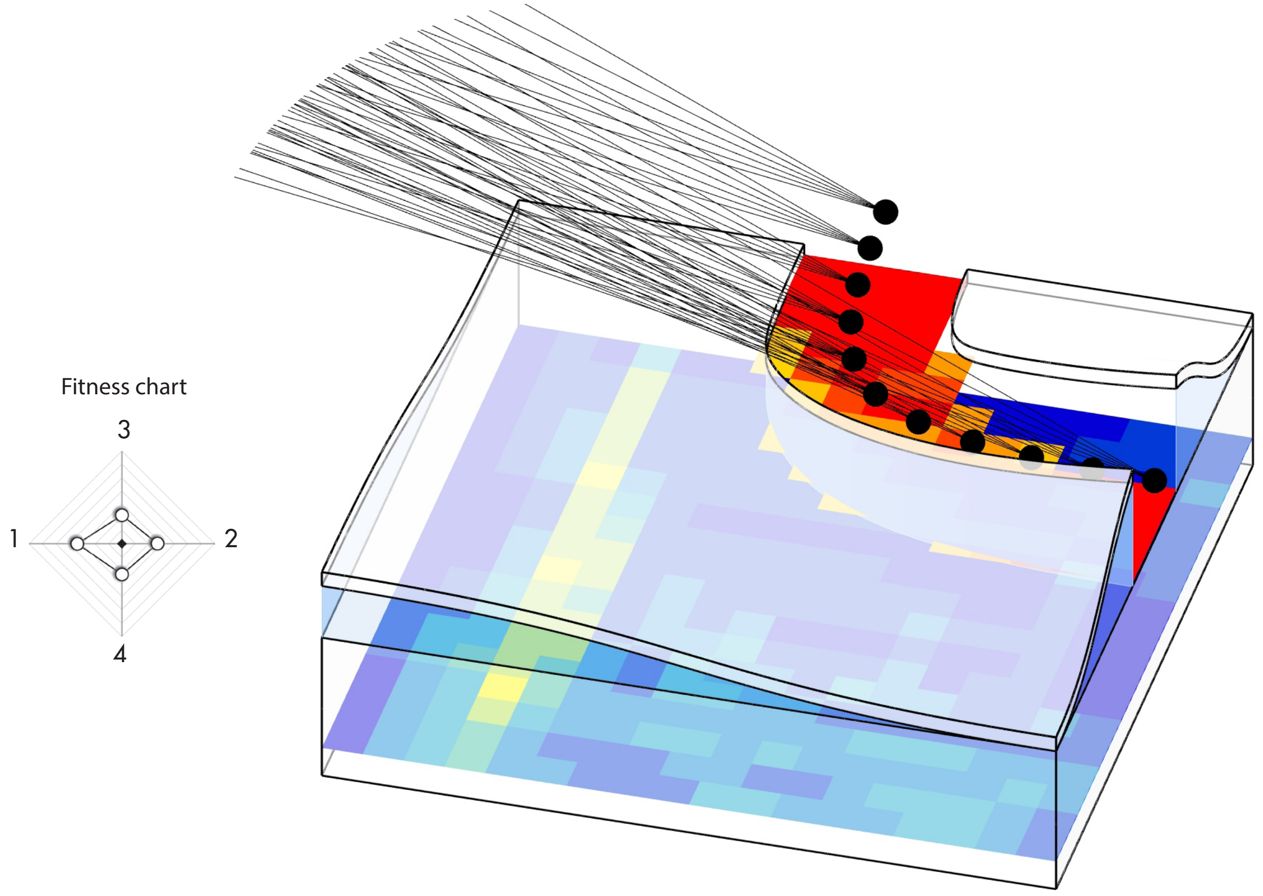


Solar hours (hr)

Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare

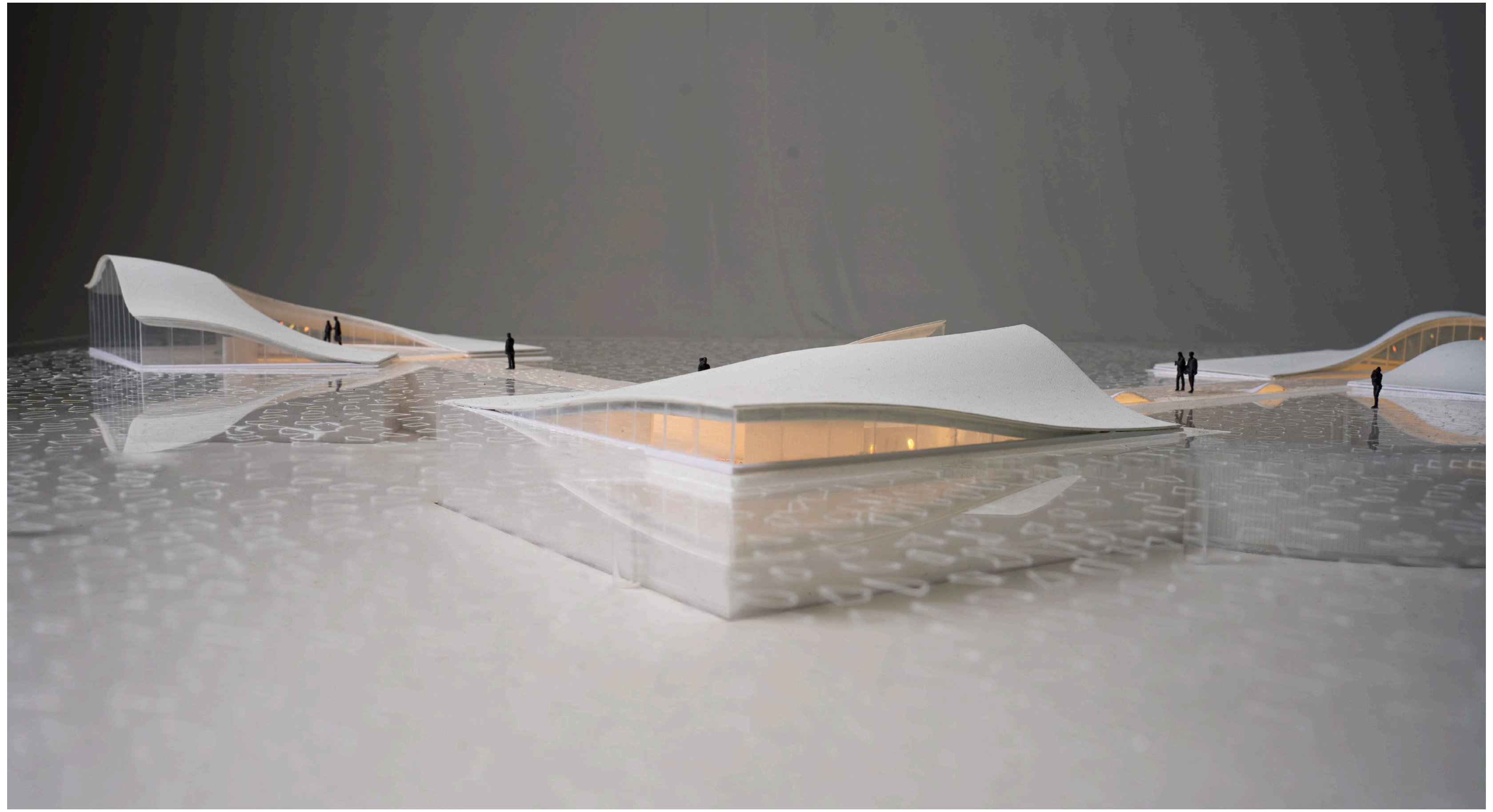
Selected iteration

Generation: 99 Individual: 7



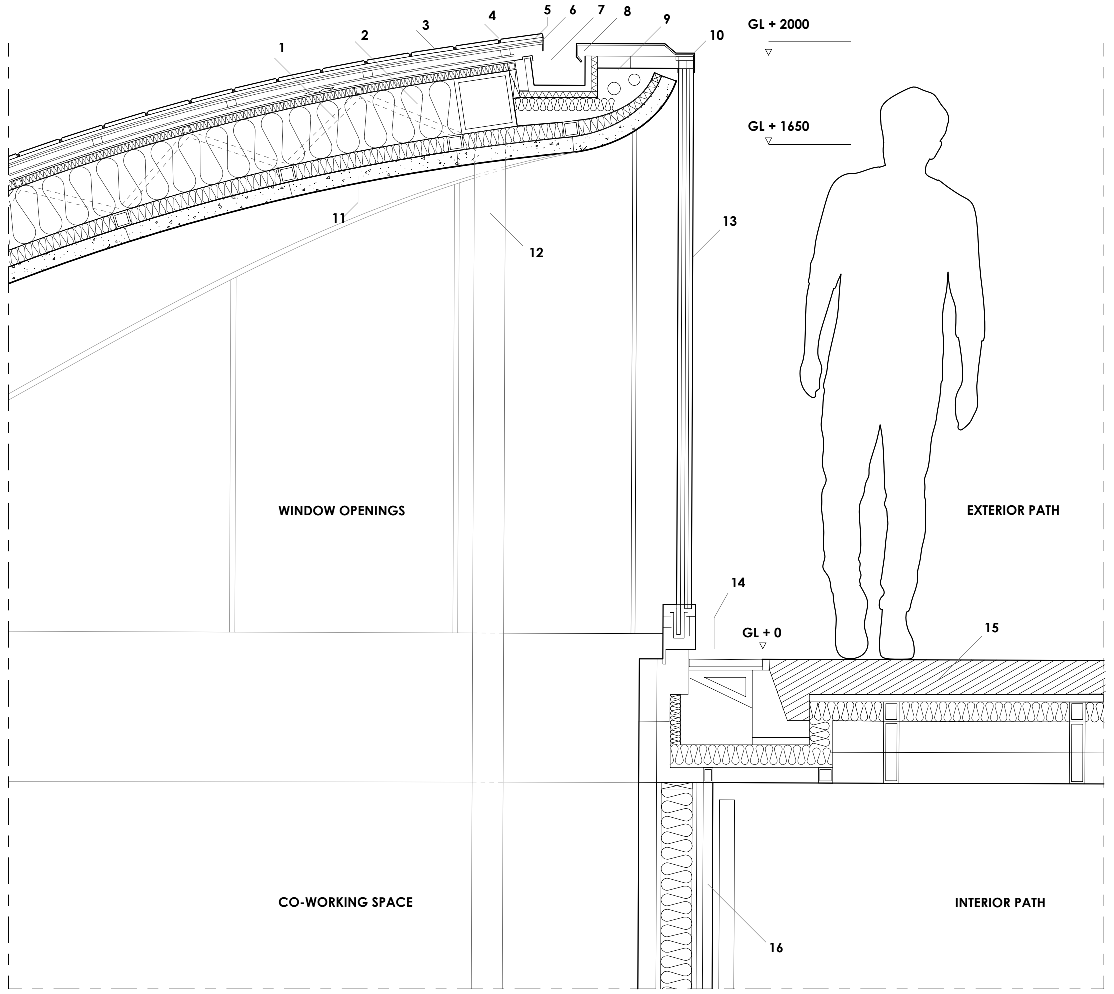
Solar hours (hr)

Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare



The algorithm came up with an unexpected slit from the ground that we decided to keep.

Birds eye wiev from east.



1. Metal roof structure
2. Thermal insulation
3. Lava tiles
4. Grout
5. Mortar
6. Membrane
7. Roof gutter
8. Folded metal sheet
9. Perforated metal
10. Glazing head trim
11. Prefabricated concrete panels
12. Pillar
13. Double glazing
14. Gutter
15. Concrete slab
16. Interior room separator

0 1 2 5 10 m

Detail drawing

Birds eye wiev from south.

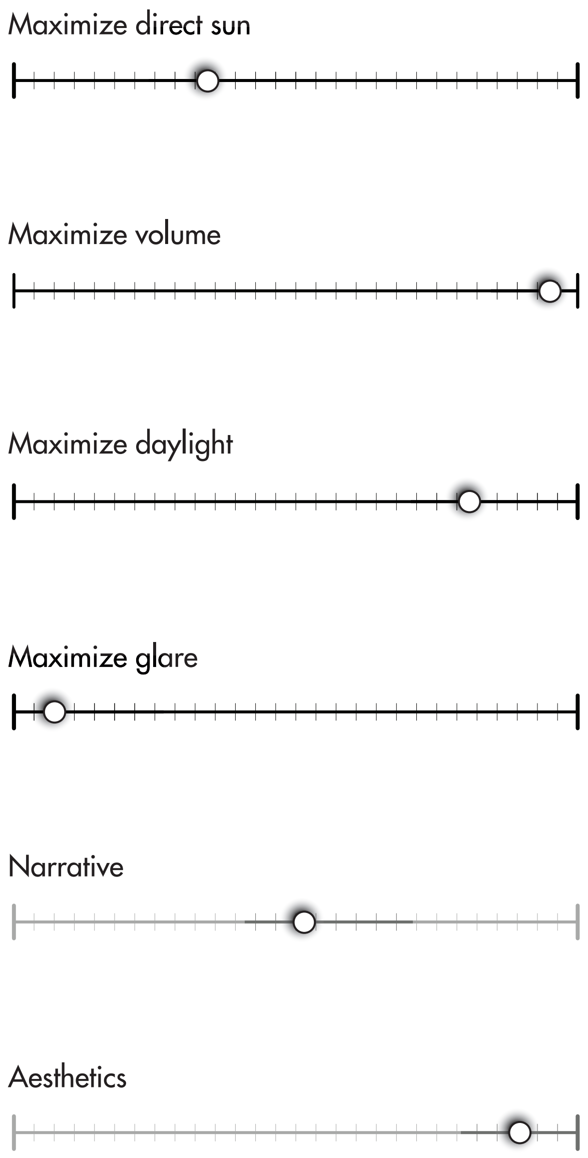
Analysis

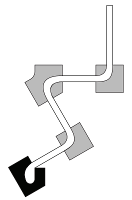
This volume showed that generative design is more than merely a tool. In retrospect, the idea to let the computer have more freedom proved successful. We almost wish that we would have given it even more freedom, by letting it manipulate the plan and the walls. This is something that we will discuss more detailed in the evaluation chapter.

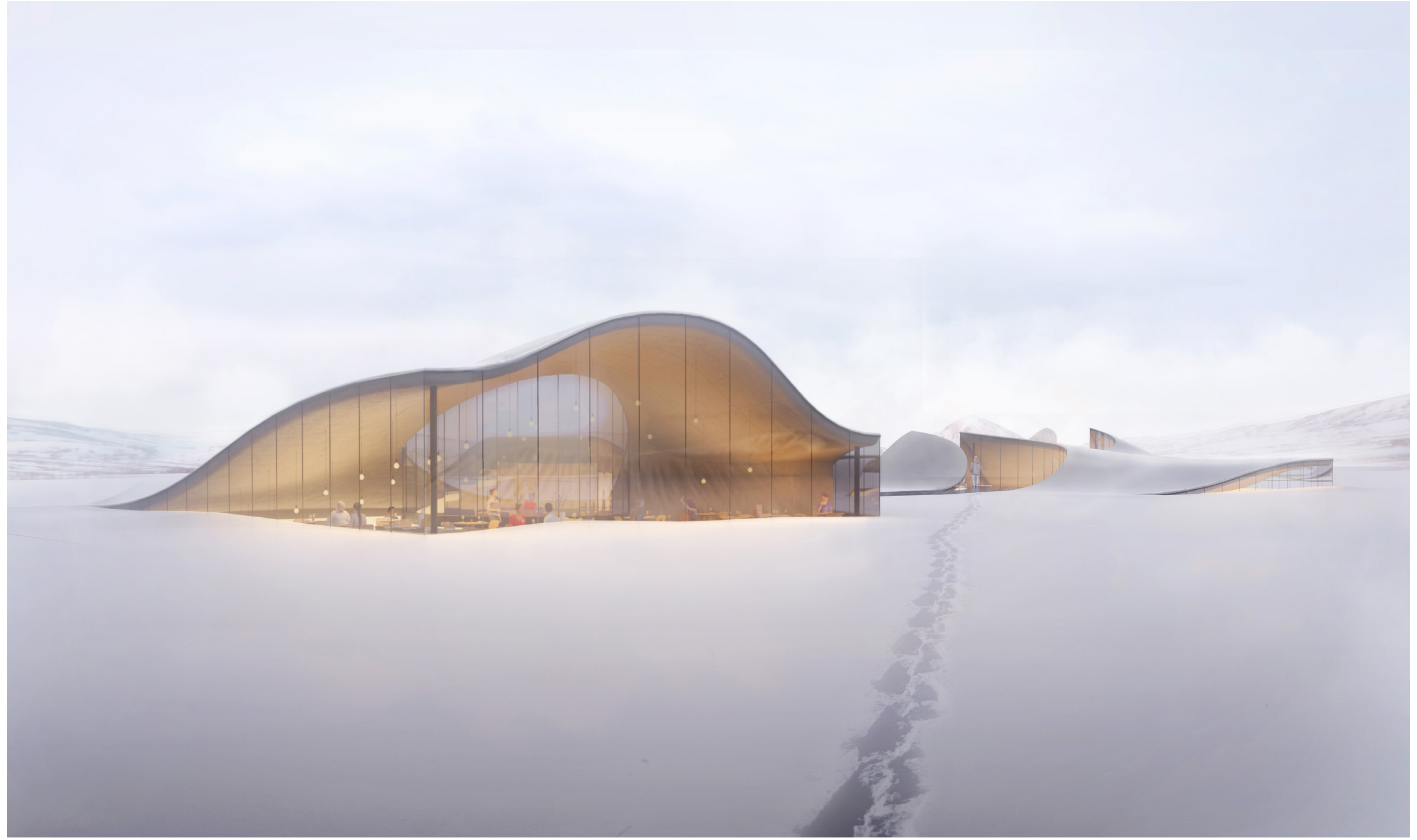
Resturant

The restaurant is the only volume with an upper level or mezzanine. We had a clear vision of creating visual connectivity between the restaurant and the volcano Hvjerfjall. The visual connection points were therefore placed inside the building. This forced the algorithm to find solutions where the roof couldn't move downwards but tried to find an elevated form.

Our primary requirement for the restaurant was a framing of the volcano. This objective was met by all the iterations of the last generation, which means that the building got good performance and fitted well into the narrative simultaneously. Secondly, we wanted a good enough amount of daylight, but we also emphasized an aesthetic that talked to the other volumes. The combination of all these factors resulted in the final form.





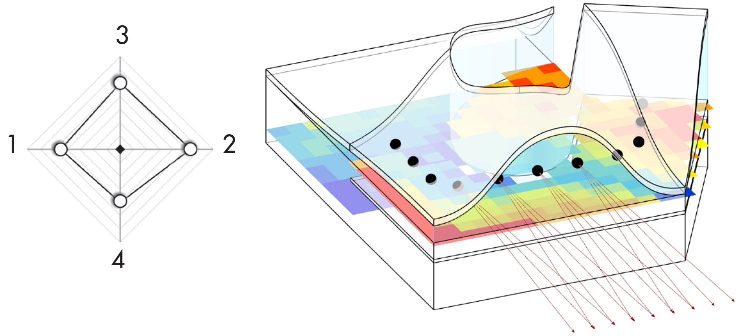


The restaurant with a view towards the volcano.

Top iterations

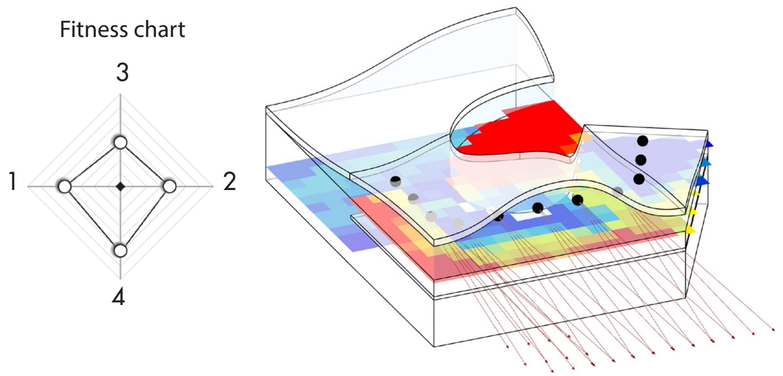
Generation: 98 Individual: 01

Fitness chart



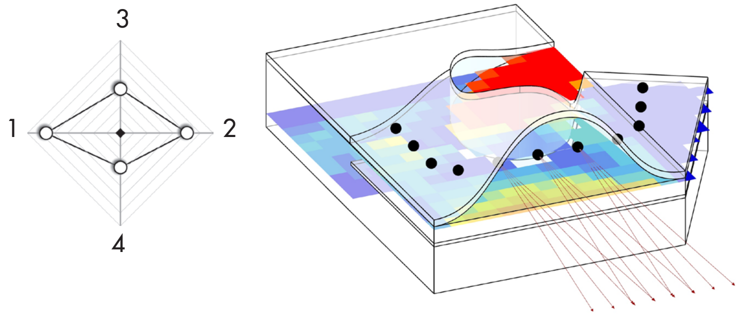
Generation: 99 Individual: 49

Fitness chart



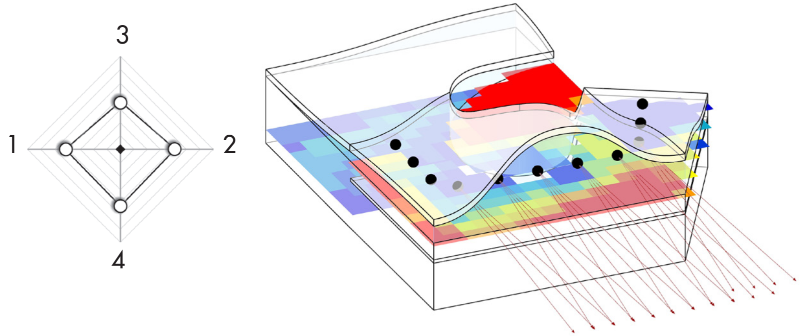
Generation: 98 Individual: 39

Fitness chart



Generation: 99 Individual: 34

Fitness chart



Solar hours (hr)

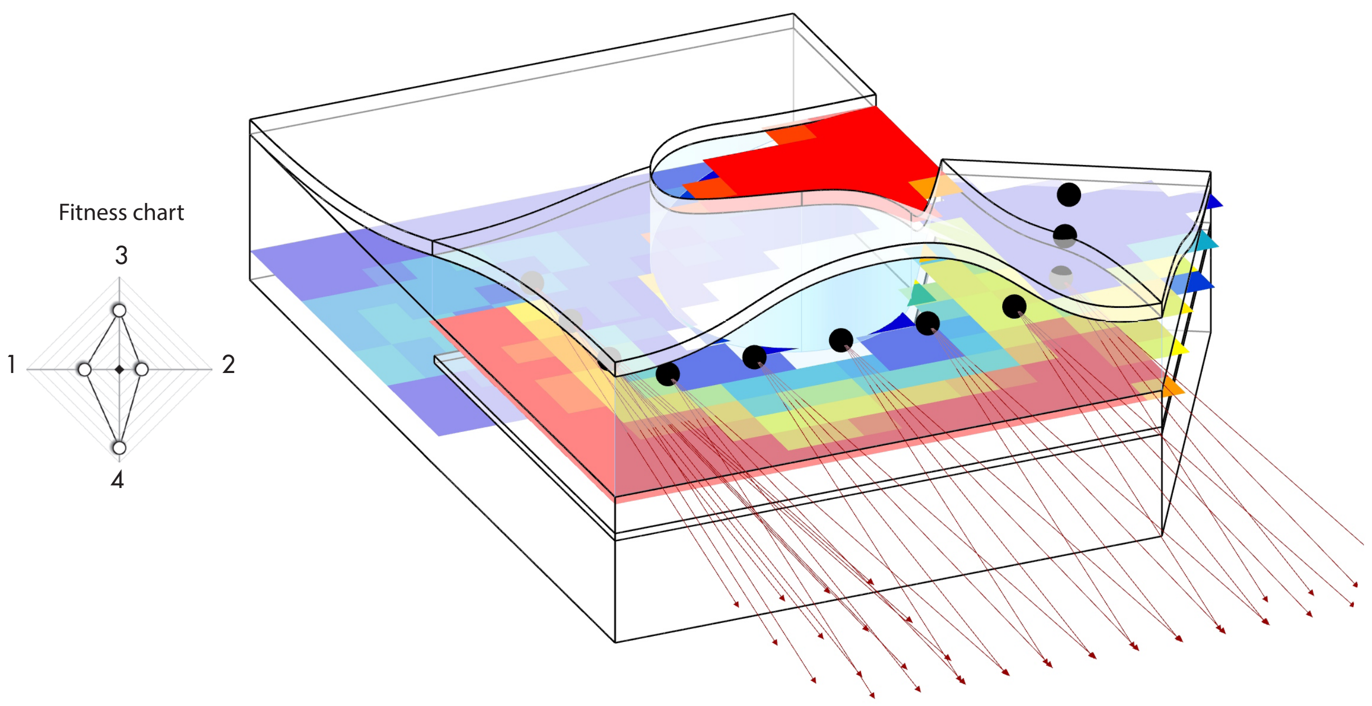
0 1 2 3 4 5 6 7 8 9 10 11 12

Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare

Selected iteration

Generation: 99 Individual: 71

Fitness chart



Solar hours (hr)

0 1 2 3 4 5 6 7 8 9 10 11 12

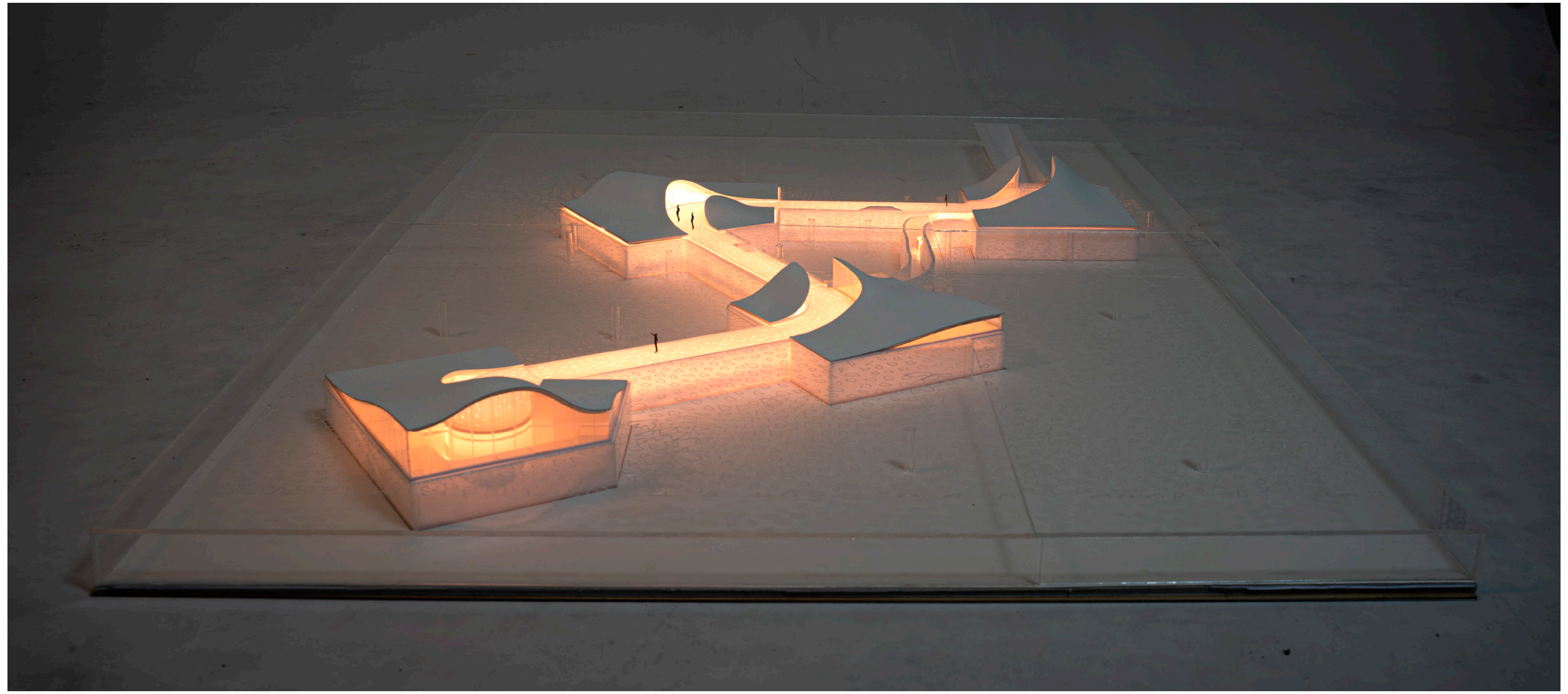
Fitness chart:
1. Maximizing window area
2. Maximizing visual connectivety
3. Maximizing direct sun
4. Minimizing glare

Analysis

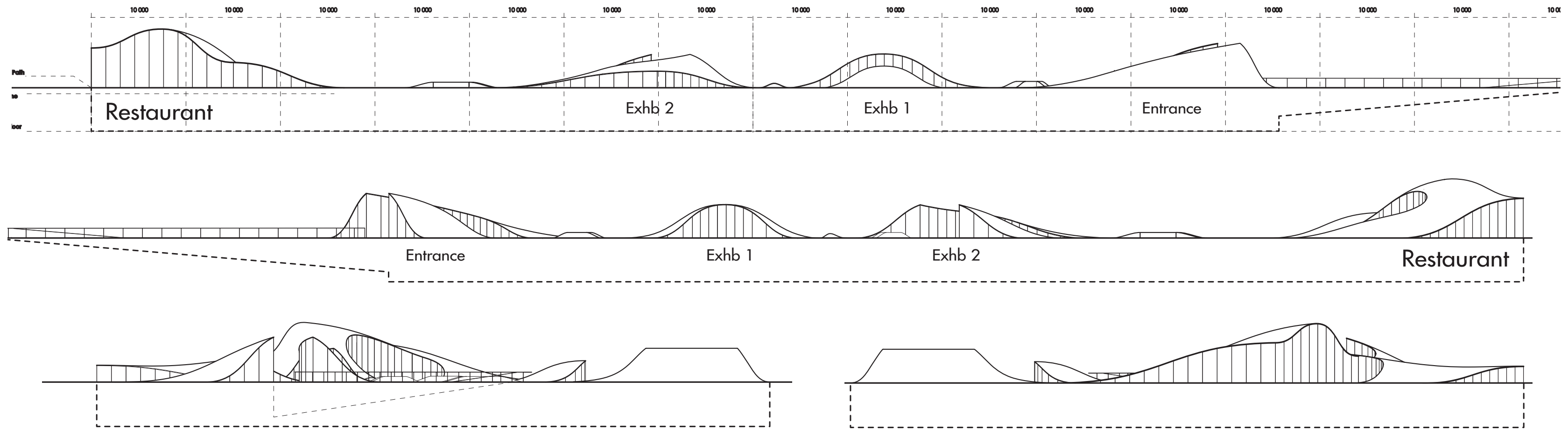
The visual connection to the volcano turned out to work out quite good. The algorithm generated a generous mezzanine where the visitors could end their day with a view towards the volcano. We thought that the iteration we chose was aesthetic and framed the view in a nice way. It also let in of a lot of direct sun for the guest in the restaurant.

The restaurant was in a way the hardest one to generate. This is mainly because the plan of the restaurant differed from the other volumes. In the other volumes, the pathway intersects throughout the whole building, but here, it ends with a courtyard in the middle of the building. This proved to create a challenge when creating the roof, since it did not really speak the same language.

On the other hand, we appreciate that something broke off from the established language of the four volumes.



Birds eye view with the restaurant at the front.



Elevations

4. Evaluation and further discussions

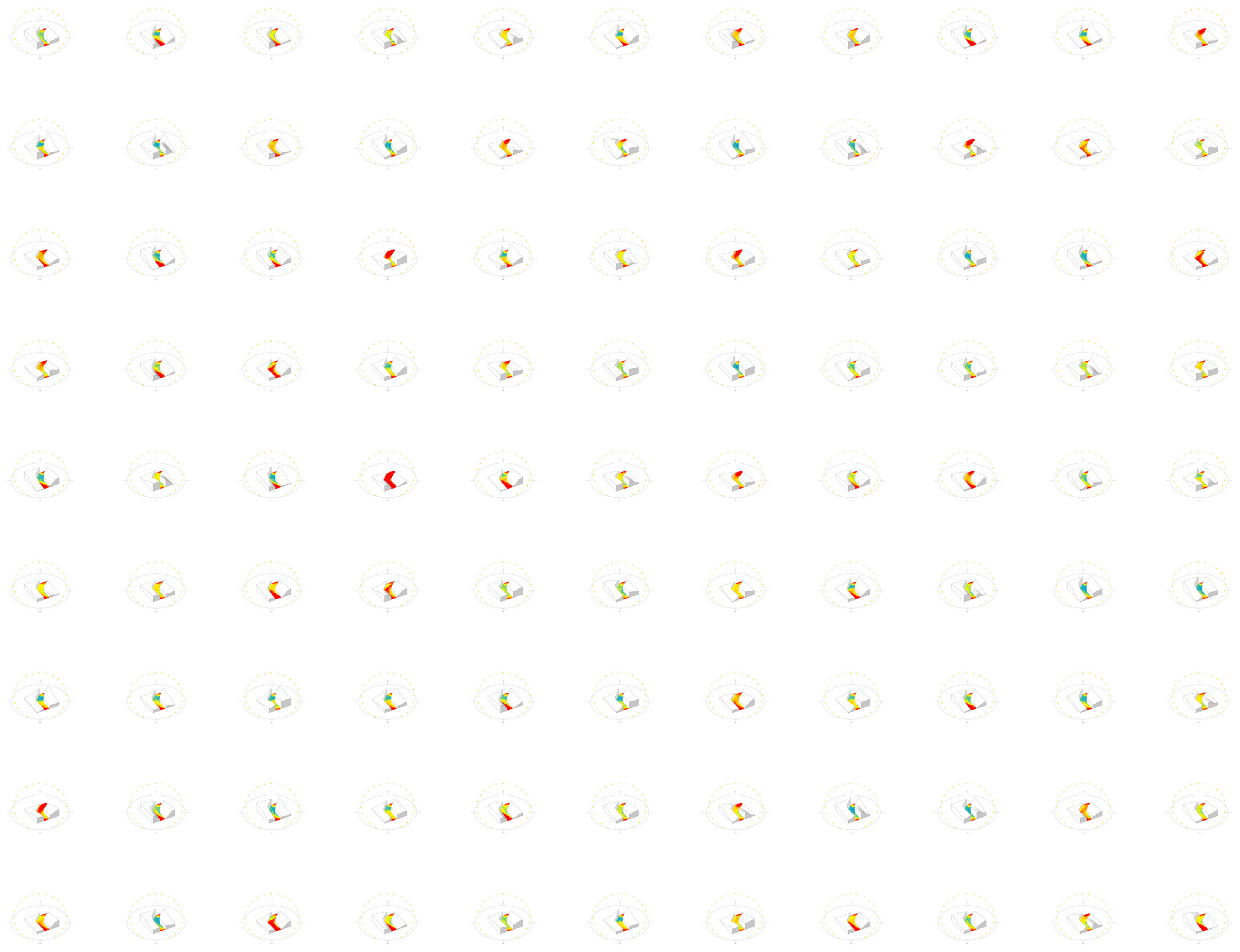
Evaluating the methodology

When looking back on the development of a methodology based on generative design, we realize that there are parts that we should have done differently. But we also realize that we have gained new knowledge about digital tools and our relationship with it. We always tried to be true to the methodology. Sometimes we lacked the knowledge or the time to do it, but in the bigger picture, we are happy with what we achieved, given the circumstances.

This methodology meant a lot of trial-and-error and learning by doing. Since we more or less are trained to work in a linear way, we sometimes had to remind ourselves that it necessarily was not a bad thing (but rather a good thing) if a specific iteration or typology did not succeed.

A lot of the mistakes and missteps could be adjusted during the way, but there are also aspects that we did not really manage to figure out during the project. It is these aspects that we now will discuss and reflect upon.

We will also discuss the relationship between optimization and aesthetics from a more theoretical standpoint.



Iterative design methodology

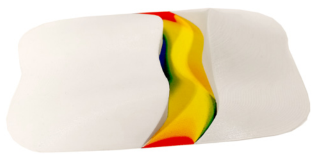
Control

During the development of the methodology, it became clear that the process is not as self-organized as it seemed. There is always a conflict between controlling the computer and being restricted by it.

The algorithm's solutions are directly linked to the parameters provided by the designer. By definition, the computer will try to optimize a solution based on these parameters. The architect must, therefore, be alert and actively check the conditions in the system (in our case the Grasshopper script). The architect must constantly strive for a balance between restrictive and enabling control.

We believe that the decision of working in a deterministic manner, or a more subjective way based on chance, is up to every architect. For us it became clear that we wanted to investigate and mix both of these two approaches in our project, to see what relationship digital tools had to different methodologies.

Too restrictive



Balanced

Restrictive controlling is very constraining and can be resembled as a dictatorship. There is a risk that the end result is already predetermined in the definition of the constraints, and the system thus becomes deterministic. However, this form of control can be useful if one wants to investigate a very specific task.

Enabling controlling is a freer form of control, but it is important to emphasize that it is not a lack of control. Instead, control acts more like a creative catalyst that steers the system towards the given goal. When we give the algorithm a freer framework, we give the computer conditions to generate solutions that we could not foresee ourselves. We used this non-deterministic approach of control for specific parts of the building. When we lacked a clear image of both narrative and performative characteristics, the computer got free reins to give us inspiration, which resulted in several different surprising solutions. It was then up to us to rationalize it, and to more or less find a function for the randomly generated forms.

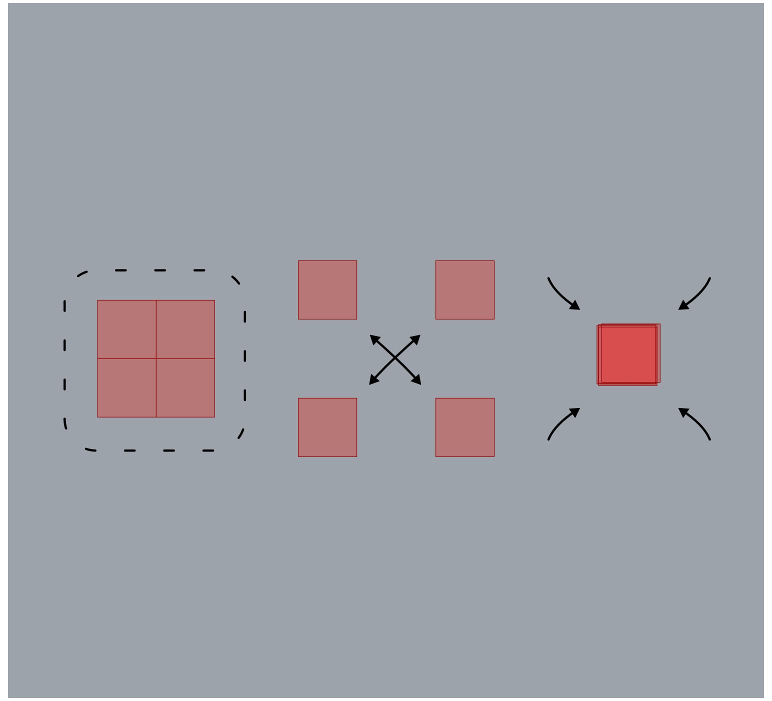
Too enabling

Balanced

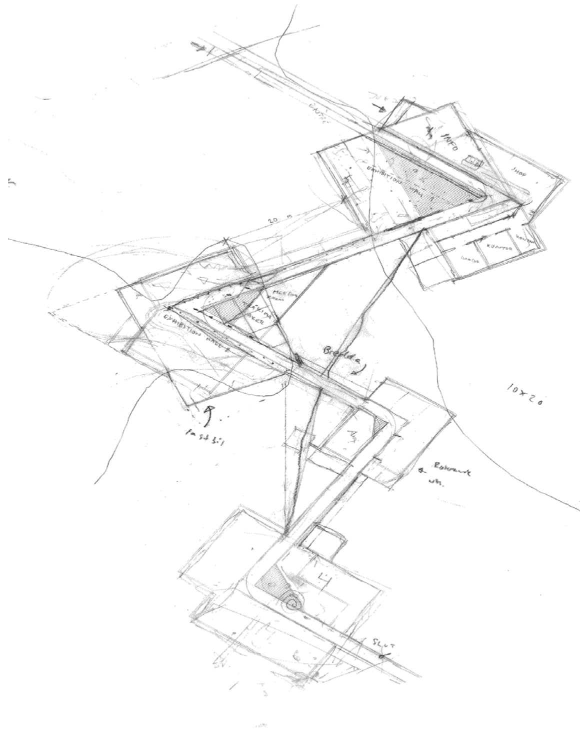
Physical-digital hybrid

The decision to draw the plan by hand was based on several realizations that came along as we developed the methodology.

We initially started off by constructing an algorithm to optimize the footprint of the museum. Our intention was that the algorithm would move around the elements based on given fitness goals. This proved to be a more challenging task than previously thought since the surrounding area more or less was a flat landscape without buildings, topology, or vegetation. We tried to optimize the floorplan after the sun, taking consideration of the quite distant volcanoes. The lack of parameters and constraints in this algorithm resulted in iterations without interest. At this point, we had to ask ourselves if this thesis was about learning as much as possible about digital tools - or investigating our relationship with them. We never claimed that all architects must abandon all traditional techniques, but rather saw this as an experiment to see which traditional tools actually can work with digital tools. We also felt that a floorplan should not only be based on technical optimization, especially not in a museum. Generative design can offer unexpected and complex solutions, but only if you have enough parameters to include in the algorithm. In a quite ironic way, the biggest opportunity for us to design a floorplan in a subjective and random way was to do it by hand. For us, this was an intriguing challenge, to create an experimental plan, and to organize and rationalize it with digital tools - a sort of physical/digital hybrid methodology. This methodology would later prove to have its obstacles as well.



We had problems digitaly generating a floorplan with interest.

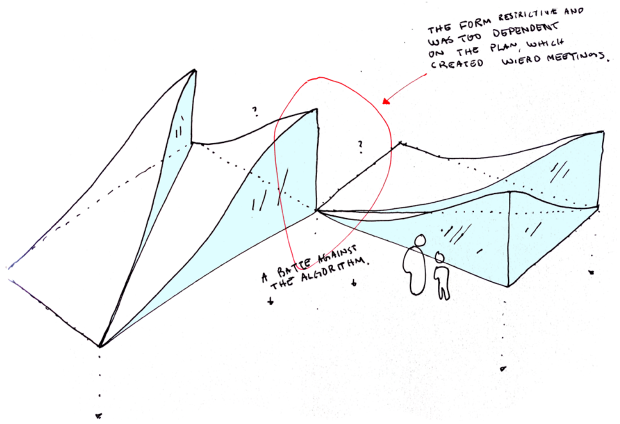


To sketch by hand was a way for us to intuitively investigate the plan.

Developing a relationship between the plan and the roof

As previously stated, you do not directly model the elements in generative design. You rather develop the algorithm, or script, and then let the computer do all the different iterations. After experimenting with various typologies, we developed a typology that we thought served the purpose in a good way. After trying out different movement patterns for the parametric surface, we concluded to constrain the surface so that it could only move vertically. When the surface could move in X, Y and Z, our impression was that the building structure became too complex.

In order to merge the plan with the roof, we scanned the plan and added the surface onto the outline of the plan. The plan consisted of a set of rectangular spaces, which were arranged along the pathway.



Our first typology, based on a modular thinking.

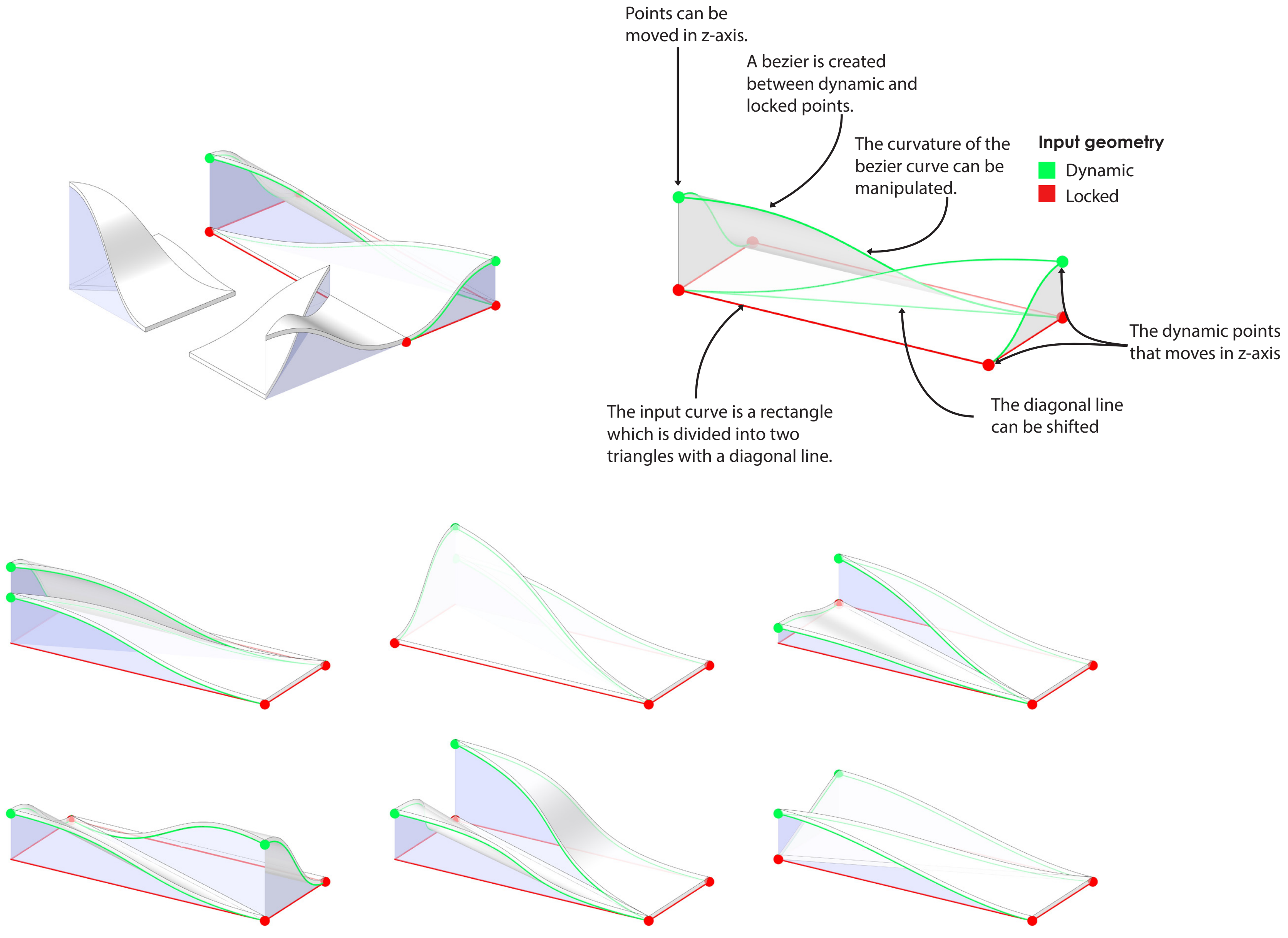
Moreover, the surface had a diagonal cut that could be shifted depending on the fitness goal. This created a window in the middle of the room that we found appealing.

We tweaked the parameters and slightly changed the plan in order for them to merge. At some point, we realized that we had constrained the building too much. The plan was not parametric, and the roof was very constrained. It became a back-and-forth tug of war between the plan and the roof, and we never really made them work in a flexible way together.

Before we knew it, we had developed a kind of modular thinking that restricted our creativity.

The more abstract the plan was, the simpler we had to make the parametric roof. The more complex the roof was, the more rational we had to make the plan, resulting in a lot of compromises between the two.

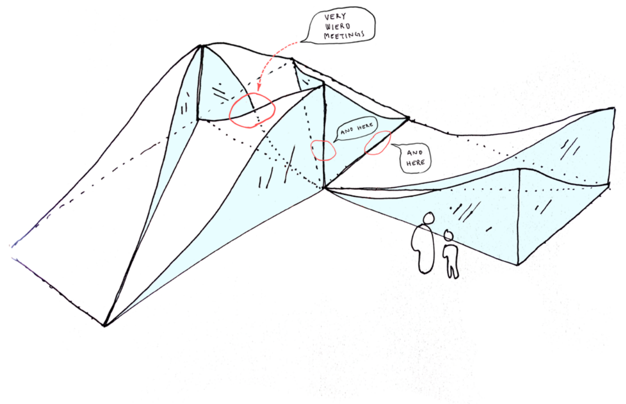
It was also difficult to create seamless meetings between the 'parametric roof modules' since we never knew what direction the roof actually would go, and because the roofs were too dependent on the locked plan.



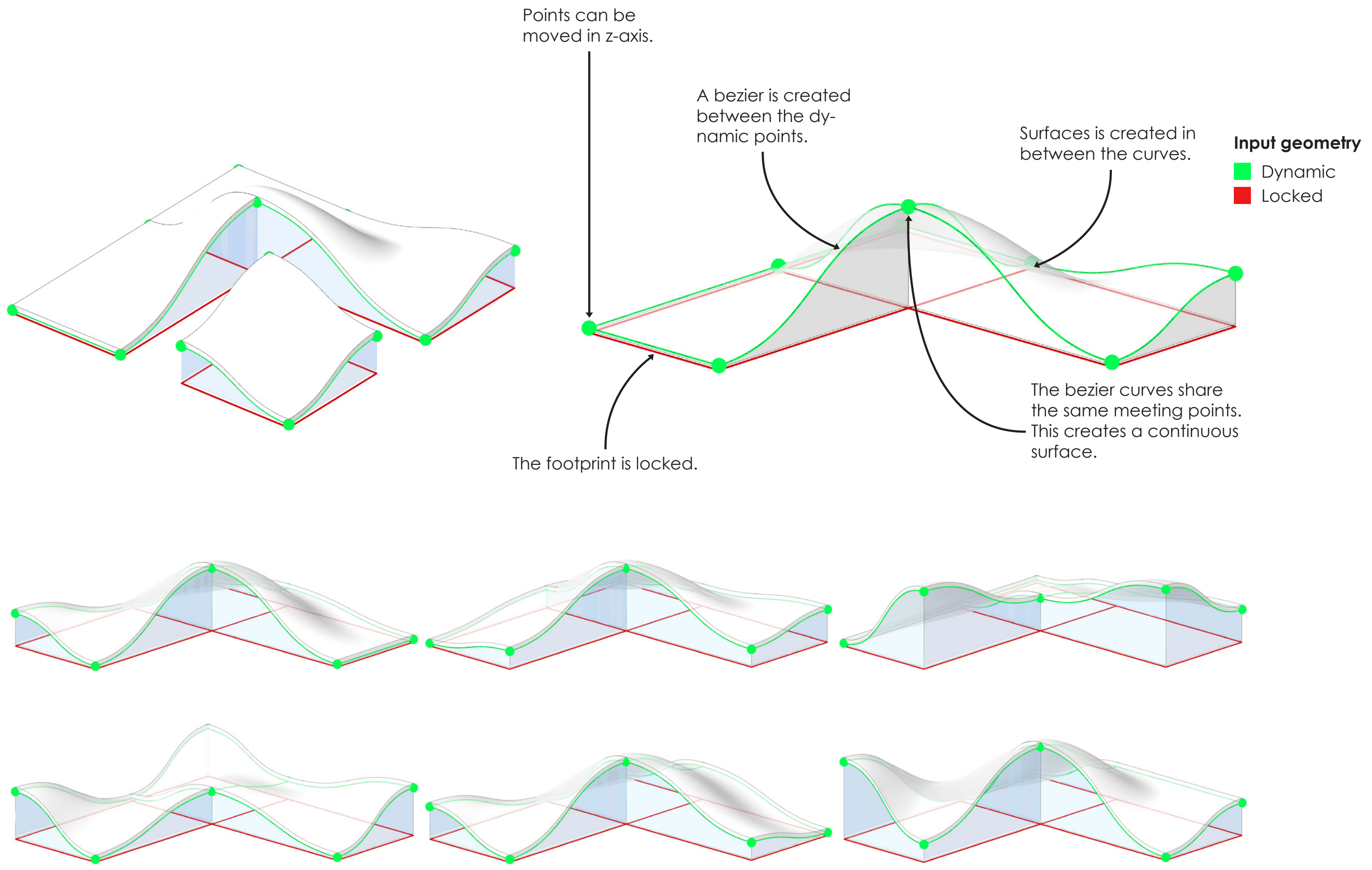
The framework of the first typology.

Adding modules

In an attempt to solve this, we went back to the plan and added additional volumes which served as connecting spaces for the roof structure. The choice stood between adding modules or scaling the existing modules in one direction. Since scaling led to challangin proportions - we started adding modules. By doing this, the roof structure got more deconstructed, which led to bigger freedom in a sense. On the other hand, it created more inconvenient meetings and required more space for columns in the interior. We then started to experiment with more flexible roof configurations, without the diagonal cut, as shown in the diagram on the opposite page.



The modular typology was not flexible enough with a curved plan.

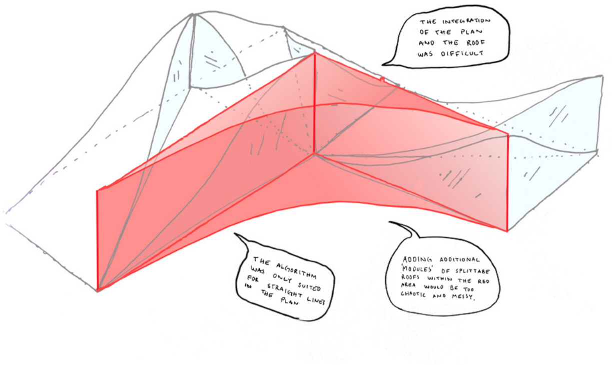


The framework of the first typology.

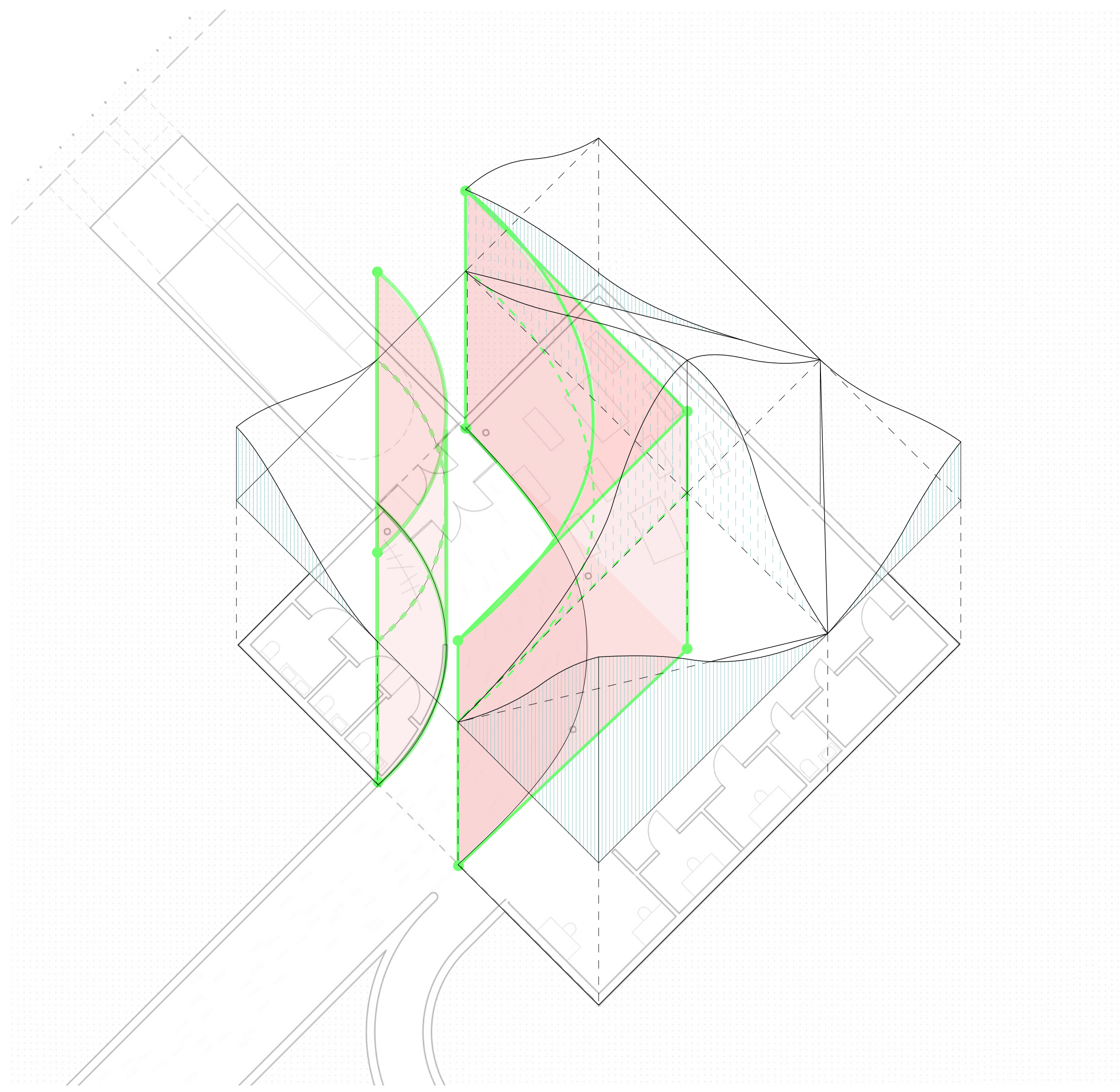
Flexibility of the modules

By this stage, we had abandoned the act of physically sketching the plan, and did it on the computer instead. After establishing some sort of plan by hand, we thought that it is easier to quickly change it on the computer. We still had this philosophy of keeping the plan locked.

In retrospect, we should have created a more integrated system of plan/section that reacted when other parts changed. A system that for example adapted if wanted to change the plan from a rectilinear set of walls to curved walls. The existing algorithm could only deal with rectilinear systems, while we started to sketch more curved plans. We realized that we had been quite stuck on this modular thinking, and went back in the process and changed the parameters of the algorithm.



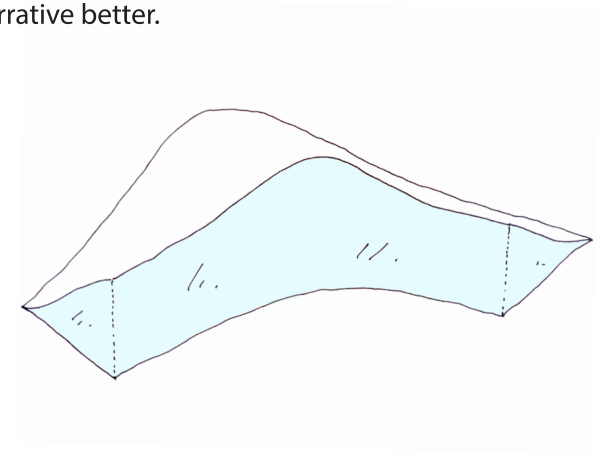
The modular typology was not flexible enough with a curved plan.



The integration of the curved plan and the parametric stucture was difficult with the current algorithm.

Changing the typology

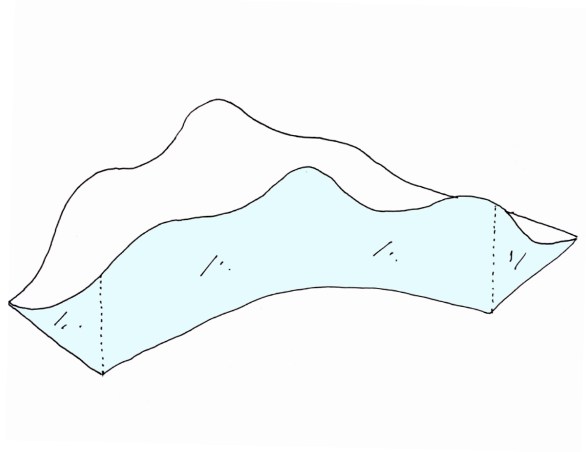
After realizing that the algorithm was not flexible enough, we changed from a modular system towards a more usable parametric surface. This version was much simpler and allowed us to change the plan more easily. We also thought that this typology resembled the Icelandic landscape better than the last one, and therefore suited the narrative better.



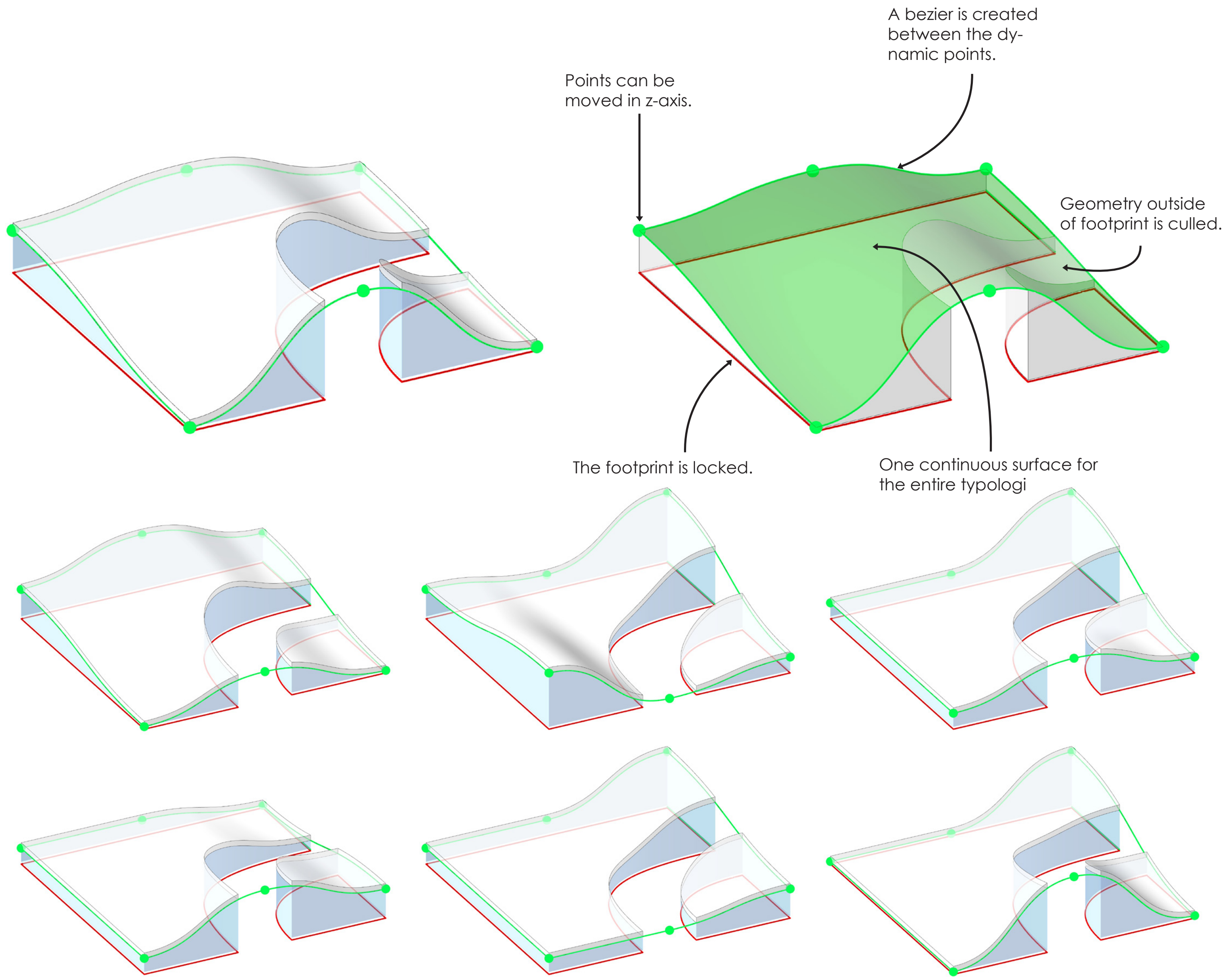
New typology, based on one parametric double curved surface.

Resolution

With this typology, we could change the resolution. Higher resolution meant that the algorithm could create iterations that scored higher on the fitness graph. On the other hand, we found it more aesthetic the simpler it was. Through lowering the resolution, we compromised some of the performance but gained some aesthetic value.



Higher resolution.

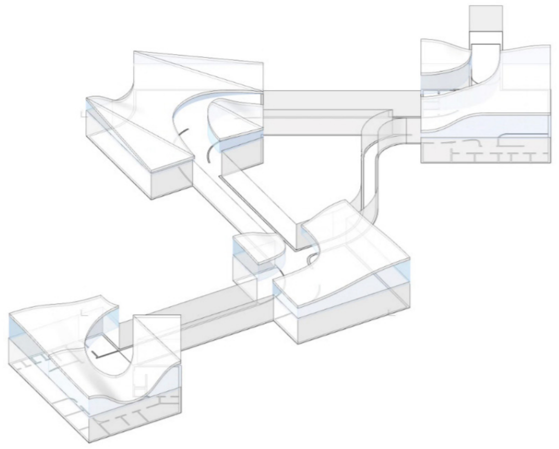


The framework of the second typology.

Relationship between the elements

By locking the plan, and constraining the roofs, we in a way lost a chance of creating a system that was created by chance behavior. And by extruding the plan vertically towards the roof, we also might have lost a chance to create a hybrid structure of a set of elements (plan, walls, roof), in our case, the building quite clearly consists of a set of separate elements. And we never clearly acknowledged the wall elements. What if they also whould be generated? What if they were not only extruded straight walls? What if they could bend, separate, or move in order to optimize the interior conditions? When it comes to the hand-drawn plan, we still think that the combination of the physical and the digital is an intriguing idea. In retrospect, maybe we should have established the rules of the plan by hand, to then upload it digitally, to then create floorplan iterations based on our established language. These iterations would not have to be necessarily performative. They could still be abstract and randomized. Maybe they would give us new ideas that we might never have thought of for the program and the functions and so on.

There was only a restricted set of possibilities for the generative design to work. We did not know exactly how this methodology would turn out, and it grew quite organically from our lessons and mistakes. We did not choose the easiest site to conduct this experiment, and quite often we speculated how it would be if we chose a competition that would have more built context.



The elements of the building never really worked in an intergrated way.

Negotiation between the fitness goals

In practice, the methodology of negotiating between different fittness goals worked quite effortlessly for us. We could look at an iteration, and compare it to the fitness chart. The rating of the fitness chart would then give us a suggestion on whether it was a successful or poorly performing iteration. We would then weigh in our human perception on the aesthetic parts of it. If it was both performative and aesthetic, it had a good chance of making it to the final building.

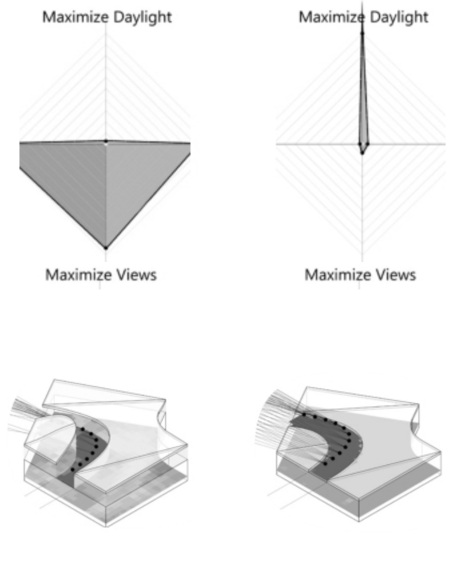
But beneath this effortlessly working methodology, there are a couple of details that bring down the realibility of the whole negotiation process.

First, we only included four fitness values; Direct sun, interior lightning conditions, views, and volume. Ideally, you would prefer to include as many values as possible. In our case, maybe the most valuable values would be wind and snow, since the site is located on northern Iceland. Unfortunately, we did not have the computational power do conduct those analyses. Therefore, we had to perceive the methodology more as an example of how you would use these tools.

Secondly, we have to question the architectural value of the actual performative aspects of a building. When doing these investigations, it is easy to develop a tunnel vision where you only focus on these issues. But as we all know, architecture is a holistic matter that beyond engineering includes societal and artistic aspects.

Either we include these aspects in the actual fitness chart, or we leave them aside, and devalue the importance of the rankings in the fitness chart. An iteration that gets the highest score might not be the most beautiful one, and it might not be the one that enables a good social life for the visitors.

Generative design as a quasi artificial intelligence technology is not able to include these factors in the evolutionary algorithm. However, there are most sophisticated versions of artificial intelligence that technically could do it, in which we will discuss deeper later in this chapter.

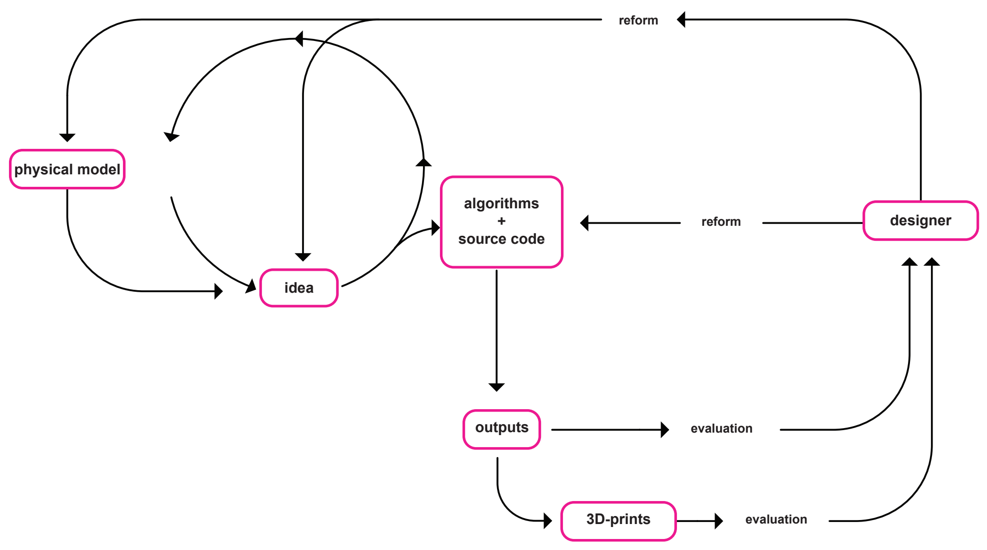


Fitness charts with corresponding iterations.

Conversation

We consider the design process as an active conversation. It can take place between the architect and the pen but also between the architect and the computer. By conversation, we refer to communication, in a circular form, where two parts take turns in talking and listening to each other. If we apply this definition of conversation to the methodology we explored, the relationship looks like this: The architect communicates a design hypothesis to the computer. The computer receives and interprets the information. The result is sent back to the architect.

In our experiments, we had a tendency to perceive the computers simulations as perfect straight away. It was quite often difficult to question the authority of the computer in that way. To always be aware that it is not the computer that defines the objectives was sometimes hard for us, as we quite often got stuck on the same objectives, instead of trying out new ones. We also struggled with always having to justify the optimization technically, by looking at the best numbers to often.



The conversational digital design process.

Semantics

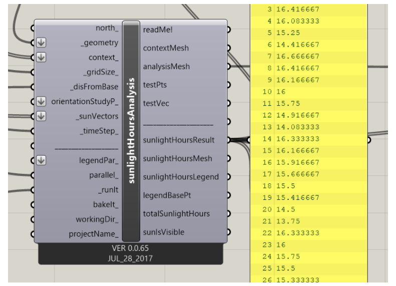
The main challenge of the conversation between the architect and the computer is that we simply do not speak the same language. The computer thinks through ones and zeros, while we tend to be more visual. To make the numbers understandable, we need a human abstraction of the information.

Digital heat maps

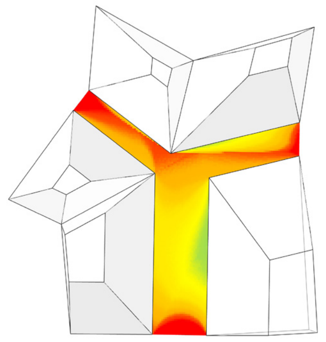
By translating numbers into colors we interpreted information in a better way. We chose colors that we could associate with. Blue for coldness and red for warmth. Those two colors respectively represented the lowest and highest values on the spectrum. To be able to clearly distinguish different values from one another, a gradient between blue and red is not enough. By introducing yellow and green, we created a gradient of four colors which gave us many shades to read. With the help of a legend, we then deciphered the information through the act of looking. This translation from numbers to intuitive color schemes was something that helped us greatly in the design process. Heatmaps were a powerful communication tool that helpedus to visualize information that could not be perceived with the human eye. Atmospheric factors such as sound, temperature and wind could now be simulated and conveyed as a kind of drawing. Thanks to this feedback, we could make efficient and more informed decisions.

Materialization

Through the act of looking, we evaluated the simulation results. With a physical object, we could also analyze through the act of feeling. It also provided new opportunities for viewing from different angles. This tactile interaction brought new associations, insights and a sense of materiality for us in the process.



Analysis result directly from grasshopper.



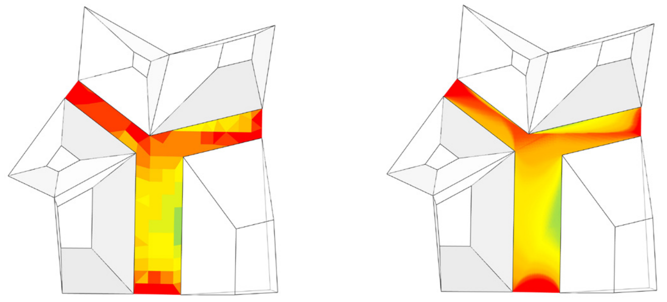
Analysis result translated to a heatmap.

Technical aspects

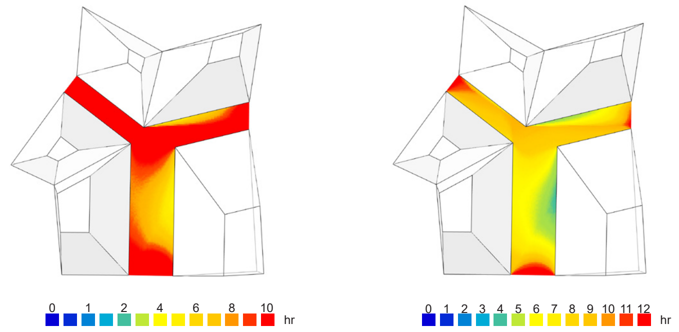
Simulation is based on digital information. In a virtual world, imperfections of reality can be overlooked, giving a polished image. In the physical world, there are factors that are difficult to predict, which might affect the actual outcome. For example, trees can affect the result of a solar analysis. By ignoring these factors, the result of the heat map might be locally false. There is a limit to how much information and parameters you can include in the simulations. It is the designer's job to choose the factors that you believe will affect the result. It allows you to miss causal relationships that initially seemed to have no effect. We can problematize our project with one example: Our site had quite special geological conditions. The landscape was relatively flat and free of trees, but there were large volcanoes in the periphery. We discussed whether or not the low Icelandic sun would be blocked by the volcanoes. The volcanoes were very far away, which meant a heavier digital model and more time-consuming simulations, which led to actively choosing to overlook the impact of the volcanoes.

In the conversation between the computer and the architect, fast communication is important in order for the design to progress. Simulations can be time-consuming. Sometimes it might be a good idea to limit the amount of information in the simulations. Of course this means you will lose some data, but you will gain time. We sometimes lowered the resolution of the analysis surface. It significantly improved communication but resulted in pixelated heat map that did not convey as detailed information as possible. Thus, there is a trade-off between efficiency and a precise decision.

Pixelated heatmap High-res heatmap



Since simulations are something that people from all disciplines must be able to understand, its important to make them as pedagogic as possible. We consider them as a kind of universal drawing that everyone must be able to intuitively understand. By translating the result into charts and pictures we can translate the result. It can be a powerful tool for validating a project. But this also places a responsibility on the architect, to be honest with the communication. Like statistics and graphs, it is easy to manipulate the data graphically so that it appears to be a better result.



The heatmaps are showing the same sun hour result but with different legends.

It would take alot of computer power to include all the volcanoes in the surrounding area in the 3D-model (Isor 2019).

Optimization vs aesthetics

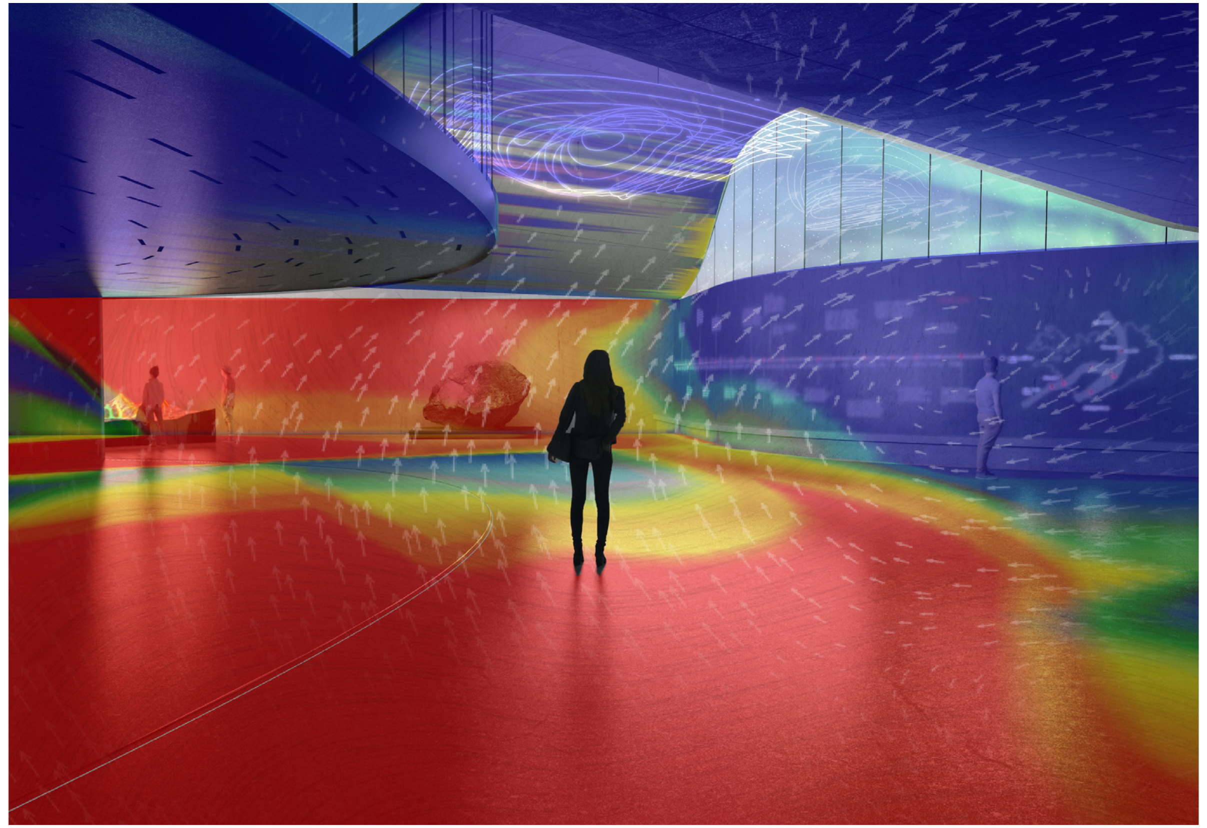
Striving for simplicity, we limited the set of objectives to interior light conditions, minimizing glare, the exterior microclimate and visual connectivity towards the local volcano.

Along the course of the project it became clear that generative design is not just about optimization but can also act as a creative catalyst. New advances can be achieved in the combination of computer computation power and our intuition, experience and judgments as architects.
 As the conversation progresses, the result improves. How do we then know when to quit? Is it as simple as quitting when the computer has generated the optimal solution to the problem? However, there is a problem with the concept of an optimal solution. When the algorithm strives for the best solution to a problem, it is we as architects who formulate the problem and the structure of the algorithm. Thus, if there is no absolute problem, there is no absolute solution. The only thing we can safely conclude is that the computer has generated the optimal solution based on the problem and the algorithm we formulated. The optimal solution can never be objective because it is always colored by our formulations of the problem. That being said, why not include the concept of beauty in the algorithm? Maybe the process simply stops when we see beauty. Beauty is subjective and linked to cultures and trends and there are architectural features that are difficult to define in an algorithm. Factors that are more about the experience of an atmosphere than optimization. Architectural theorist Juhani Palasamaa formulates this:

'Every touching experience of architecture is multi-sensory; qualities of space, matter and scale are measured equally by the eye, ear, nose, skin, tongue, skeleton and muscle… an architectural work is not experienced as a collection of isolated visual pictures, but in its fully embodied material and spiritual presence' (Pallasmaa 2005, 41-44).

We did not have the digital knowledge nor tools to generate some sort of beauty, as long as you don't define beatuty in modernistic terms of performance or function. We simply had to stick to our intuition and gut feeling when it came to aesthetics. Most often, we stopped when we *felt* that a specific iteration had beautiful or aesthetic characteristics. In this way, we saw our human conciousness as a part of the algorithm.

However, there are ways to exclude the human out of the algorithm and theoretically optimize the aesthetic parts of architecture. Even if we did not do so, we will now discuss how that would be conducted, in a quite theoretical and speculative manner. We will also discuss how more advanced technology, such as Deep Learning, can offer solutions to this problem.



Vision of simulatied atmosphere.

Optimization, aesthetic measurement and AI

We set out to investigate how architects can work in symbiosis with new generative tools, and wanted to find a suitable methodology for this. In retrospect, we realized that some aspects worked better than others. Optimizing performative aspects was a relatively smooth task. The process of negotiating between the different fitness goals, and curating the iterations between the different generations also made a lot of sense. We think that we achieved good results from from that perspective. On the other hand, we encountered bigger problems when trying to 'optimize' the aesthetic parts. Of course, we wanted a good technical building, but we also realized early on that a volcano museum in Iceland would have to put a large amount of emphasis on narrative and aesthetics. By drawing the plan in a traditional manner, and constraining the parametric freedom to a large extent, we also minimized the possibilities of generating something unexpected and novel. Here we wish that we would have been a bit bolder. One of the advantages of generative design is that the computer can offer solutions that we could never even come up with with our human consciousness, and in a way, we lost an opportunity to do so.

Given the technological and knowledgeable resources that we had, we realized early on that we would have to, in an intuitive and human way, control the aesthetics ourselves without involving the computer much. We therefore always tried to be present in all design decisions, to try to steer the building into what constitutes a volcano museum in Iceland. The concept of aesthetics is very complicated. On the one hand, aesthetics can mean a more objective view

Icelandic Volcano Museum. Physical model.

of how the object in itself is perceived in terms of beauty, but it can also be about narrative and context. Of course, we wanted to fulfill all of these factors as successfully as possible. Since we are researching digital tools in our thesis, it would be interesting to ask ourselves the question; what if we could optimize aesthetics with the computer? What do we have to know about aesthetics to do so? What different historical discourses do we have to take into consideration? And do they really matter? And what technology can do it? What would the implications be on our role as architects? To be able to follow out this thought experiment, we need to start off by defining aesthetics. We also need to find out if it is possible to obtain quantifiable data on aesthetics. Can we humans evaluate aesthetics or do we need to use technology? And how would we use that data in the algorithm to optimize aesthetics?

Aesthetic ideals

Alexander Gottlieb Baumgarten stated that aesthetics is the *'science of perception that is acquired by the means of the senses.'* Since the 19th century, however, the more general definition 'Of or pertaining to the appreciation or criticism of the beautiful' has been more frequently used (Cohen 2014. 4). The act of theorizing about aesthetic ideals has been done since ancient times, or even before. Many theories and perspectives have come and gone, while others have gained a foothold in a larger part of the timeline of architecture. The discourse has always been characterized by a quantitative or qualitative approach, focusing on measurable or non-measurable characteristics (Ingemark Milos 2015. 8). While Baumgarten represented a somewhat scientific view of aesthetics, there were philosophers who laid the foundation for a more relativistic attitude. According to Kant, *'there is no Science of the Beautiful, but only a Critique of it […]. For […] if it could be decided scientifically, i.e. By proof, whether a thing was considered beautiful or not, the judgment upon beauty would belong to science and would not be a judgment of taste'* (Cohen 2014. 7).

Philosophical trends, architectural styles, and societal changes have always intertwined and influenced each other's ideas. Measuring aesthetics is a very complicated task, because one must constantly weigh objectivism, rationality, and absolutism against subjectivism, skepticism, and relativism. These different approaches contain many factors that must be considered, such as complexity theories, design principles, psychological models, and a large amount of social and cultural factors.

Early aesthetic ideals

The ancient Greeks experimented with the proportions of the mass using mathematical principles, that resulted in buildings such as the Parthenon, which is based on the golden section (Gangwar 2017). They thought that the golden section created the most aesthetically pleasing proportions of a rectangle (Carlson 2019). This concept arose a few centuries later in Vitruvius' texts. Strength and utility are something a majority of us can reach some form of consensus on. Venustas, however, that beauty arises as long as a design refers to the body's 'undeniable' hypothesis of proportion and symmetry, on the other hand, can be promlemized (British Library). Even if these theoretical proportional systems never really got scientifically validated, the architects of the time *believed* that they worked and that they through 'the truth of nature' had desirable aesthetic qualities (Cohen 2014. 12). This approach was resumed during the Renaissance in Alberti's texts. Palladio also contributed to a new wave of strict numerical ratios and notions of symmetry (Ingemark Milos 2015. 17).

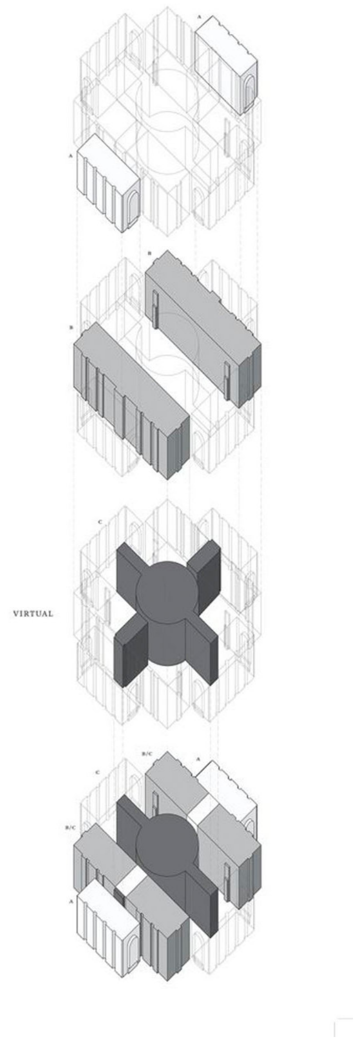


Diagram of Villa Rotonda, by Peter Eisenman (Architectural Review).

Geometric proportions

Before the Renaissance, in the middle ages, the architecture contrasted the numerical or grid-based classical architectural proportion through geometric medieval proportions. Wittkower argued that the history of architecture was characterized by these two dominant premises; ie 'medieval geometry vs. renaissance number.' He sums it up as follows: *'two different classes of proportion, both derived from the Pythagoreo-Platonic world of ideas, were used during the long history of European art, and […] the Middle Ages favored […] geometry, while the Renaissance and classical periods preferred the numerical, i.e. the arithmetical side of the tradition'* (Cohen 2014. 5). Even if these two world-views contrasted each other with different proportional ideals, they still had a common objective framework that they related to. A strong focus on proportion as an element of a good aesthetic composition was a common trait to all of the important aesthetic ideologies from antiquity to the Renaissance, or as Alberti put it: *"Beauty is the adjustment of all parts proportionately so that one cannot add or subtract or change without impairing the harmony of the whole."*

Modernism and it's systems

One would believe that the modernists were the first who broke with the classicist ideals of aesthetics. The modernists' emphasis on functionality and new rational construction techniques is not necessarily synonymous with not having an aesthetic stance though. In fact, it was the marriage between new technology and aesthetic ideals that defined their aesthetics (Rutsky 1999. 9). The strict classicist rules of form, proportions, and perception were neglected and the focus was now on *"the expression of volume rather than mass, the emphasis on balance rather than preconceived symmetry, and the expulsion of applied ornament"* (Eupolis 2016). Even if the modernist aesthetics expressed something completely different, they still continued to romanticize aesthetics as something absolute or spiritual. But unlike earlier ideals, which did so through organic metaphors, modernists did it with technology. A kind of technological enlightenment was sought. Here, mathematical and abstract geometric forms were still used to attain spiritual attributes. An example of this is Bruno Taut's glass pavilion, where he tried to achieve something aesthetically beautiful and spiritual with the help of new technology and new materials. With their focus on technology, standardization, and rationality, the modernists wanted the aesthetics to reflect the Fordist contemporary age (Rutsky 1999. 9-10).

Glass Pavilion. Bruno Taut (Stepan Kiskin).

R. L. Rutsky writes that; *'Yet, this belief in "functional form," in a "machine aesthetic," betrays the extent to which modernism misunderstands its own "aesthetic" uses of technology. Indeed, modernist aesthetics is very often based on "the myth of functional form." Taking technology and mass production as models for art and artistic production does not, after all, make modernist art inherently more functional. As Reyner Banham has shown in discussing architectural modernism, its "functional forms" were rarely particularly technological or functional; they merely "looked" technological, functional'* (Rutsky 1999. 11).

The modernists also used unquantifiable proportional systems. Frank Lloyd Wright was one of the first architects to resume this line of thought and developed a grid and module system as a basis for his drawings. Walter Gropius and Ludwig Mies van der Rohe also used similar methods in their buildings. The italian rationalist Guiseppe Terragni applied the module system fully to both the exterior and interior of the Casa del Fascio from 1932 (Ingemark Milos 2015. 17-18).

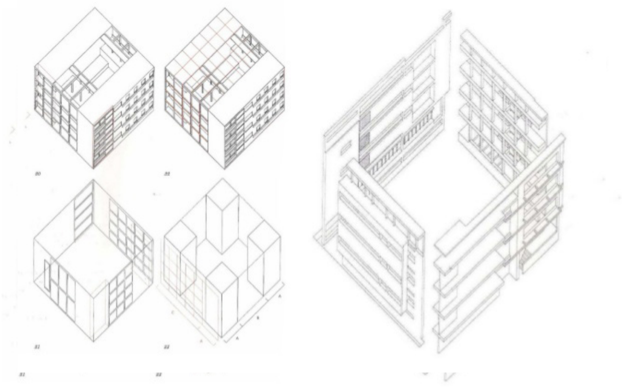
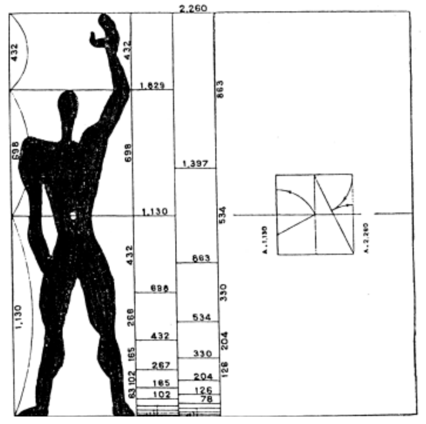


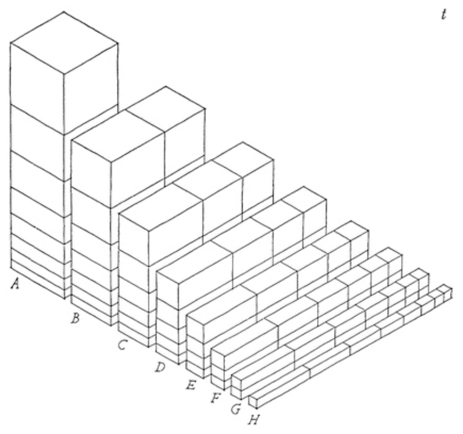
Diagram of Casa del Fascio, by Peter Eisenman (Palumbo 2016).

Perhaps the most prominent example of this was Le Corbusier, who developed Vitruvius's measurement system in a modern context with his Modulor Man. He writes in La maison des homme from 1942: *"The proportions determine the harmony of the building, its smile, its pleasures /… / Music, architecture and mathematics, sublime expressions of numerals - what a noble unit!"*[quote translated from swedish] (Ingemark Milos 2015. 10). Another example of a proportional system is Hans van der Laan's 'plastic number', which is a more 3-dimensional system.

These proportional systems were sometimes technically impractical and did not necessarily exist to guarantee a certain technical or performative result, but rather relied quite heavily on the metaphysical orientation that characterized thinking well before the 20th century. These systems were used just as in the Renaissance to generate desirable but immeasurable qualities that would generate order and harmony (Cohen 2014. 12). Even if it technically was not possible to evaluate the aesthetics of these systems, they corresponded with the modernists' pursuit of universal and absolute truth.



Modulor Man. Le Corbusier (Khanna 2012).



Plastic number. Hans van der Laan (Delpht 2014).

Postmodernistic views

The first true reaction to the established view of aesthetics as something 'scientific' and absolute came with postmodernism, which was considered by many as a liberation from the conservative and elitist shackles of modernism.They reacted to the modernists' belief in process and rationality by advocating, among other things, appropriation and recycling, blurring out high and low, and by declaring ideology dead (Shusterman 2003. 2). Instead of designing buildings according to established aesthetic templates and systems, they worked with ramdomized techniques (Shusterman 2003. 5). Rather than seeking a universal and original view of aesthetics, the buildings would now serve the needs and taste of the local context, in an aesthetic and social way. By drawing attention to local building traditions, postmodernists encouraged the use of local vernacular materials, and generally advocated a more stylistic pluralism and eclecticism, where different styles from different eras were mixed in the same building (Shusterman 2003. 3-4).

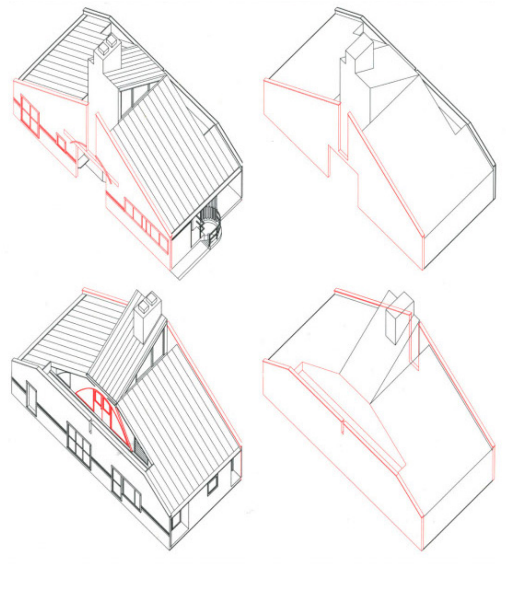


Diagram of Vanna Venturi House, by Peter Eisenman (antithesi).

In contrast to the modernists' rational consensus and unity, postmodernists rated 'artistic experimentation' as an aesthetic ideal. The postmodern thinking can be likened to the Kantian aesthetic theory of 'judgments of taste and sublimity'. Or as Jean-François Lyotard wrote: *'The post-modern philosopher, like the postmodern artist, expresses an aesthetic sublime beyond modernism by seeking 'the unpresentable in presentation itself', by going beyond all pre-established, rational rules'* (Shusterman 2003. 7).

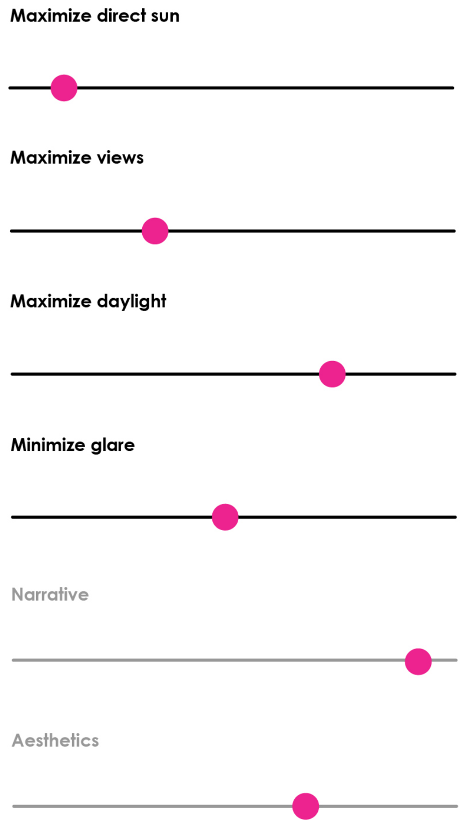
In addition to ambiguous experimentation, postmodernism turned against theory and towards narrative, which they used as a creative and aesthetic force. Trust in truth and metaphysics was replaced by creative interpretation and genealogical rewriting (Shusterman 2003. 8). In the artworld, Marcel Duchamp and his readymades are an example of how the object in itself was not the art, but rather the unexpected choice, and the public's reactions were what was considered as art. The readymade also defied the notion that art must be 'beautiful' (MoMa 2019).

R. Mutt. Marcel Duchamp (Keats 2017).

Quantifying an object

Generative design is driven by data. To obtain data on aesthetics, we must for the sake of the thought experiment, theoretically consider aesthetics as something quantifiable. If we do this it is possible to, in addition to technical parameters, add aesthetic parameters as fitness functions. The classical proportional systems have never been verified, but in the 20th-century researchers began to establish and analyze links between aesthetics and information theory, (Schmidhuber 2012. 325) which is the study of quantification, storage, and communication of information (Wikipedia 2020). The connection between psychological studies and established design principles could theoretically verify an aesthetic value that we could use as data in the algorithm.

In accordance to this thought experiment, we would technically be able to include aesthetics, or atmosphere, in the algorithm. In our project we manually took care of that bit, as the diagram to the right shows. In this scenario, the aesthetic fitness goals would compete with the more functional fitness goals.



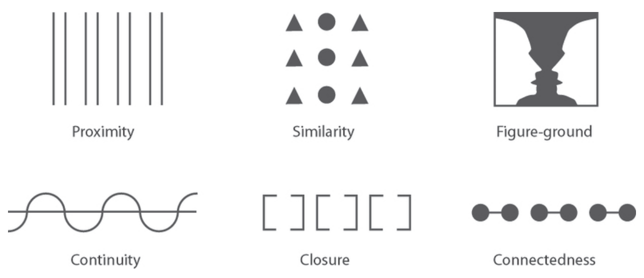
Psychologic aesthetic measure

One way to measure aesthetics is the Gestalt principle, which is a set of laws arising from 1920s psychology, describing how humans typically see objects by grouping similar elements, recognizing patterns and simplifying complex images.

The Gestalt principle focuses on six primary factors: Continuation, closure, proximity, similarity, symmetry and figure & ground.

Another example is 'Unity and Variety'. Unity in an artwork creates a sense of harmony and wholeness, by using similar elements within the composition and placing them in a way that brings them all together. Variety adds interest by using contrasting elements within the composition (Sofia 2020). The diagram below illustrates the principle, using circles of different sizes and colors to show how a composition can be unified by similarities, and how interest can be added by varying aspects of the composition.

This is something that we manually thought about in our design process. We wanted the four volumes to speak the same language, but still break and do something unexpected sometimes.



Gestalt Principle (Burkhard 2005).

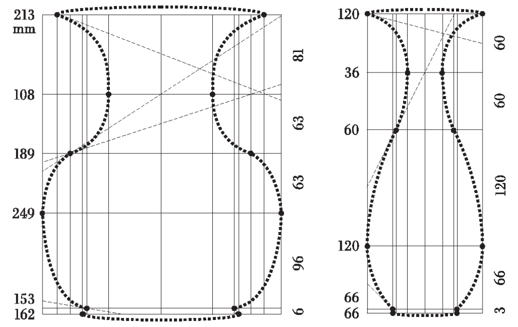
Icelandic volcano museum.

Birkhoff's Aesthetic Measure

Another example of aesthetic measure is George David Birkhoff's formalization of aesthetics, which he proposed in his book 'Aesthetic Measure' from 1933. By quantifying the aesthetic reward through an ideal ratio between the expected and the unexpected (order vs complexity), Birkhoff sought to explain an aesthetic experience in the context of information theory or complexity theory (Schmidhuber 2012. 325). The equation M = f (O C) works as follows; by dividing order (O) with complexity (C), the result is M, which stands for the aesthetic measure of the given object. The specific definitions of O and C depend on the type of the analysed object. Birkhoff applied the formula to everything from vases, to music, or even poetry. According to Birkhoff, the aesthetic experience consists of three stages:

"… (1) a preliminary effort of attention, which is necessary for the act of perception, and which increases in proportion to what we shall call the complexity (C) of the object; (2) the feeling of value or aesthetic measure (M) which rewards this effort; and finally (3) a realisation that the object is characterised by a certain harmony, symmetry, or order (O), more or less concealed, which seems necessary to aesthetic effect" (Douchová 2015. 40-41).

However, researchers have questioned the validity of Birkhoff's choice of parameters in his studies. Especially regarding the computation of order, with the underlying problem of distinguishing formal and connotative associations (Douchová 2015. 50).



Birkhoffs aesthetic measure, exemplified here by two vases (Staudek 1999).

Neurological methods

In recent years, we have seen the introduction of neurological studies. They measure the arousal of the brain based on what one sees. It is made possible in part thanks to brain imaging technologies such as fMRI, PET, and fNIR. Fractals are one area of interest that according to studies is pleasant to look at. Studies by neurologists and psychologists indicate that this is true. To reach this conclusion, they have analyzed human reactions to fractals found in nature and art, but also computer-generated images of fractals. For example, there have been studies where neurologists have analyzed Jackson Pollock-paintings, which are based on fractal systems. By analyzing how our eyes move, and which areas of the brain gets activated, the study showed that human visual systems are adapted to regard fractals as something aesthetically beautiful and soothing (Taylor 2017).

'Convergence' (Pollock 1952)

Measurable vs unmeasurable data

Today, we technically have the prerequisites for evaluating how an individual person, or an overall average, responds to one on a specific object. But before we conclude that it is just to insert that data, and then to generate an objectively beautiful building, we must take into account a large amount of social and contextual factors that are difficult to integrate into the algorithm. If we ignore these factors from an objectivist and absolutist standpoint, we could argue that if a clear majority of people perceive some things as more beautiful than others, then those who disagree are merely an anomaly. These anomalies need not be considered in the algorithm in that case. The idea then is that people generally share the same aesthetic experience of an object. A relativistic objection to this is that one can assume that within a certain society, people are educated to a similar aesthetic view. For example, the golden section would be a typical western preference according to this attitude. It could also be argued that in a society there are subcultures with different aesthetic preferences. Depending on factors such as education and social status, we develop subcultures with different aesthetic preferences (Eriksson 1989. 53). Collected data for a particular type of population in a particular type of geographical area, can therefore not be used in a completely different context. The dataset will always have to be site-specific. And it will always have to take into consideration what kind of people will experience the building.

The relevance of design principles in generative design

When we design buildings today, by sketching by hand or working in CAD, the chance is very little that we would use a given proportion system to achieve a desired harmony, and it would almost serve more as a creative obstacle. An architect should know intuitively when the contrast and dynamics between elements is so big that harmony is endangered. But these systems can theoretically come in handy in an evolutionary computer-driven process.

When we work with generative design, we have to establish a set of specific rules for the computer to adhere to, so that everything won't be too randomized. In practice, we can teach the computer to only generate forms based on a specific proportion system, where the iterations that achieve the most 'harmonic' result get the highest 'points' and thus becomes best ranked.

We do not claim that we must teach the computer the golden section, or a medieval mystic geometric system. We might as well invent our own system that we ourselves consider aesthetically pleasing, or use surveys to find out what most people like, in a given context, of course. The same principle goes for psychological theories, where we could use the Gestalt principles or fractals as fitness goals.

Quantifying the context and the narrative

To design a good volcano museum in Iceland, a clear narrative was needed. The only problem is that narratives are explorative, subjective, and difficult to quantify, if not even harder to generate. With the technology we used, *Supervised Machine Learning*, there was no possibility for us to 'optimize' the subjective, as the algorithm lacked any signs of 'consciousness'. Therefore, with our human consciousness, we had to supervise the algorithm and control it so that it would fit into the narrative. We let the computer optimize the performative aspects (and could also theoretically optimize aesthetics from a modernist perspective) because we had the technological tools for it. There is more advanced AI technology that can take humans out of the algorithm, and independently generate the ambiguous and the subjective, or even the artistic, which we will discuss further below.

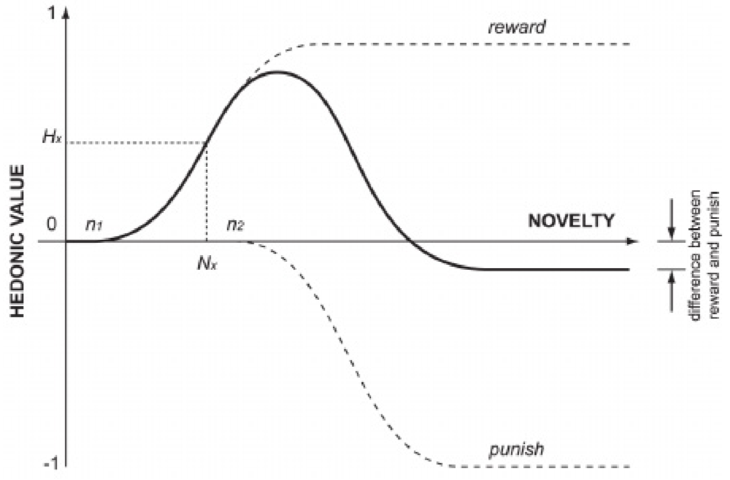
'The unexpected' from an aesthetic perspective

If modernism believes in absolute aesthetic hierarchies, postmodernism wishes to collapse them, in order to explore the relative and the experimental. A strict modernist proportional system or fractal system will rarely offer any unexpected solutions, and the result will be deterministic. An objectively perfectly executed act towards a given goal may then lack a layer of authenticity. Postmodernism's ambiguous view of aesthetic ideals makes it complicated to gather concrete data that can be used as a fitness function in an algorithm. But on the other hand, they value the unexpected, the random, and the novel. That if you dare to break the preconceived and established rules, new good things can arise.

To dare to fail is, therefore, an important strategy for achieving true progress. Good aesthetics would, in many respects, be regarded as a balance between order and disorder, that is, between fulfilling expectations and providing surprises. Too much of the former leads to boredom, but too much of the later loses the audience (Galanter 2012. 276).

One scientific example that supports this is the Wundt curve, which has been related to theories of aesthetics, most notably in the work of Daniel E. Berlyne. The basic idea was that aesthetic objects should neither be too simple nor too complex, which assigns maximal interestingness to data whose complexity is somewhere in between the extremes (Schmidhuber 2012. 325).

Our argument for using the computer as a design partner has always been that we believe that the computer can come up with solutions that our human intellect would never even think of. The more freedom we give the computer, the more unexpected solutions we get. The postmodernist perspective, that no absolute truth can be reached, means that we do not have to put any aesthetic constraints with questionable design principles in the algorithm. This gives the algorithm more freedom to generate the unexpected. However, it can also lead to not having enough aesthetic framework to relate to, and thus generating too much complexity and randomness, which automatically becomes confusing.



Wundt curve (Saunders, Gemeinboeck et al 2010).

The 'synthesis' scenario

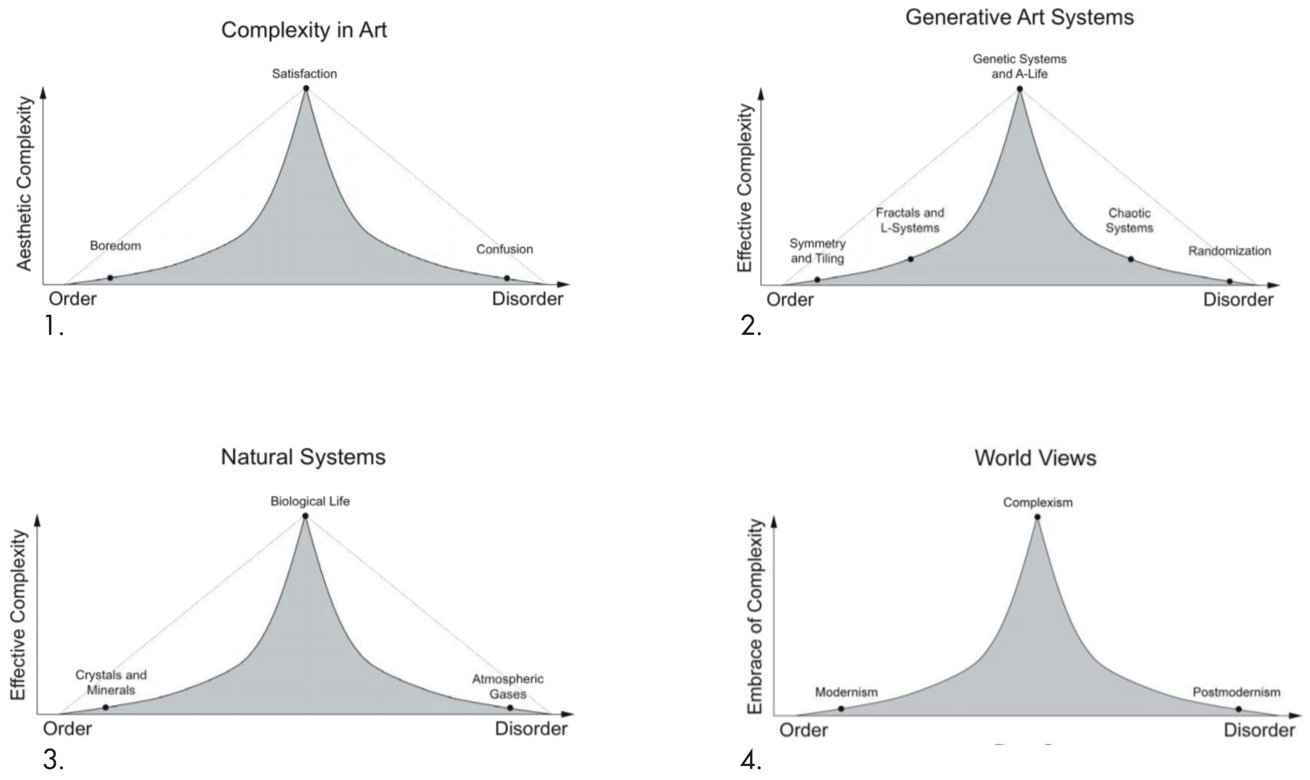
Philip Galanter offers a speculative yet interesting synthesis between the two former world-views. He suggests that the usage of generative design can reconcile the differences between the modern culture of science and the postmodern culture of the humanities. He argues that if a universal measure of complexity were to be used as a form of aesthetic meter, it would probably correspond to the complexity theory of 'effective complexity' by physicist Gell-Mann, who measured aesthetics in the relationship between order and disorder [graph 1]. Galanter places evolutionary generative design in a relationship between modernism and postmodernism, which corresponds to the highly ordered and highly disordered [graph 2]. He believes that the generated, just like biological life, is combined by order and disorder, and that satisfaction arises in a dynamic tension between the two [graph 3] (Galanter. 1-3). Galanter argues that computerized art has traditionally either has been very ordered, or very disordered, but that with the introduction of evolutionary generative design, an intermediate position is offered between these two. With Gell-Manns definition on the ordered vs the disordered, that would mean that generative design in itself creates art that balances the two in an aesthetic way. He argues 'that the earliest forms of generative art, those noted above as involving symmetry, pattern, and tiling, exploit simple highly ordered systems. In the 20th century the use of chance procedures, i.e. randomization, introduced highly disordered systems in generative art'. And just like biological life is an aesthetic combination of order and chaos - evolutionary generative design offers the same characteristics (Galanter. 4).

Modernism	Postmodernism	Complexism
Absolute	Relative	Distributed
Progress	Circulation	Emergence & co-evolution
Fixed	Random	Chaotic
Hierarchy	Collapse	Connectionist networks
Authority	Contention	Feedback
Truth	No Truth	Statistical truth known to be incomplete
The Author	The Text	The generative network
Pro Formalism	Anti Formalism	Form as a public process and not privilege

Complexism as synthesis between modernism and postmodernism.

If we use this table we see that generative design (which Galanter refers to as 'Complexism') is a synthesis between absolute modernism and relative postmodernism. Instead of a fixed modernist system, and a completely random postmodernist system, generative design consists of a 'chaotic' evolutionary system, based on feedback and networks [graph 4]. *'Complexism reconciles the absolute with the relative by viewing the world as a widely interconnected distributed process. Complexism posits processes that are neither fixed nor random, but are instead complex feedback systems that often lead to deterministic chaos. In the broader culture complexism can nurture a visceral appreciation of how the world can be mechanical and yet unpredictable'* (Galanter. 7).

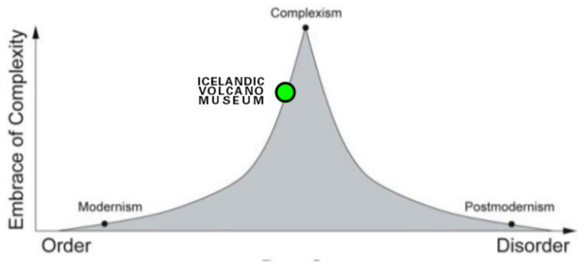
Galanter believes that common to both Modernism and Postmodernism, a mistake of avoiding complexity is done, even if they do it for different reasons. The modernists do it by avoiding disorder, while the postmodernists do it by avoiding order. This oversimplification leads to the loss of complexity for both ideologies (Galanter. 8).



Graphs showing the relationship between order and disorder in art (Galanter).

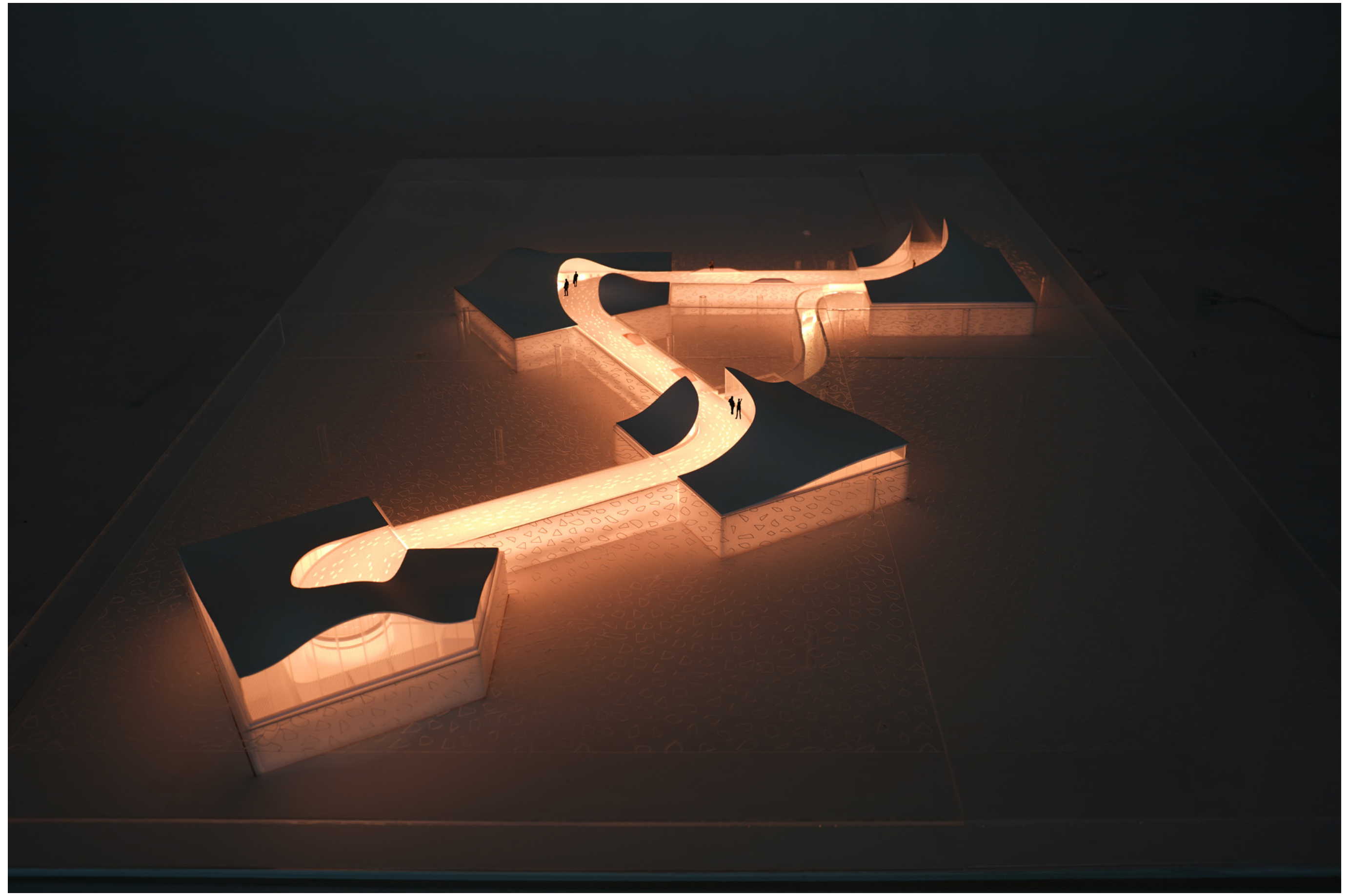
The aesthetics of the Volcano Museum

Perhaps good aesthetics do arise when we use a mixture of quantitative and qualitative architectural qualities - when we balance order and disorder. We would place our project a little more towards the ordered "modernist" direction. Partly because we didn't take any chances with the hand-drawn plan, but also because we limited the framework of the three-dimensional parts too much. If we had dared to let go of the rules a little, then the unexpected might have happened, and we would have placed the project higher up on the complexity curve. Using a Bezier surface as a roof structure means that a lot of information got lost. The surface creates an average of all vertices. If we had used a building structure that was more "cloud-like" like for example a voxel structure, it would have given it more freedom to do exactly what it needed to get good points in the algorithm, or for that matter find unforeseen design solutions.



The Volcano Museum in a ratio between order and disorder (Galanter).

We were very focused on learning the programs and making them work. The first step was to learn how to optimize the technical parameters - which we think we managed quite well with. The museum got good lighting, good microclimate, and good views - it became a good machine. To first collect and then generate quantifiable data on more relative factors such as context and narrative was more difficult. Since narratives are largely subjective and unmeasurable, we used our human consciousness, knowledge, and judgment as a part "in the algorithm". It was up to our subjective judgment and taste to make the narrative fit into the context. All material choices, construction techniques, and proportional systems were chosen by our intuitive consciousness and knowledge. We applied what we thought would fit to an Icelandic volcano museum. The irony is that it is precisely in this area that we feel the project never really made it - maybe it was not a volcano museum in Iceland? Did it really fit into the context? Did visitors really get a volcanic feeling as they descend down? In some aspects we think we could have done more. But there are also aspects where we are happy with our design desicions. For example, we wanted the perforated pathway to light up in the dark Icelandic landscape. The lightened pathway would then resemple magma that flows through the landscape. Unless we would have very advanced digital tools, this is an example of where our human conciousness actually contributed to the algorithm. We tried to be aware in all such design decisions, and are aware that we didnt make it through on all aspects, but at the end of the day perhaps the biggest reason is that we simply did not have enough experience and knowledge of how to tell a building's story.



The lightened pathway resembles flowing magma in the dark Icelandic landscape.

Generating the relative

Generative design is part of Machine Learning, which in turn is a primitive part of artificial intelligence or AI. AI means that the systems that perform the tasks replace human intelligence. In machine learning, we collect data, train a model on that data, and then let the model make predictions on new data. The work process involves training the computer step by step and then evaluating the result based on feedback. We then use the feedback to teach the computer until the results got as good as possible (Dettmers 2015).

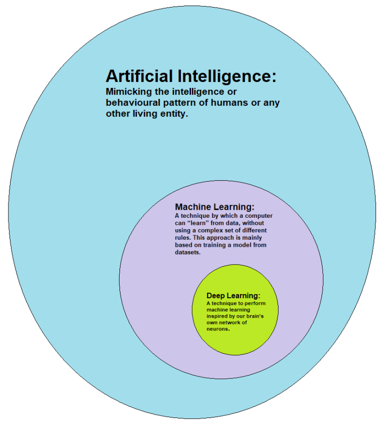
To use, and get feedback on, performative data worked well. And in a way, we worked in the same circular way when it came to the narrative, only that it was our human consciousness that controlled that process, in a fairly conventional way (through physical sketch models, conversing, sketching in the computer, etc). We established the rules and restrictions for the computer that we thought would fit into the narrative.
Since the computer automated a lot of less stimulating design tasks for us, we had more time to discuss design choices. To speculate on whether one can optimize even the subjective is almost a project in itself, and is quite remote for us at the moment. We believe that architects will work with machine learning as a design partner for a long time to come.

Implementation of AI in other industries

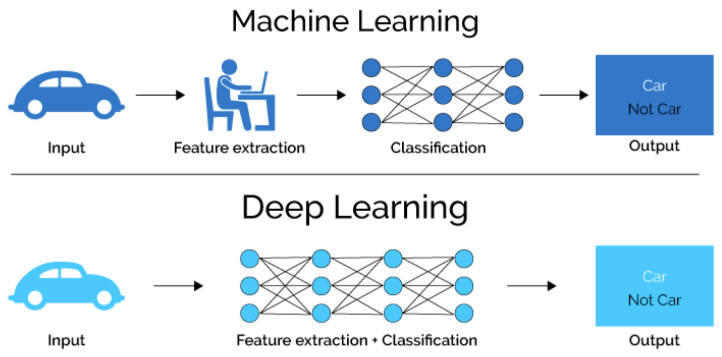
In other industries, a more advanced part of AI, Deep Learning, has begun to be explored. We can not say for sure how deep learning will be used in architecture, but we believe that in one way or another, it will help us take a step towards automating the more artistic aspects of a project. Deep learning consists of a huge amount of machine learning networks. This network forms a neurological algorithm that can gain greater knowledge of their subject by diving deeper into the relationships found in the data (Sheppard 2019).

With deep learning, the computer creates its own feedback process, which could be likened to the human feedback-driven design process, thus taking a step towards something that could be called a consciousness.

Deep learning is implemented in areas such as object detection, speech recognition, language translation, self-driving cars, voice and text assistants, but also to generate art and music. It differs from machine learning in the sense that it can automatically learn to identify representations of data in the form of images, video, text, or sound. The analyzed data is collected into a large dataset. The more data, the better the predictions (Nvidia).



Relationship between AI, Machine Learning, and Deep Learning (Wikipedia 2019).

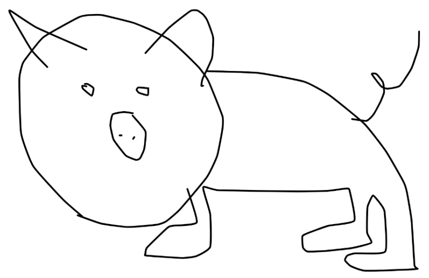


Deep learning "removes" the human from the algorithm. (Thinkwik 2018).

Augmented human intellect

There are artistic computer programs where the AI intuitively helps you achieve what you want to achieve. By telling the AI what it is you want to draw, you then train the AI by uploading a large database to a particular category. The AI basically picks up where you left off, and makes suggestions based on a large number of precedents. Let's say you were to design a museum floor plan. In that case, you would gather as many museum floor plans as possible. The AI would then analyze them and identify as many common denominators as possible, to conclude what factors constitute a museum. The same principle could be applied to the context. If you upload thousands of images on vernacular architecture (or use online websites that collect those images), the AI would then be able to pick out the typical Icelandic vernacular buildings. When we start drawing, it would understand where the concept of for example the plan is going, and make interactive suggestions on what would be the next logical step to make.

If we would have teached the algorithm about both architecure and volcanoes, the algorithm might have suggested us to light up the pathway in order to look like magma. But since we're not there at the moment, we had to stick with doing the research and brainstorming ourselves. This has also been done with music, where programmers have trained the AI a dataset of a specific type of music, which could be anything from baroque to electronic music. Subsequently, the AI has independently generated a song in a given genre. The results vary, and you can't say that technology can really replace human consciousness so far. We already use very sophisticated AI technology today. One example is when we write and get suggestions on what the next word or sentence should be. It's not that technology writes everything for us, but it acts more like a smart assistant. It is possible that we somehow will work with architecture in this manner as well. We will control the process, but the technology will be an augmentation of our intellect. It will, in fairly simple and intuitive ways, help us to communicate, and to frame a narrative (Eck 2017).



AI generated pig.

Even if it is in it's earliest days, with Dough Ecks AI-program 'Magenta', you are now able to generate a specific object (be it a pig, a bicycle or a butterfly), based on a large dataset of earlier sketches on the given object. The more people who draws, the more the algorithm will learn and get better. Of course we will have to ask the same questions that we have asked about generative design. Will this lead to a modernistic absolute goal without surprises? Or can it offer surprises that we as architects did not think about in the first place?

Implementation of AI in architecture

That deep learning would completely replace our human consciousness is very far away, and most definitely not even desirable. However, we see more realistic and not very distant opportunities where for example image-recognition technologies could help us gather data on people's movement patterns, behavioral patterns, and social encounters. With this dataset, we can make more informed decisions, which hopefully can give better quality for the people that will inhabit the buildings.

We believe that the architecture discipline will have to acknowledge these issues and possibilities in the very near future. It is difficult to know exactly how we will use advanced AI like Deep learning. However, we see that Machine Learning and Generative Design already is being established as a methodology in architectural offices. Kåre Poulsgaard, who is the head of innovation at 3XN / GXN in Copenhagen, approaches the adaptation of AI in the architectural discipline as: *"AI is automation on steroids. These are tools that allow us to make sense of the world around us. To understand large amounts of data. To learn from these amounts of data. And to basically give us new answers to some of the questions we have, or can automate some of the processes that we are doing"*

Poulsgaard argues that it is not just about finding the most optimal floor plan. It's also about knowing how the floor plan fits within the building, how it tells a story. Those are factors that can help generate value for people, in more ways than being efficient. He thinks this is where architects come into the picture, that there is still a role to be played by architects here. The question then is, how to take these tools and use them to automate parts where we can save time without losing a lot of extra value, and use our time on other things that we are really good at, like spatial configurations, creative resolution of complexity, and public relations (Poulsgaard 2020).

5. Conclusion

Having worked with generative design and artificial intelligence, we have personally realized that it is not a threat to us architects. Some work will be taken by this technology, but as long as we adapt to it, we will always add value. Perhaps this methodology does not go faster than a conventional design process - but it technically produces better results. Choosing between 10,000 iterations has its advantages over choosing between 10 sketch models, as long as they are done with consideration to architectural qualities. And even if it is incredibly difficult to measure aesthetics, we think that generative design can act as a creative driver for us. This principle also goes for the technical optimization. Sometimes the negotiation between the fitness goals can be quite arbitrary and far fetched, but actually that is not a huge issue. It will still offer a space for us to think and reflect on the architecture that we are making. The more data we collect about a building's behavior, the more feedback we will get for the next project. We see this circular process as a big part of the architects' professional role - to constantly collect data on how people feel and how they perceive a building. We will not be the ones who directly model the 3D models. A large part, however, will be to train the algorithm itself, and to control the concept. In order to create a good algorithm, we must also be aware of architectural design principles. Without these, it will be difficult to trust that the computer is actually generating anything of interest. In order to do this, we architects would benefit from becoming more data-literate, but we must also not forget what we will get much more time to do what we actually are good at. In our Volcano Museum, we focused alot on generating the technical aspects of the project. We did this because those aspects were concrete, but also because we were in a learning phase. If we were to do this again, we think that we would have more experience and knowledge about optimizing the technical. This would mean that we would have more time to curate the other architectural aspects of the project.

So after implementing generative design on a project, would we still argue that digital tools will serve more as a creative collaborator than just a tool? This is not an easy question to answer. In one way, we think that the answer to that is personal for every architect. Good architecture can arise from multiple sources of creation. Some architects might feel limited by digital tools, while others will become more creative and efficient.

We personally believe that we can learn alot from working with computers. The more we learn, the more intuitive and natural the digital design process gets. We are happy that we jumped down the rabbit hole of generative design, and look forward to further investigate it in the coming future.

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