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METHODS FOR MORPHOGENESIS AND ECOLOGY IN ARCHITECTURE

DESIGNING THE BOTHNIAN BAY CULTURAL CENTER

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Designing The Bothnian Bay Cultural Center

University of Oulu
Department of Architecture

Toni Österlund

Methods for morphogenesis and ecology in architecture -
Designing the Bothnian Bay cultural center

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Tiivistelmä opinnäytetyöstä

Olen hyödyntänyt diplomityössäni algoritmisia työskentelymenetelmiä uudenlaisessa suunnitteluprosessissa, jossa käytän luonnonilmiöitä sekä niiden taustalla vaikuttavia voimia arkkitehtuurin muotokielen pohjana. Digitaalisen morfogeneesin keinoin simuloin rakennuspaikan ekologiaa ja sen vaikuttavia tekijöitä kolmiulotteiseen kappaleeseen. Tähän prosessiin pohjautuva suunnitelma yhdistää visuaalisesti simuloituja luonnonvoimia sekä perinteisiä, manuaalisia suunnittelumenetelmiä. Käyttämällä algoritmisia työskentelymenetelmiä, on tarkoituksenani ollut löytää uusia tekniikoita ja inspiraation lähteitä arkkitehtisuunnittelun tueksi. Algoritmisten menetelmien käyttö toimii apuna niin inspiraation etsinnässä, kuin myös suunnittelun apuvälineenäkin.

Tämä diplomityö jakautuu kahteen osioon; prosessinkuvaukseen sekä prosessiin pohjautuvaan suunnitelmaan. Prosessinkuvaus esittää käyttämäni työskentelymenetelmät sekä niiden taustalla olevan ajatteluprosessin, jossa hyödynnän luonnonvoimien simulointia osana luovaa suunnittelua. Suunnitelmaosio havainnollistaa prosessin avulla tehtyä suunnitelmaa. Lopullisen työn arvioimisen kannalta molemmat osat ovat yhtä tärkeitä; yhdessä ne kuvaavat koko prosessin konseptista suunnitelmaan ja siten täydentyvät kokonaisuudeksi.

Tavoitteenani on ollut tutkia nykyaikaisen arkkitehtuurisuunnitteluprosessin kehittämistä algoritmisten työskentelymenetelmien avulla. Tarkoituksenani ei ole ollut saavuttaa suunnitteluratkaisua napin painalluksella, vaan saavuttaa algoritmisten työskentelymetodien sekä perinteisen luonnostelun pehmeämpi integraatio. Algoritmiset suunnittelumenetelmät tarjoavat uusia tapoja älykkään informaation ja motivaation etsimiseen suunnitteluratkaisujemme pohjaksi.

Hyödyntäen algoritmisia työskentelymenetelmiä, tein työkalut, joiden avulla simuloin visuaalisesti luonnonvoimien vaikutuksia objekteihin. Niiden toiminta perustuu NURBS-pintojen (Non-uniform rational B-spline) kontrollipistematriisien muokkaukseen, eli pintoja säätelevien kontrollipisteiden siirtämiseen. Testasin ja analysoin erilaisia alkioita (eng. seed) evoluutioprosessin alkuasetelmina ja näiden avulla suunnittelin alkion, jota käytin lopullisessa suunnitelmassa. Evolutiivisten menetelmien sekä vaikuttavien luonnonvoimien avulla päädyin ratkaisuun, jota pystyin hyödyntämään informatiivisena luonnoksena työn jatkosuunnittelussa.

Lopullinen suunnitelma on arkkitehtoninen kuvaus digitaalisesti kasvaneesta orgaanisesta muodosta. Olen pyrkinyt välttämään tuttuja maneereita sekä olemassa olevien ratkaisujen suoraa referointia; pyrin inspiroitumaan rakennuspaikan yksilöllisestä ekologiasta sekä suunnittelutehtävästä. Käyttämäni uudet tekniikat mahdollistivat inspiraation etsimisen luonnollisista lähtökohdista, tarjoten luonnosteluun avaramman katsantokannan.

Abstract of thesis

This diploma work employs algorithmic design methods in a design process that uses natural phenomena as the basis of its architectural morphology. It implements digital morphogenesis in reaction to ecology and the influential forces of the building environment. The resulting design of this process is a combination of the application of these forces and the use of traditional design methods. With the help of algorithmic design methods, my goal has been to find new techniques and inspiration in the aid of architectural design. The use of computational methods in architecture have the ability, not just to aid in the design, but to aid in the search for inspiration for the design as well.

This work is divided into two equally important sections; the description of the process and the case study. The description of the process demonstrates the methods used and the thinking involved in incorporating nature's influential elements as part of the creative task, as the case study illustrated the outcome of that process. Both sections are equally important in evaluating this work. Without one, the result of this diploma work would be incomplete and uninformative. Together they describe a fluent process from concept to design and as such, the distinctive parts complete each other.

My intention was to study different possibilities in which algorithmic aided design could develop the process of architectural design. My intention was not to reach a final and definitive answer to the design problem just by creating a set of design tools and then pressing a "start" button; the methods used in this diploma work offer a more soft-touch integration of computational methods as an extension of our inspiration and sketching processes. Algorithmic design methods offer new ways of searching for information and motivation to reinforce our design intentions.

Using algorithmic design methods, I created tools for simulating nature's environmental and visual forces. These tools create transformations in NURBS-based (Non-uniform rational B-spline) surfaces through the translation of their respective control point matrices. Using these tools, I tested and analysed several different seeds that would work as the starting point for the evolutionary process. Based on that information, I designed a seed to be used in the process of the final design. Through evolutionary methods and the influential environmental forces, I received a final solution that I then used as an informed draft to further refine my design.

The final case design is a digital representation of an organic architectural form. I have avoided the use of pre-learned mannerisms and direct references to existing solutions. This offered the possibility to be inspired by the location, its ecology and the design problem itself, rather than just looking into recent architectural publications as source for inspiration. These new techniques offered me a way to break free from the limitations of my own mind, and truly search for alternative solutions through the inspiration of nature.

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MORPHOGENESIS

Natural morphogenesis is a process of evolutionary development and growth that causes an organism to develop its shape through the interaction of system-intrinsic capacities and external environmental forces.[1]

ECOLOGY

The study of the relationship between organisms and their hosting environment.[2]

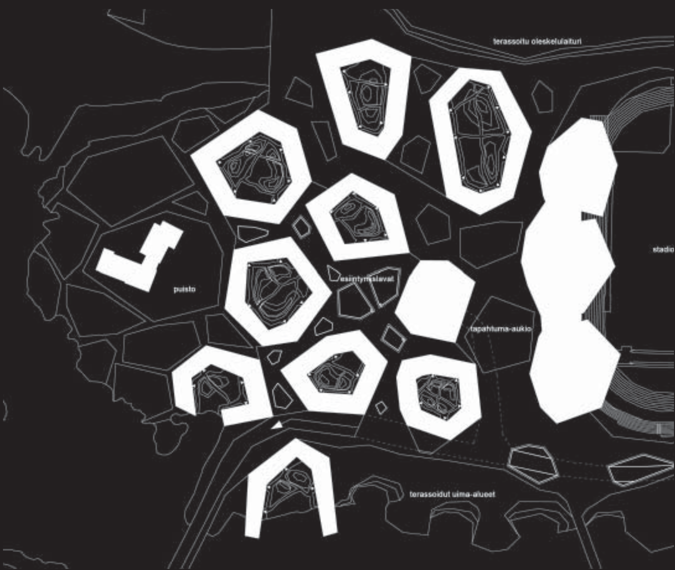
01. PREFACE

The shift towards digital design processes in architecture has coincided with the start of my study of architecture and I have been fortunate enough to be taught to use these tools from the beginning. The use of a computer as a tool for my design is as natural as using pen and paper to search for and illustrate ideas. The computer does not change the basic principles of architecture or the design goals but offer a wider range of possibilities.

In my opinion, digital design tools offer vast improvements over manual drawing; for example, the ease of editing and the possibility to create all the design and construction drawings from a single computer model. Also, possible conflicts or problem areas are easier to detect from a three dimensional presentation of a building. These models require more initial set up, but the proceeding phases progress faster and more accurately.

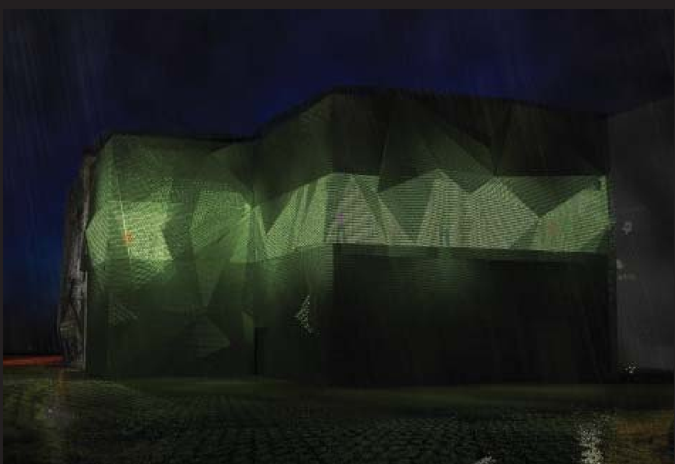
When looking back on my own exercises in architectural design, I noticed early on how they leaned towards the use of computational methods. The apparent complexity, yet underlying orderliness of nature and its systems, have always fascinated me. The works were often based on systems that implemented some sort of organised chaos into the design. This was before I had learned about algorithms or parametrics, but my interest in the use of them was already present, the knowledge and tools just eluded me.

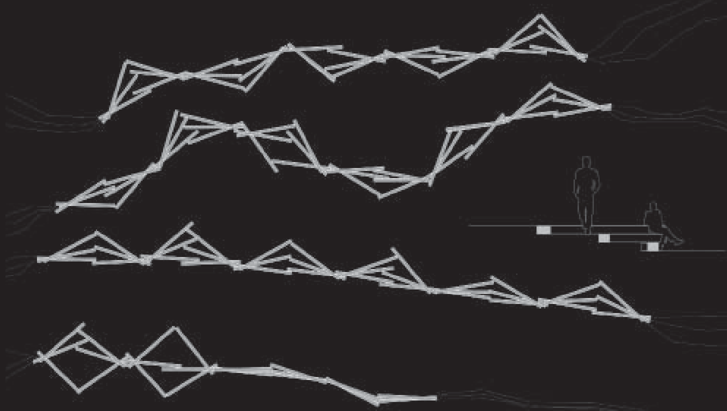
In my own studies, algorithmic design methods have proven their worth several times in their ability to enable and speed up complex design processes. Though possibilities seem endless, it is important to proceed with caution, and to explore the possible use of these new tools in built architecture and not just blindly use



This page: Early exercises, Toni Österlund: apartment planning in the island Raatinsaari in Oulu; performace building for the Oulu Music Video Festival; competition entry and 3rd prize for ideas for yard and environmental constructions held by Kainuun Etu Oy.

Opposite page: Voronoicellular structure made from plywood: realized plywood structure, consisting of three cells and 17 unique plywood pieces; perspective rendering of a canopy structure; all of the different plywood pieces from a 50 cell structure.

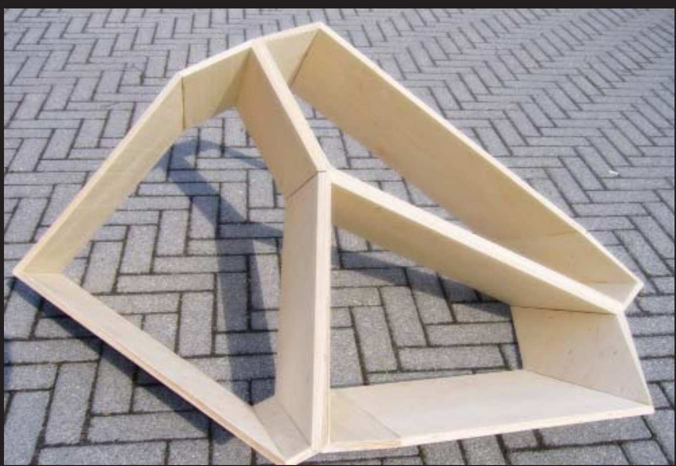




them for their novelty value, without critique. The added functionality they offer should be directed towards the development of architecture while evaluating their true worth. The tools we use in design will undoubtedly affect the outcome, but it should not be dictated by them.

Algorithmic design methods are tools for architectural design, tools for both inspiration and for realisation. They allow us to search for new concepts for our design. The limits of the tools should be tested and exceeded through different design experiments, as experimentation is the key for new information and inspiration. Algorithmic design methods have the potential to produce an endless catalogue of inspiration for architects. Through that inspiration new forms and paradigms gradually emerge.

Researching algorithmic design methods has been time consuming; searching and adopting information proceeded without a broad view of the process or guiding authority. At that time, only a few books were published on the subject and the information relied mostly on forums and internet blogs. And of course they were always written in English. I wanted to share my knowledge of algorithm aided design with my fellow students pondering these same questions. Together with fellow student Eero Lundén, we wrote an extended description of our findings. The essay was called *Algoritminen arkkitehtuuri - monimuotoisen arkkitehtuurin yksinkertaisuus* (Algorithmic architecture - the simplicity of polymorphic architecture[3]), which was derived from the book by Kostas Terzidis *Algorithmic Architecture* [4]. The essay contained basic descriptions of algorithmic design methods and their terminology and my first algorithmic design experiment; the voronoi-cellular structure built of plywood.



Algorithmic design methods are not just about the tools used, they can be described as a way of thinking, they do not limit themselves merely to the computer age.[5] Their benefits have only become clearer with the help of computers and their computational powers. In the process of making this diploma work, I became intrigued by the theory and work of the Finnish architects Reima and Raili Pietilä. Reima Pietilä's theoretical intentions were aligning very closely with my own. He studied the morphological effects of nature in his work and tried to continue nature's own topology in his architecture[6]. Pietilä used the spatial and topological structures of the environment in the building itself, where as my objectives are to find the underlying factors and natural processes that have created and moulded the surroundings in the first place. His work is very impressive and inspiring, and as early as 1966, he had stated written rules in the magazine *Arkkitehti*[7] and described how the arched walls of the Kaleva church in Tampere, Finland, were formed. They were clearly numbered definitions of a followable algorithm.

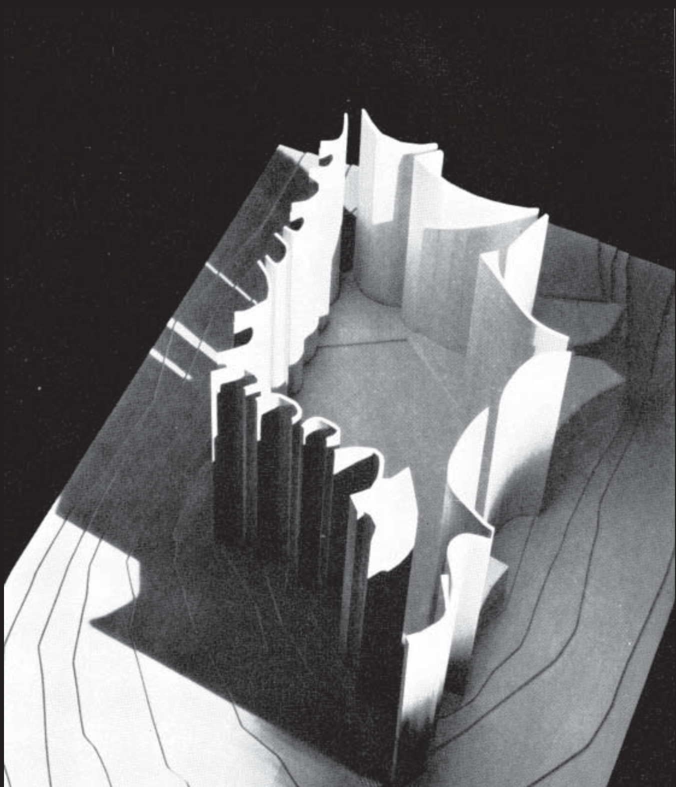
My methods and goals differ from Pietilä's, and because of that, I do not consider this diploma work a continuance of his theory. The alignment of my intentions with his, are semi-coincidental in the way that I was not intentionally working towards that goal. This diploma work is a parallel study and I have tried to avoid referring to previous works of other architects, at least in the morphology of the design. Instead I have used nature as influence and inspiration. Nature's never-ending complexity and transformations never seizes to amaze me, in spite of its scale.

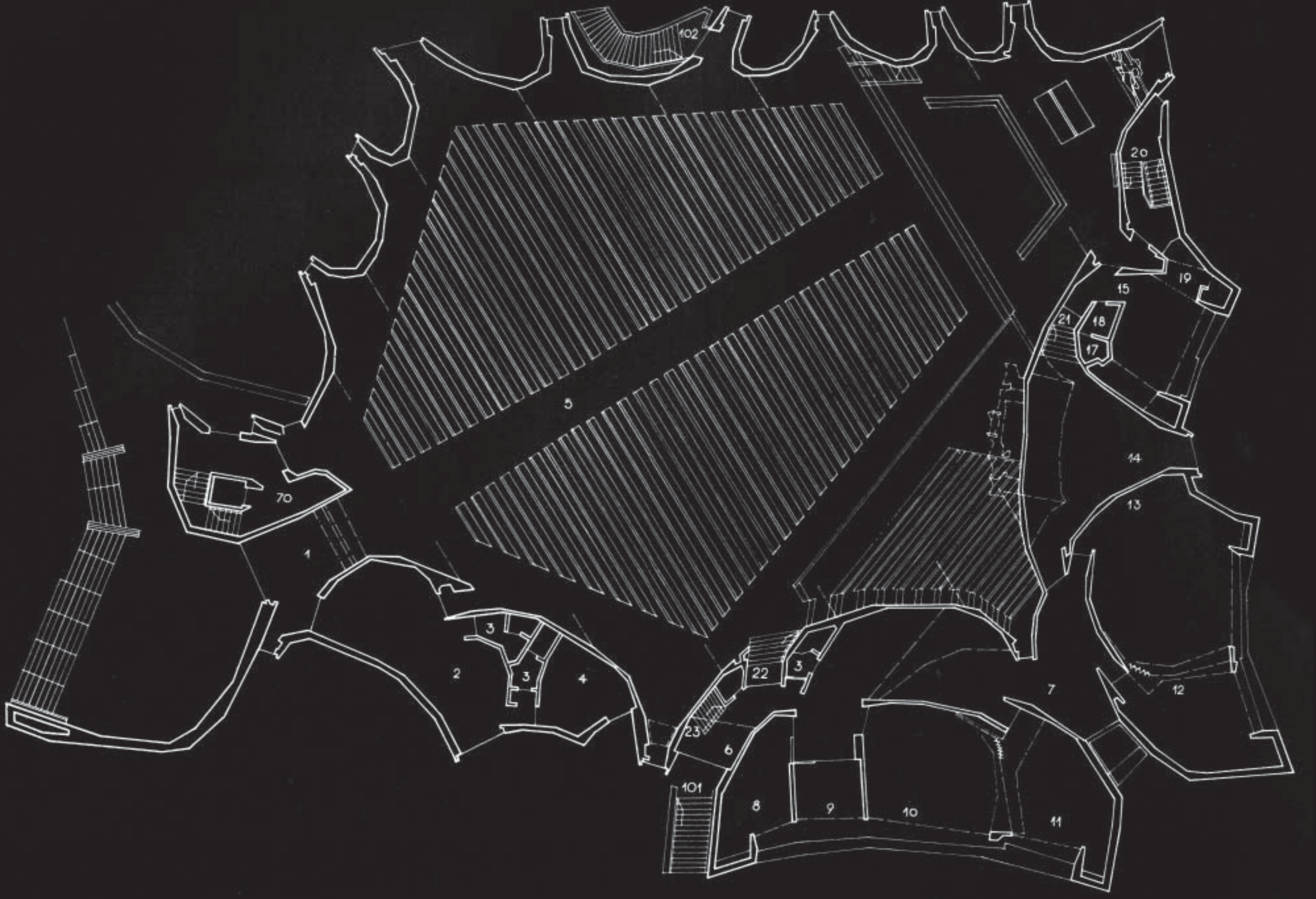
I was once told that there are two kinds of diploma works; those that implement acquired knowledge into a design, and those that still try to discover new things while being designed. This diploma work falls into the latter category.

Toni Österlund
28.04.2010

Below: Photograph of model from an early stage of design, and view of the finished church hall.

Opposite page: Plan of the main floor.





The following form relationships give the composition its character:
1) as the "form embryo", an angled line,
2) all "embryos" vary in size,
3) at least four "embryos" in each form unit,
4) the form charasterictics are continuous in adjacent form units, and
5) there is continuous use of form characteristics within the groups of form units differing in denomination.

Reimä Pietilä and Raili Paatelainen in
Arkkitehti 11-12/1966
(translated by Fred A. Fewster)

Acknowledgements

In the few years that I have studied algorithmic design methods, I have received a great deal of help from the students and staff of the University of Oulu, Department of Architecture. Without their help and support, I would not have been able to pursue my objectives. I would like to thank Eero Lundén for joining me in this quest and for the way he is constantly seeking new ideas. I would also like to thank Aulikki Herneoja for her relentless, unselfish support and unbelievable energy. I thank Professor Emeritus Jyrki Tasa and Professor Rainer Mahlamäki for their enthusiasm and Jukka Laaksonen for his guidance and support. Also I would like to thank Jussi Tervaoja for his knowledge and information in engineering, Pekka Tuominen for giving me that first nudge into the right direction, Professor Jouni Koiso-Kanttila for making the initial research possible and Paavo Väinämö for his knowledge and help in wood fabrication. Especially I would like to thank all the workshop students I have been privileged to teach. And last, but not least, I would like to thank my wife for all the support and understanding I have received during these years.

"When nature *continues as architecture* it means that natural forms, or more correctly; their morphology, the metamorphoses caused by natural forces, etc, are incorporated into our architectural idiom, parallel to Euclidean form language, or even as replacement for it."

Reima Pietilä[8]

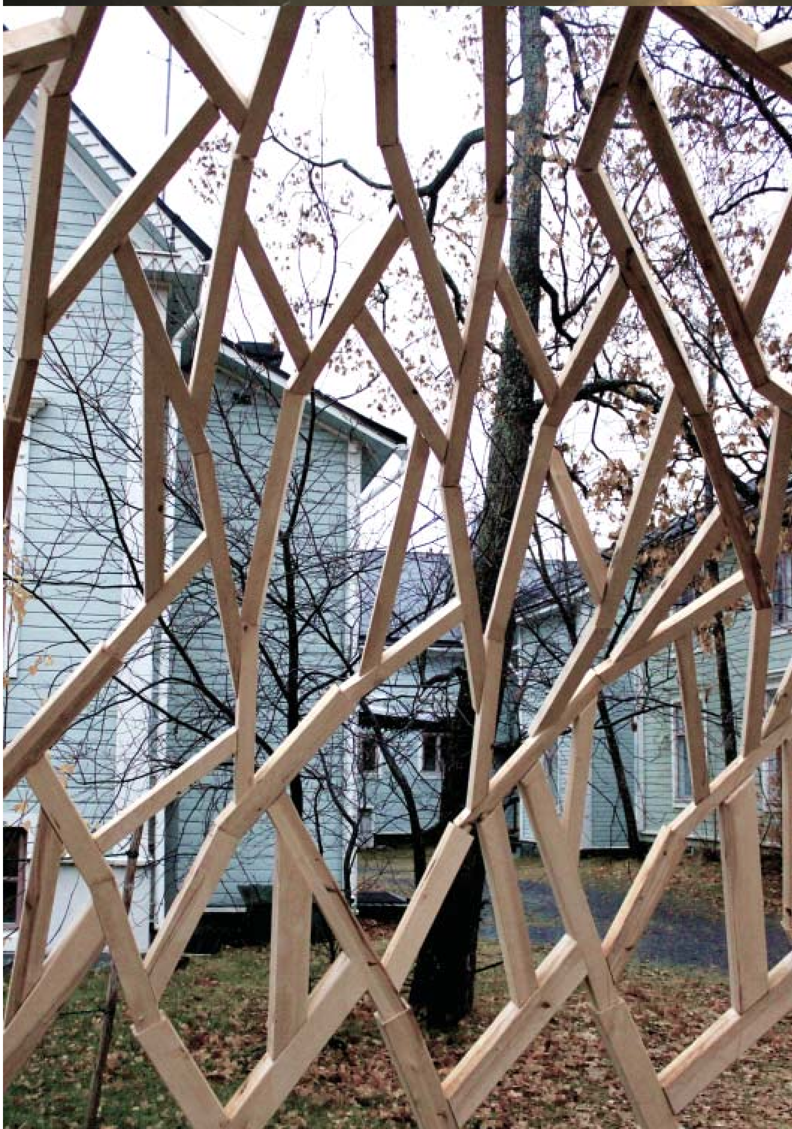
02. INTRODUCTION

Digital (r)evolution – new tools for architecture

The field of architecture is going through a shift where its basic principles are being challenged by the changes that are happening around us. The abundance of new techniques and technologies in architectural design, as well as in fabrication and construction, force us to rethink our design methods and processes. The global changes that drive us toward an ever-growing need for technology and insulation in our buildings provide us with the opportunity to search for new holistic solutions. But new solutions cannot be made with obsolete tools. Michael Weinstock stated that the direct emulation of the past is fruitless, yet we must learn from the lessons it provides[9].

New architectural paradigms are forming with the help of the transition to digital design, new tools allow us to find new sources of inspiration and solutions. Parametric design software has already established itself in Finnish architectural practises and it is now common that designs incorporate computer modelling. But these tools only mimic old design processes and do not themselves any new possibilities or inspiration for design. Kostas Terzidis states that they offer the benefits of computerisation but not the overwhelming opportunities of computing[10].

The use of scripting and parametric software offer designers the potential to search for optimal results through the whole design process. It offers the incorporation of interdisciplinary knowledge into the early stages of the process, where it can influence the rationality of the outcome, rather than, afterwards, trying to solve the problems in sequential order. Independent of calling the process computational, biologic, biomimetic, morpho-ecologic, genetic, algorithmic, parametric, performance-oriented design process, the changes in the design process are gradually happening and with the digital integration of architecture, engineering and biological processes, it will affect architecture in the future.



Above: Exhibition structure "Kudos" from the exhibition and seminar "Generate - from algorithm to structure" by Sauli Kosonen, Sami Logren, Olli Metso, Ville Rautiainen, Tuulikki Tanska and Toni Österlund

Below: "Ligna", pavillion for Woodpolis Oy by Eero Lundén and Toni Österlund

Opposite page: "Juuret" (Roots) competition entry and first place for the Liminka traffic roundabout environmental art competition.

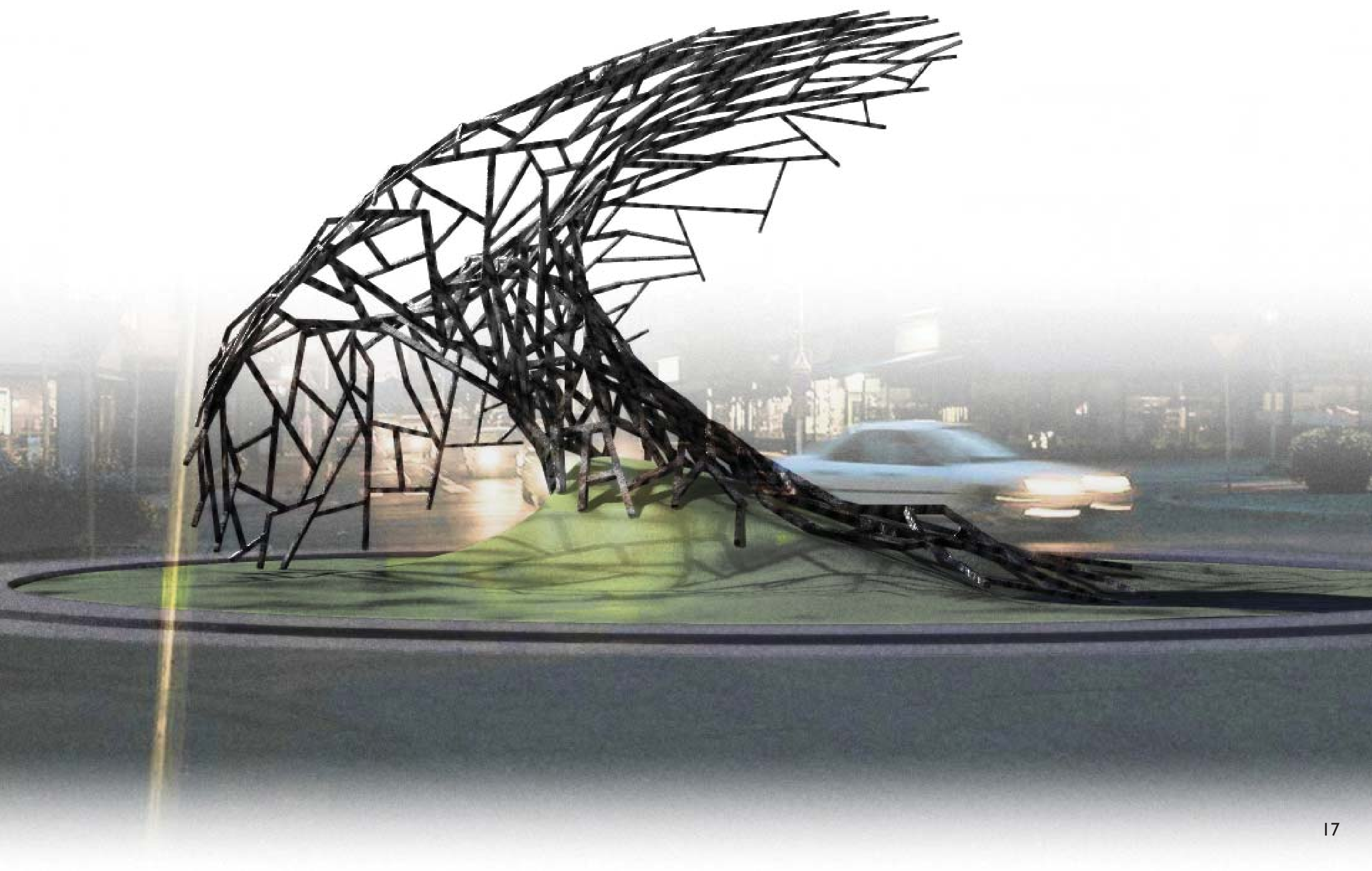
Algorithmic design tools

Algorithms are not just about software and computers, they describe a process of logical thinking and as such its history precedes the computer. According to Terzidis, they are commonly associated with computer science, as the term is mostly used there, but the use of instructions, commands and rules in architectural practise are, in essence, algorithms. Many of our design choices are controlled by laws and regulations, and certain decisions rule out or enable new options. As with algorithms, we too are controlled by if-then-else conditional choices. We make decisions based on validated data and those decisions guide us through the design process.[11]

Terzidis points out, that design is about conceptualization, imagination and interpretation, it is the activity of formulating ideas, as opposed to planning, which is about accomplishing a pre-set objective[12]. Design should leave room for serendipity, a chance to find something completely unexpected, yet desired. This cannot be achieved by conforming to current rules and practises. It applies to the use of algorithms as well; if we control the end result with overly specific rules, we leave no room for new emerging forms. There is no point in designing something, if you already know the final outcome.

Terzidiz states that algorithms are only a single tool used in the design process, not the design process itself and that design is strongly influenced by the tools utilized, so conversely, tools have a profound effect on the design[13]. Some claim that the prolific use of computers in design, produces recognisable results in form and structure. This seems to be a critique toward computer models, as though a computer had played a determining role in forming the design. In my opinion, most of this critique is misdirected towards the computer, though it should be directed towards the designer. Terzidis explains that the mouse-based manipulation of control points on NURBS-based (Non-uniform rational B-Spline) or mesh surfaces is not an act of computing, as much as it is transformations, based completely on the visual decisions of the designer[14]. The use of the computer or computing in architectural design does not dictate any pre-defined shapes or style. But with the help of algorithmic design methods, it is possible to extend our creativity as designers.

Form and geometry have always been important in architectural discourse and their significance have been re-emphasised by the advances in design tools and their link with digital fabrication methods. Tools that were in the past perhaps considered only for visualisations can now be an elemental part in the fabrication and



construction processes. Previously, an architecture project may have had two-dimensional drawings made in one program and a three dimensional visualisation model made in another. They were representations of each other, but the link between them was weak and manual alterations to match the appearance of one to another were required. Today, through parametric modelling and digital fabrications methods, we can use the same model to represent the different projected two dimensional layouts, visualisation as well as detailed information about fabrication and construction. These new methods allow us to set up the building geometry as inter-linkable relationships that enable us to search for the final form, rather than using our whole design capacity in the realisation of an early fixed idea.

Using an open design process and incorporating the use of different design branches simultaneously, rather than consecutively, we can search logical and effective options. For this to happen, we must wander beyond our traditional comfort zone and Terzidis suggests that this might be the first time architectural design is not aligned with formalism or rationalism but with intelligent form and traceable creativity[15]. The use of these new methods does not limit the intuition of the designer or the form of the design. As change can only be additive, not subtractive, they do not reject or deny existing approaches to design[16].

Digital morphogenesis

Natural organisms form through evolution, which requires numerous generations of mutation and genetic selection. An organism's DNA holds the coded sequence that controls their growth. As a general rule, nature tries to do things as simply as possible. Their mechanics may, at first, seem incomprehensibly complex but underneath lays a set of very simple algorithms.[17] Many of the emergent algorithms we may use in our design are based on these natural processes. Terzidis points out that the processes may not be regarded as human inventions but rather human discoveries[18]. Genetic algorithms, cellular automata and voronoi-diagrams are just a few examples of nature's ingenuity that we often exploit in our design[19]. Alberto Estévez says, that the new methods in architecture allow us, not simply to create in nature, but to create with nature[20].

Natural morphogenesis is a process of evolutionary development and growth. It produces polymorphic systems that obtain their complex organisation and shape through interaction between their material capacities and the external environmental influences and forces, as described by Achim Menges.[21] This process gives the organism its distinctive shape and internal cellular structure. Through simulation, the mathematical representation of the interaction of real-world objects, we can use these methods for the benefit of architectural design.

Using evolutionary methods and the active modulation of simulated environmental conditions, morphological differentiation of form and structure can emerge. Forms are prescribed digitally as surfaces or solid objects that are manipulated through the transformation of their defining control point matrices. This gradual mutation is driven by the external environmental forces, but the amount and disposition is controlled through the internal characteristics and bounds of the object and its point matrix. The internal factors can include coded information about the physical parametrics of the intended construction materials and fabrication methods. These can provide the binding factors within the translation occurrence. The shape is altered through external motivation, yet the internal composition defines the result. Because of this, the shape and location of the seed, the starting object for which the manipulation will be directed toward, is crucial in the end result. With different seeds the result may vary tremendously.

Our attempts to find finite and in some ways completed geometrical forms which will be ruined when they are added to or removed from, are defied by natures total disrespect towards them. Reima Pietilä calls them *terminable* and *interminable* objects, where terminable objects find a state of completion and interminable objects allow infinite enrichment both qualitatively and quantitatively. Though, the "completion" of an object is indicative of the inner tensions of the composer and are, as such, more a psychological expression.[22]

During morphogenesis, natural or digital, the organism is in a constant state of change. Whether through growth or environmental factors, every moment is different in structure and composition. Because of this, every single moment in its composition is as meaningful and as beautiful as the next and we cannot point at a moment of completion. Nature is never complete, nor is it ever exactly the same. Derived from the way in which nature works, the way a simulation of nature should work is based on our choice of a point when we are satisfied with the results. Using these methods in architecture, we cannot expect a "finished" product, optimised to perfection, but we will receive a form that is just a snapshot in its evolutionary history.

Ecology - as enabler for evolution

Michael Hensel describes ecology as the interdisciplinary, scientific study of the relation between an organism and their hosting environment. It can be studied at various levels ranging from the individual organism to populations, communities of species, ecosystems or even the whole biosphere. The specific host environment is in constant and dynamic feedback relation with the organism which evolves functionality.[23]

As a term, ecology can be expanded to describe a way of thinking that leans towards sustainable living. In that meaning, ecology implies actions that influences our environment as little as possible or does not leave long

Left: The "Ligna" pavilion was constructed using the Lindenmayer system (or L-system) and it consisted of 19 digitally grown trees, that formed their structure on a seed surface. The resulting structure is similar to the structure of natural trees.

Right: "Stick studies" by Reima Pietilä from 1957 show different terminable and interminable compositions of wooden pieces.

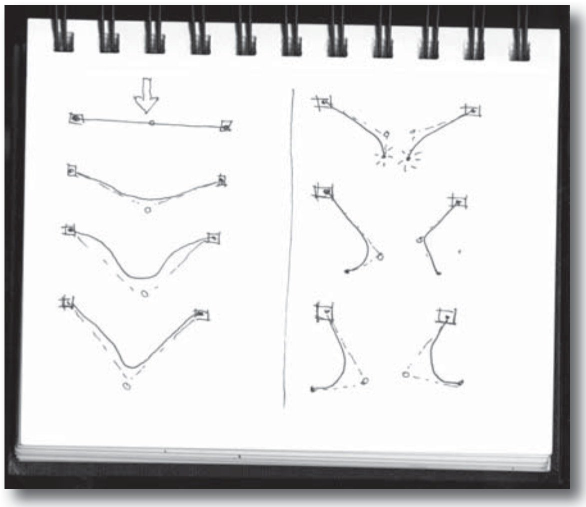
term effects. Sustainable living tries to minimize the effects of man on his environment. The use of the term in this diploma work is not in its expanded meaning, but in its original root where it describes the study of the relationship between organism and its environment[24]. As such, the term does not imply or hold any indication of the nature of this relationship or the possible impact the organism and the environment have on each other.

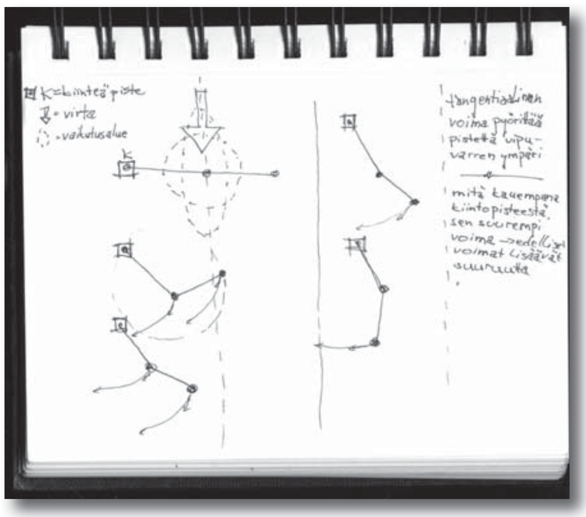
Environment is a collective term for the conditions in which an organism lives. It is the complex and dynamic exchange between these two that enables evolving functionality, as stated by Hensel.[25] As external environmental factors influence the development of form and function; it makes this subject interesting in the field of architectural design. Hensel points out, that the response to external stimuli could be in the core of the generative process of architecture, instead of the consecutive step-by-step, objective-by-objective optimisation at the end of the design process[26].

Ecology enables mutation in genetic processes, as it acts as a motivation for the form or structure to evolve to be better suited in surviving in its environment. The simulation of mutation and its effects are completely in the hands of the designer, who makes the decision as to how the best solution of a population will be calculated. One criteria for that can be the structural optimisation of a form, but that alone does not take into account all the effects of the environment, but only a narrow sector of the physical forces affecting the form, albeit a very crucial force in the realisation of a construction. Different factors can be used in the mutation of the form as well as in the criteria on which the fittest solution is evaluated.

Evolutionary methods

In this diploma work, the evolutionary process from which the solution emerges relies on the *human-based evolution strategy*. In this process, the fitness of a solution is based on the preferential decision of the user, in this case the designer. It is an evolutionary computation technique that relies on human innovation and is one of the simplest evolutionary procedures.[27] The process is based on the mutation of the seed and the selection of the fittest offspring. The mutation of the solution is not random but is controlled through the algorithmic and parametric tools acting as the influential environmental forces. In that way, the role of the building site is emphasised, since the ecology of a certain place is unique because the supporting environment changes.



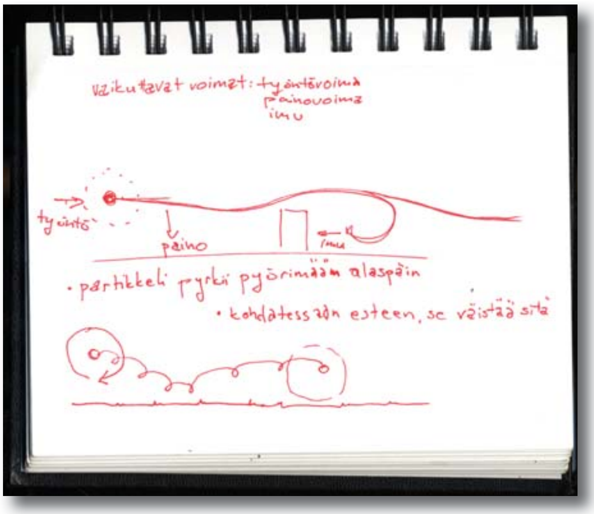


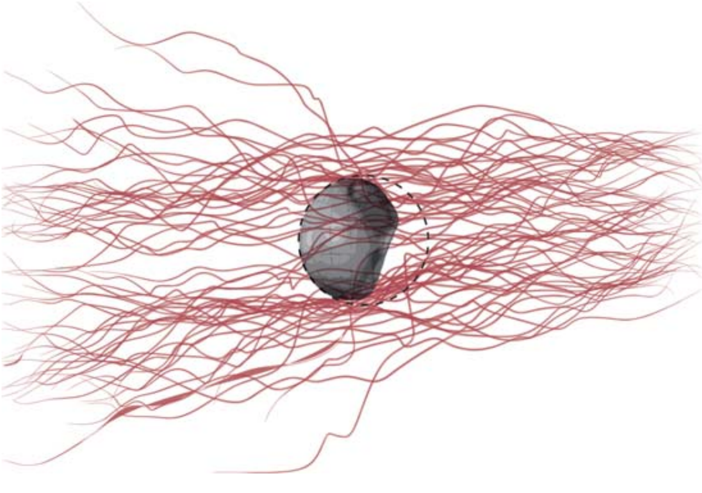
In other words, the chosen building site influences the digital evolution process. True genetic algorithms entail testing, recombination of the genetic material and random mutation. The methods used in this diploma work cannot be viewed as the use of genetic algorithms as they lack the genetic representation of the solution and its recombination.

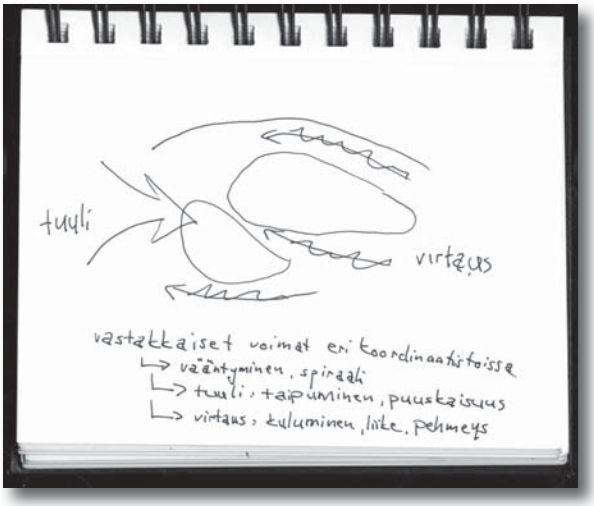
The use of genetic and evolutionary methods in architectural design suggests that evolution could be understood as a process of optimisation, as pointed out by Hensel[28]. Through successive generations, the solution should get better informed and more fit to fulfil its predisposed meaning. But as my design intentions are more complex than the optimisation of a certain aspect of a building, it would be virtually impossible to deduct such optimisation criteria and constraints in a way that the optimisation goal could be defined[29]. And as genetic methods are not the main research topic of this study I ruled out the problem-oriented search for specific, optimised results. My design is not intended to achieve realistic physical optimisation of any natural force or structure; the evolutionary process is guided to fulfil my visual and artistic requirements and the solution's fitness is tested through my own aesthetic perspective.

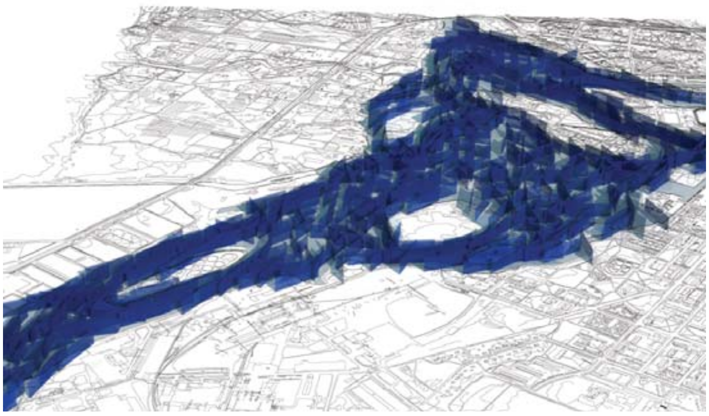
If I had implemented physical calculations and structural optimisation into the process, I would have created, arguably, a more structurally sound form. But as not all of the aspects in architectural design are concerned with the optimisation of structural loads, I would have missed the opportunity to use these tools to determine a more holistic solution for the entire building environment. As such, I did not take into account the structural or material properties of the seed and just let the environment implement its forces on a purely aesthetic level.

The environment, in which the seed lies, is a simulated playground with its own laws of nature, and the crossing from that world into the laws of our reality would have to be made in the future design steps of realising this project. By ruling out physical optimisation, I achieved a visual plan to cover the whole design area, from the form of the building to the routes of the pathways. The result was not as explicit as a structurally optimised form but the design was hidden in the shapes and curves of the final solution. It was my job as a designer to find the underlying form. The design was inspired by and originated from nature; it ends in an organic and holistic treatment of the natural environment and by using it as an informed draft, I could continue my design process.









03. PROCESS

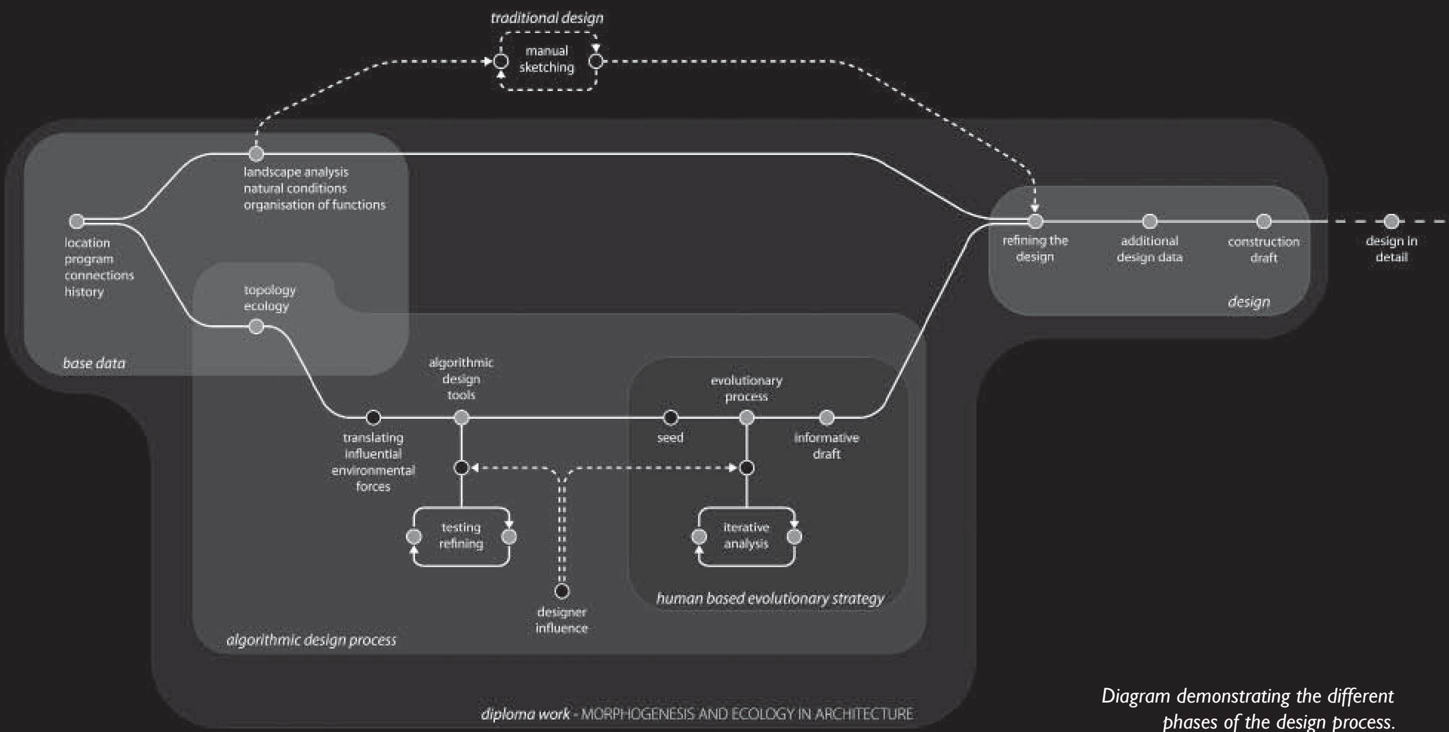


Diagram demonstrating the different phases of the design process.

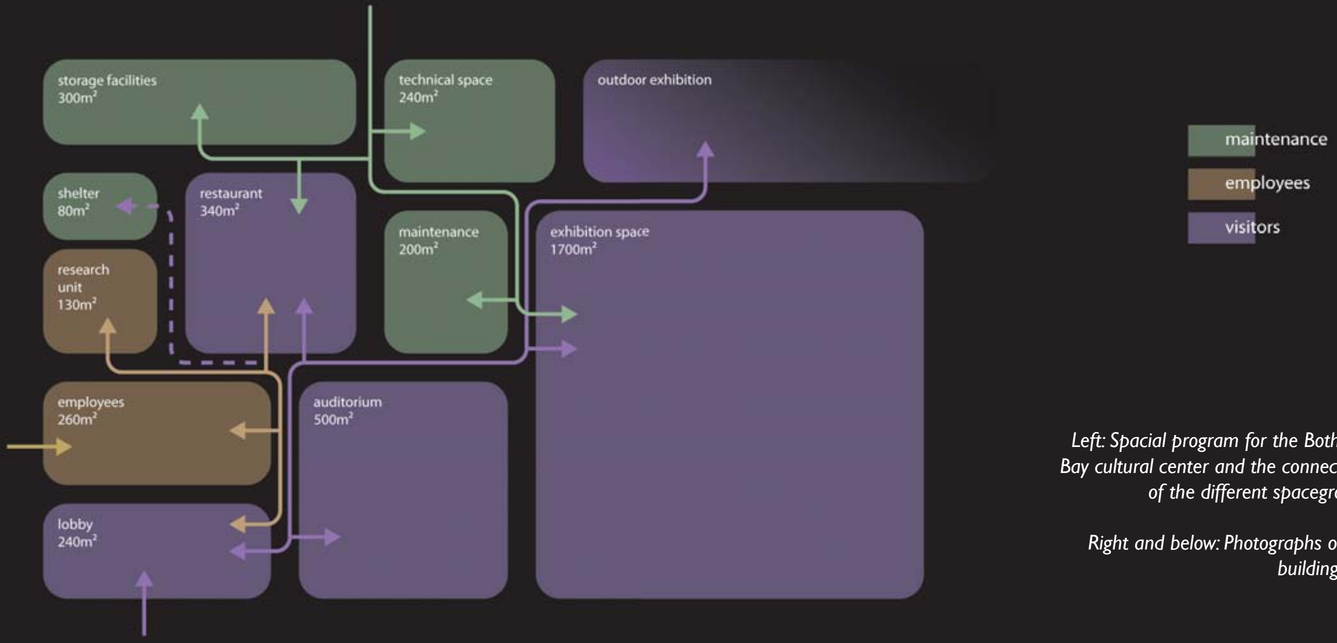
Incorporating nature

An integral part of this diploma work is the description of the process that leads to the design outcome. The process illustrates the methods used and the thinking involved in incorporating nature's affecting elements as part of the creative task. A description of the process requires an extensive depiction of the different phases included in the method as well as the presentation of the final design. Both, the depiction of the process and the design outcome, are equally important in evaluating this work. Without one, the result of this diploma work would be incomplete and uninformative. Together they describe a fluent process from concept to design and as such, the distinctive parts complete each other.

A depiction of the process reveals the possibilities of these novel tools and methods used, and possibly offers further inspiration to future developments in this area. Because of this, the documentation of every phase is important for a coherent path to emerge, as the process incorporates the design theory in practise and illustrates the steps I have taken to get to a desired result. The process is not a result of a haste decision but the culmination of my personal aspirations as an architect and therefore represents a range of my knowledge of design, theory and practise. This description of the design process is intended as the description of the thinking and working process which took place during the making of this work. It is not just about the end result but also about the journey which lead me there.

The inspiration for this work comes from the complexity of nature and its organic composition. My interests do not lie in transcribing or copying its visual form but in understanding the underlying logic behind the formulation of the form itself. Trough research, the natural processes could be translated into simulations and this would create architecture that is truly organic and site-specific. If we incorporate ecology and it's environmental forces into our design processes, we can create architecture that continues and expands the natural elements of the location in it's morphology. Architectural design is influenced by pre-learned formal languages and the past design experiments of the designer, thus limiting the possibilities. Through designer-controlled, yet naturally chaotic simulated environments, we can expand our range of influences and reduce the limitations of our abilities.

Aerial photograph of the city of Oulu in the year 1947.



Left: Spacial program for the Bothnian Bay cultural center and the connections of the different spacegroups.

Right and below: Photographs of the building site.

Base data

The goal of the design process is a building that incorporates the possibilities envisioned previously in this text. The design intent is set up in reverse, as I have not made the process to serve a single building-specific problem but made the tools for the process first and then used them in practise when designing the building. For this, I had to choose a location and the use of the building in question. The only way to evaluate the process and the methods used in the architectural design was to use them in a case project and document the different phases of the process. The volume and area of the building influence the evaluation of the fitness of a solution, as such; a solution that could not hold the intended spacial program would constitute a failure. The building's location determines the ecology and the influential environmental forces of the place. These greatly influence the assessment of whether this process would be feasible to use as a part of architectural design.

The location for the building would have to be under the influence of varied and distinct environmental forces. The force of moving water and its potential visual effects on the form of the building intrigued me, so I selected a site that would be near moving water. I did not want to limit the mutation of the shape through external factors such as existing buildings so I ruled out urban fabric as a location. These two factors defined the characteristics of the site's location.

As possible site locations the Oulu region offered plenty of small islands near the river Oulujoki and its delta. An historical aerial picture of the city of Oulu, from 1947 offered me further inspiration as it showed the organic shoreline of that time contrasted with the diagonal grid

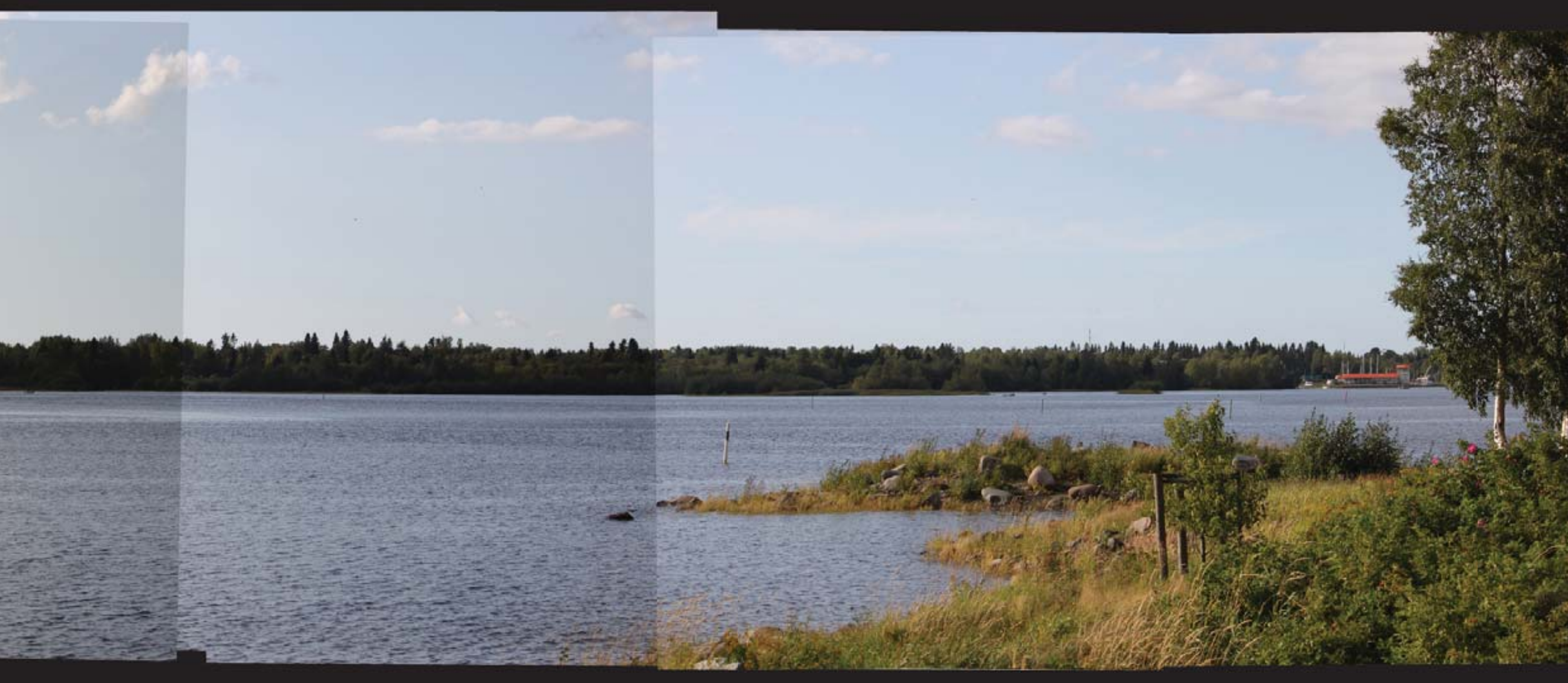





of the ordered city layout. The Oulujoki River was used to transport timber and the picture clearly shows the floating rafts of logs that create long tentacle like beings and show distinctive forms emerging through their internal assembly and external environmental factor, i.e. the water currents.

The combination of historical reference, favourable site locations and accessibility, led me to choose an island group in the mouth of the river Oulujoki. The islands Kiramosaari, Sorsasaari and Mertasaari are located next to the island Hietasaari and are visible from the city's marketplace, which is a vibrant area of the city, especially in the summer. These islands, which are not built upon, were a suitable location to test the feasibility of the process since they possess a unique ecology that differ from their surroundings and they are exposed to different environmental factors. Their location near the city center, easy access through existing routes and the unobstructed view towards the city, offered the potential for an organic building that could differ greatly from its surroundings.

Inspired by the historical reference and location, I conceived the use of the building as a Bothnian Bay cultural center. It would be a multifunctional seminar and exhibition building, through its exhibitions it would display the history of the Bothnian Bay; the building itself would display the present and the seminars held there would present the future. The room program is relatively simple, containing three distinctive functions: the exhibition space, the auditorium and the research facilities. From the basis of the building program, I resolved the dependencies of the different spaces and constructed a three dimensional representation of them to be used in the evaluation of the evolutionary process.



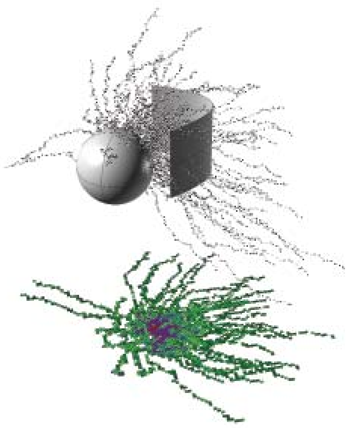
Deciding on influential forces

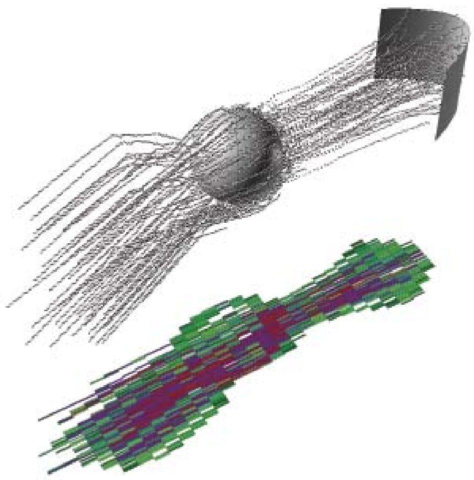
The natural environmental forces that affect the site are too complex and enumerable to simulate to their full extend. Because of that, the simulations were limited to only a few decisive factors that would hold the most influence in the mutation. As correct physical simulation of the forces had already been ruled out, it raised the possibility of using some purely design-based factors that would not influence the natural growth of an organism but which are factors in architectural design, such as views from and to the building. The use of these elements offer the integration of design data into the otherwise simulated natural processes.

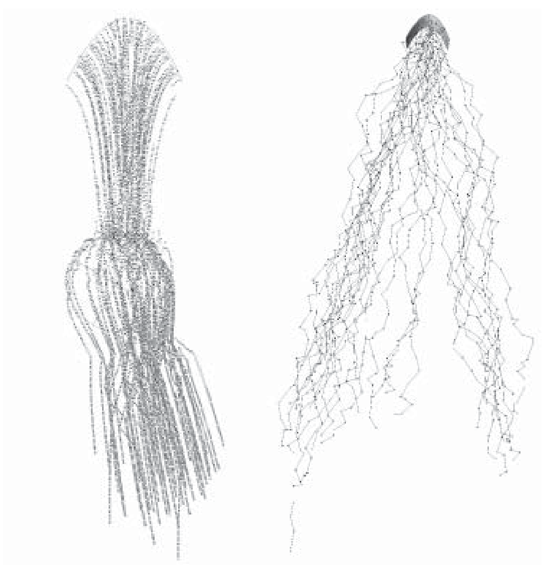
Compared to a normal design process where the decisive factors are calculated mostly in the designers mind, for this design, I had to gather and process that detailed data so that it could be used in the computational process. The factors in forming the building had to be able to be reproduced computationally and through a set of different tools. Some design steps I conducted were still aligned with the traditional design process, including the preliminary analysis of the building site in order, to map out its features. From the gathered information, I could compile a thorough set of tools that would facilitate the design process towards morphological differentiation through scripting and parametric applications.

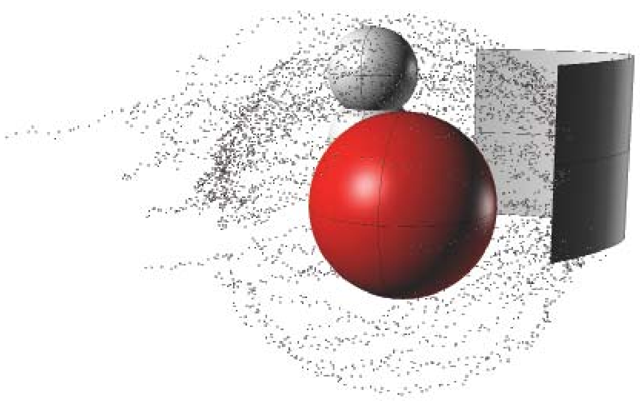
The algorithmic and parametric tools work consecutively on the object and they are applied with different settings so that their effects vary over different prodigies. The tools provide an external agent that produces a reaction within the object, which then recognises the reaction and translates that reaction into a transformation of its control point matrix[30]. The order in which the tools are applied, have some effect on the overall morphology of the solution.

The environmental toolset is applied to the seed with varying parameters for a finite amount of times. This produces a small population for visual evaluation, from which the fittest solution will be selected to become the new seed for the next generation. Through evolutionary methods and consecutive generations of different solutions of the starting seed, the shape and form of the final solution slowly starts to emerge.





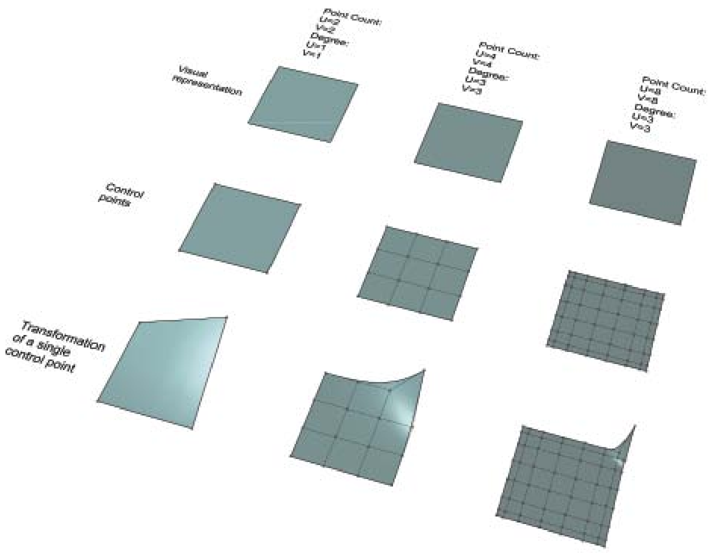




Different phases of the tools during their scripting. All of these pictures are from the work-in-progress version of the toolset.

Function of the toolset

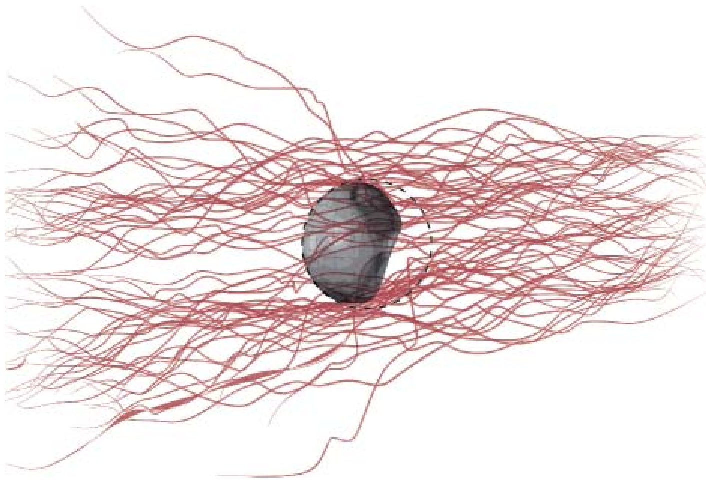
The purpose of the toolset is to simulate, to a certain accuracy, the behavioural characteristics of natural and visual forces, and most importantly, to convert that information into the transformation of a simulated surface. Through consecutive runs, or iterations of the tools, their effects on the surface become clearer after every new iteration. The tools are designed with different parameters that control the amount of their effects and allow a certain degree of variation in their application, enabling different compositions of environmental forces. Using the tools with varying settings causes different results in parallel runs. The amount of iterations is the most influential factor in the mutation of an object, as it has more influence on the solution than the parameters that control the amount of the effect.



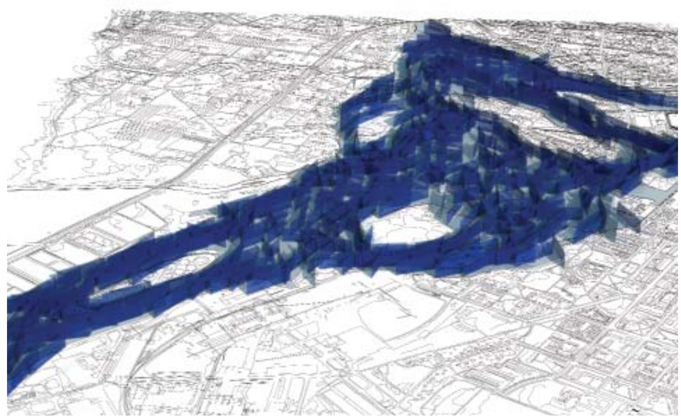
Above: The transformation of a NURBS-surface through the move of a single control point. The amount of control points on surface increase, affecting the range of the transformation.

Below: Finished tools demonstrating the effect of wind on spherical object and the distribution of water currents on the site.

The affected object is represented by a NURBS-based (Non-uniform rational B-spline) surface that is controlled by a matrix of control points and their weights. With respect to the Bézier curves, it allows local modification of the surface by changing the control point coordinate, without affecting the rest of the surface[31]. The level of detail, and thus the level of effect the tools have on the surface, is controlled through the density of the control points. As the move of a control point affects the surface only locally, their degree and density dictates the shape and the amount of the transformation.



The modification of the seed surfaces are controlled through the modification of their respective control points. The resolution of the control points can be used to control the complexity of the solution. The surface's resolution also determines the level of detailing the tools have on it; more control points on a surface means a more defined result. The amount and direction of the transformation is directly controlled by the individual tools which all function differently from each other in order to facilitate force-specific results. The tools are applied through scripting and the use of parametric application. The simulation environment was created using Rhinoceros 4.0 three-dimensional modelling program based on NURBS and a parametric plug-in, called Grasshopper.



All of the different simulated environmental and visual forces function through the displacement of the surface's control points. The vector for each transformation is calculated through the internal algorithm of the tool in question and each force's effect on the surface is unique. The amount of single transformation is relatively small, but the cumulative effects of the forces together yield distinctive results.

Testing the tools on a hemispherical object

The simulated environmental forces were individually tested to ensure their function as operative design tools. The effect they would have on the transformation of a surface were evaluated visually and modifications to the code were made on those results. The testing and rewriting process was used to refine the tools until they functioned as desired. A scale-factor was added to them to ensure the desired amount of influence on variously scaled surfaces. The final simulation environment consisted of the entire Oulujoki river delta thus the accuracy of that model was calculated in meters.

The shape and form of the surface object distinctly affects the outcome; the starting object, or seed, which is placed in the simulated environment transforms according to its original form. This makes the design of the seed crucial since the mutation obviously varies for different geometries. The forces affect different objects similarly but based on the original morphology of the form, the reactions are different, as are the solutions. The tools were tested on differently shaped objects to visually evaluate their effects and then their cumulative effects were tested on a spherical object to see their combined affect. The sphere was situated on the intended building site in the simulated environment, so a clearer conception of the environment of the site could be evaluated.

A sphere is easy to comprehend as an individual object and all of its transformations are clearly visible even with a quick review. In just after five generations of reaction and transformation to the environmental forces, the cumulative effects on the object are easy to analyse. In its original morphology, all of the surfaces normal directions are unique and differ from each other. The transformations on every section of the hemisphere are different and the result shows the complete effects of the evolution.

The isolines on the NURBS-sphere show the resolution of the control point matrix. The object is defined by a single surface, thus on the sphere the lines represent the seams where the different ends of the surface connect. The seam is not clearly visible in the results but it is the only place on the objects where the dependency of the neighbouring control points disconnects. This could cause the seam to crack as the ends move separately. This however, does not happen during the transformation of the spherical object.

The transformations of the sphere are not drastic, but in five successive applications of the environmental forces, their effects become clearly visible. The height of the sphere gradually decreases simultaneously as the shape become more elliptical and less circular. Interestingly the transformations are not symmetrical on both sides of the object, as the prevailing wind d and water currents tended to shift the form of the sphere more to the shape of the island itself. The visual forces affect also the object.

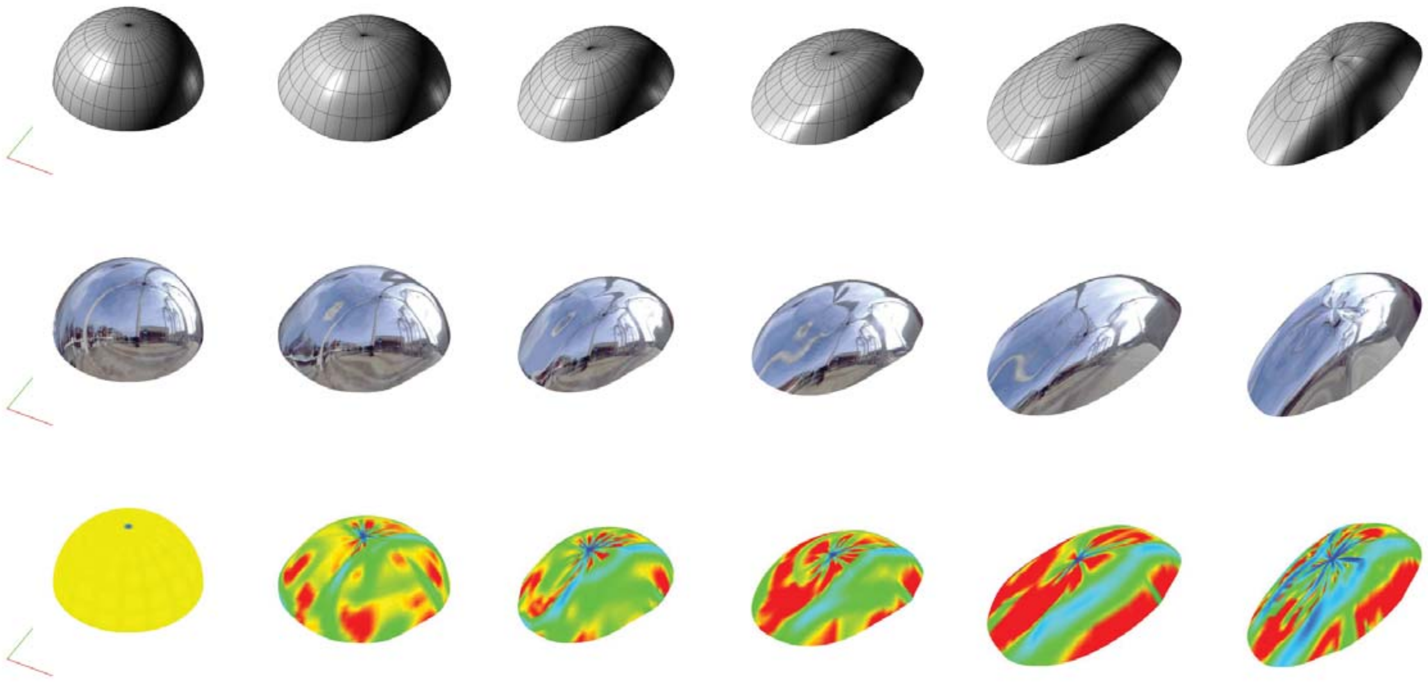
The overall shape of the sphere has changed to become more aerodynamic and less resistant to turbulence, however, I must point out that this was not the main objective of the experiment, nor have the tools been programmed to produce these kinds of results. There were no visual or structural reviews done for the sphere during its evolution and even if the results yield a "least resistant" outcome, it does not necessarily mean it is the best result in terms of visual and structural feasibility or even in terms of functionality. These reviews must be performed manually at a later time. But this test indicates that these tools can produce interesting results with a simple seed and perhaps it is possible to find a seed that, through comparative evolution, could offer viable solution for a building's form.

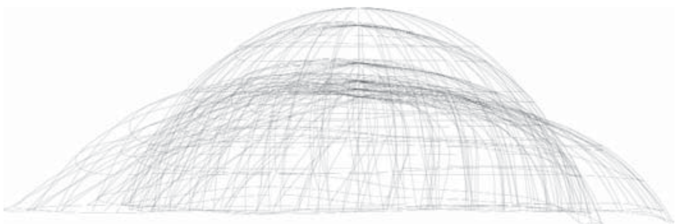
Seed finding

Choosing and designing a seed for the final phase of the design process is one of the most influential factors in the final design outcome. It has a great effect on the visual interpretation of the form and serves as a guideline for the end result. Before designing the final seed, I analysed a variety of diverse forms to see the reactions on different geometries. The tests were conducted on the simulated environment of the building site and only one solution was calculated per generation. The intention of this test was to see the reactions of differently defined objects and the dispersion of the forces on the island's surroundings.

Some of the objects tested represent a single surface thus transformation of the defining surface control points affect the surface as a whole. The move of a single control point affects the surface only to a certain degree, but as they are located on the same point matrix, i.e. a single surface, their transformations affect the morphology as a whole. Others consist of multiple surfaces and, as such, the influence of the forces is limited to a single objects and the transformation of one surface does not affect others.

The information gathered from the test seeds is used in the formulation of the final seed design. This phase in the design is important because it shows the expected transformations and their influence but it also provides inspiration for the following design steps. The different seeds are then given names based on their initial morphology to more easily identify them during the process.

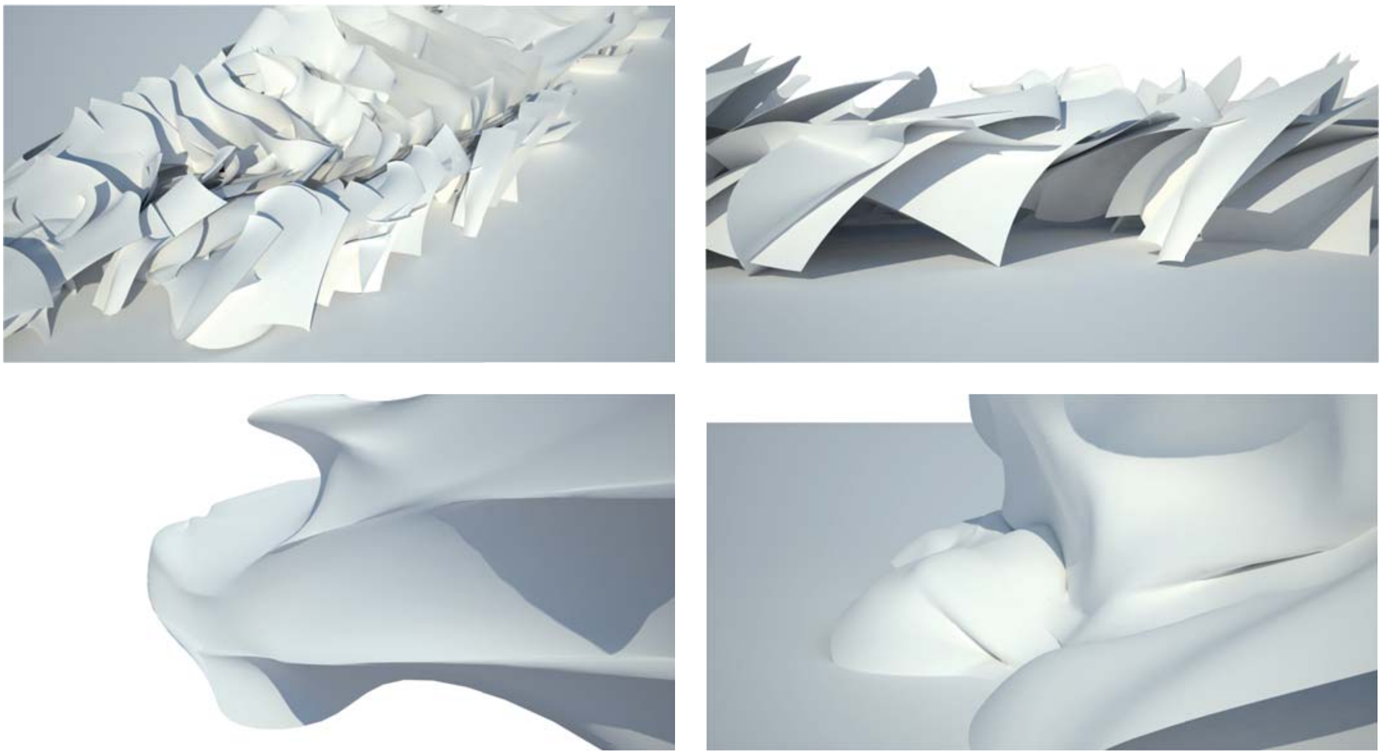


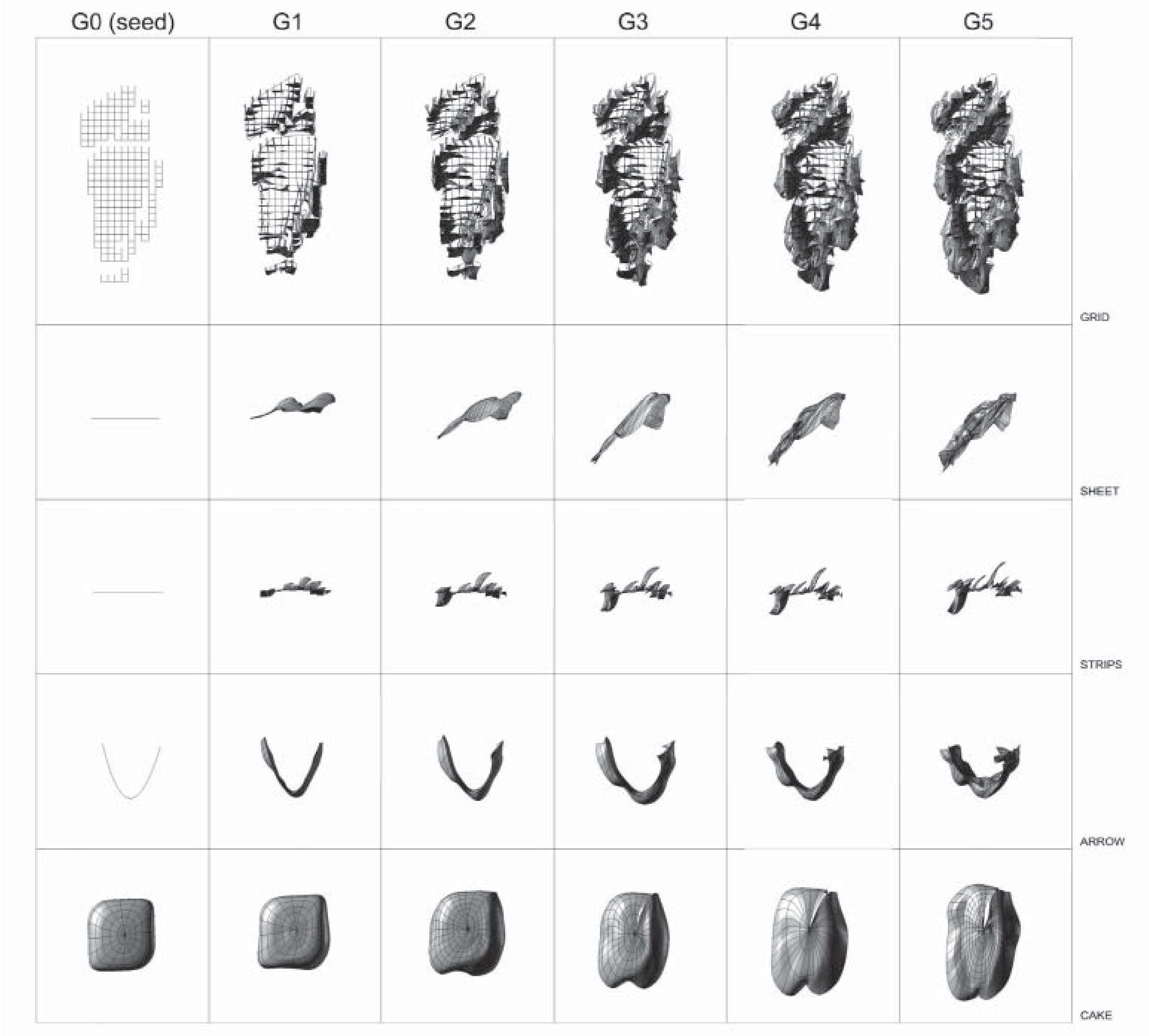


Above: The evolution of the spherical object under the influence of the affecting forces.

Center: The transformation of the profile of the spherical object. The picture displays all of the six different solutions of the evolution overlaid on each other.

Below: Detail renderings of the different test seeds.





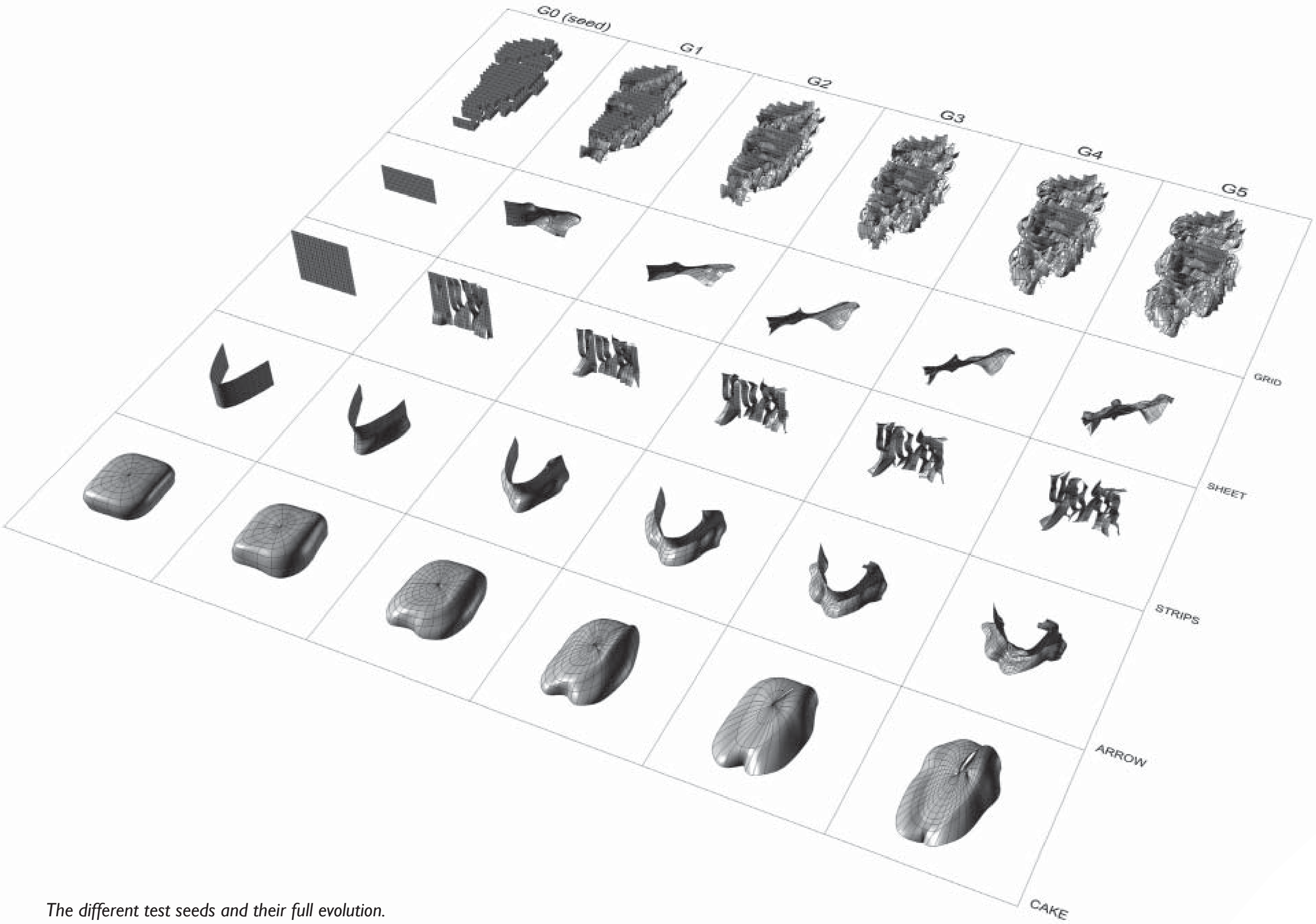
GRID
The purpose of this seed was to understand the cumulative effects of the environmental forces and their distribution over the building site. It was organised so that it covered the islands in a 20x20m grid. The heights of the surfaces were 20 meters in the South-North axes and 40 meters in the East-West axes. The different heights reveal the transformations on the East-West axes better, as their situation is perpendicular to the prevailing wind directions and the water currents.

The environmental forces affected the geometry mostly on the shoreline and on the southern peaks of the islands. The water currents tend to drift the geometry along the shoreline and therefore it does not affect objects in the inner parts of the island. Nor does the wind seem to reach the inner parts, except on the left side of the main island, where it has been caught by a protruding geometry and has been rerouted towards the inner areas. The blocking and directing geometries affect the resulting solution as the transformations happen in distinct areas of the islands.

SHEET
As the grid demonstrated the distribution of the forces on the whole building site, the sheet as a single planar surface and the simplest starting position of a seed, was used to analyse the effects the environmental forces would have on a single object. The transformations were excessive and the starting geometry was not visible from the final solution. The seed behaved visually much like ice, being carved by a continuous stream of water. The analogue is most clearly visible in the 3rd and 4th generations, where as in the 5th generation the different sides start to overlap. As there were no other geometries to block the flow of the forces, all of their transformations were focused on this single object and that caused it to mutate rather rapidly.

STRIPS
Geometrically similar to the sheet, this seed was segmented into different slices to remove the dependencies of the control points. The effects of the forces were local on different geometrical objects and not on a single planar surface. The original appearance of the two different seeds is identical, yet their behaviour is quite different.

As the starting seed was similar to strips of paper, rather unsurprisingly, they also behaved like strips of paper moving as the forces transformed them. After the second evolution, there were actually no significant transformations to be seen, as the



The different test seeds and their full evolution.

strips were not connected, and so the transformations of one strip were not dependent of another. Their geometry was tall and narrow, so they changed mostly in the vertical direction. Adding more evolutionary steps only increased the seemingly random distribution of the strips and did not create any viable results.

ARROW

The transformations of this seed showed very gradual changes at first, as the shape seems to be quite resistant to the external influences. This was because the general shape of the surface was already in alignment with the direction of the most influential environmental forces. At the third evolution, there was a slight shift in the front end of the shape, as it starts to buckle inwards. This caused rapid shift in the geometry's ability to resist the forces and the transformations accelerated. The final solution after five evolutionary steps is visually very interesting; the shape seemed to be forming a kind of vortex in its right side, where it is elevated and the left side is collapsing down. Similar results could be observed in the spherical seed. Also the same kind of "canyon-effect" as was seen in the sheet-seed, can also be observed in the arrow seed. The buckling and folding of this seed is visually interesting, as its evolution seems to accelerate further and further from the original arrow-like geometry.

CAKE

The spherical object was a very simple single surface object, which showed very distinctive transformations. I wanted to see how a similar yet different shape would react to the affecting forces, expecting the outcome to be very different, as the shape is more defined than the sphere. The results of these two evolutions did not vary much from each other though the cake seed is more complex. In the end the differences were remarkably small. The edges of the starting geometry were still somewhat visible and because of the qualities of the NURBS-based surface, the control point dependency is not located on the surface seam, letting the ends move separately from each other.

The front end of this shape was located on simulated land, and thus the water currents did not affect that part and a small indentation occurred in the front of this seed. The shape started to elongate quite quickly from the effects of the different forces and also evolved some aerodynamic characteristics. The right side seems to have elevated where as the left side drops.

04. CASE

The Bothnian Bay cultural center

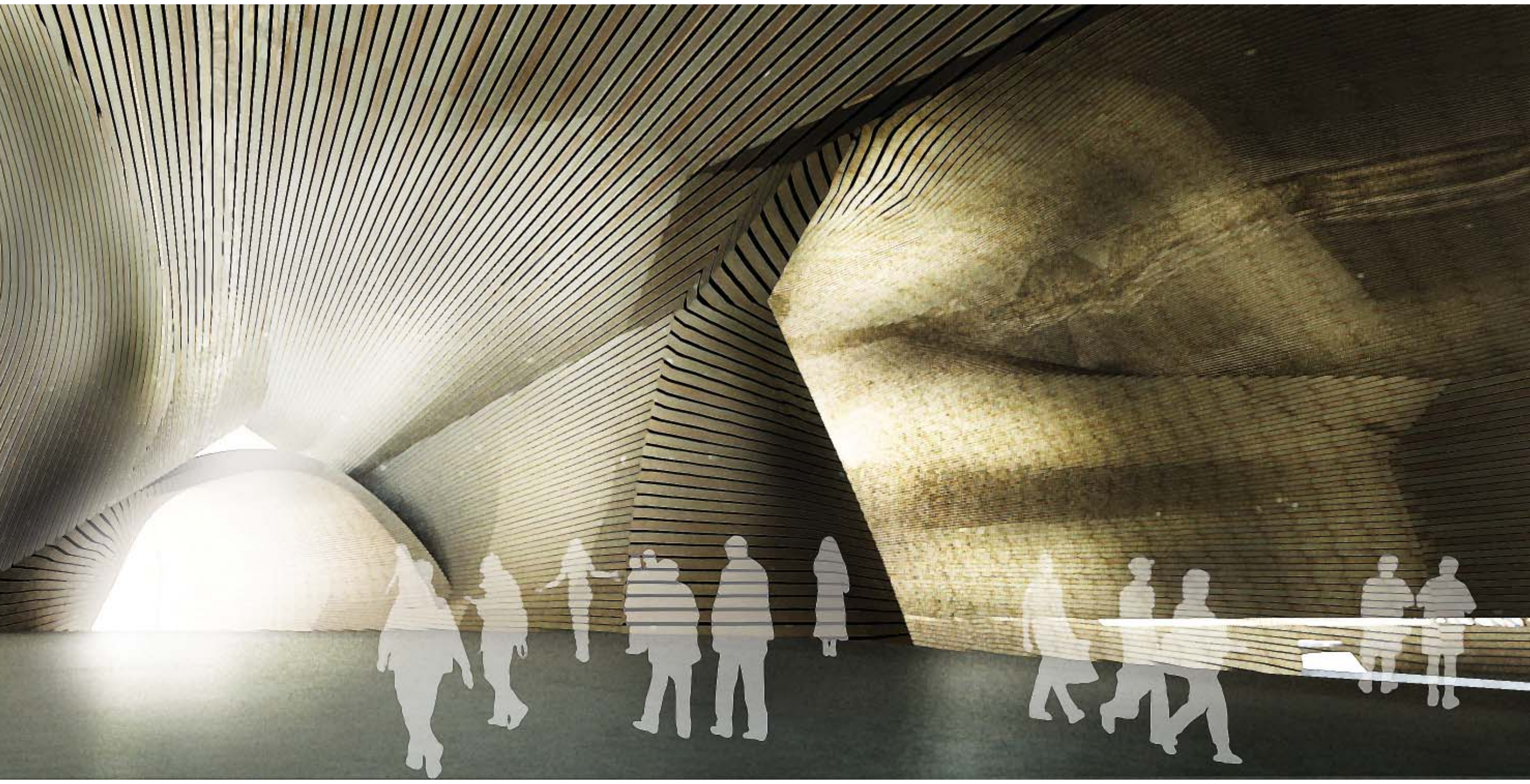
The Bothnian bay cultural center is dedicated to the history, present and future of the Bothnian Bay. It includes an exhibition space, auditorium for seminars and research facilities, and is intended to be open to the public. It enables researchers and interested individuals the chance to discuss and interact with all matters regarding the Bothnian Bay and its related history. It also hosts a small restaurant for the use of the general public and research personnel. The center acts as a mixed use building for research and culture and its location near the city of Oulu offers very versatile usage.

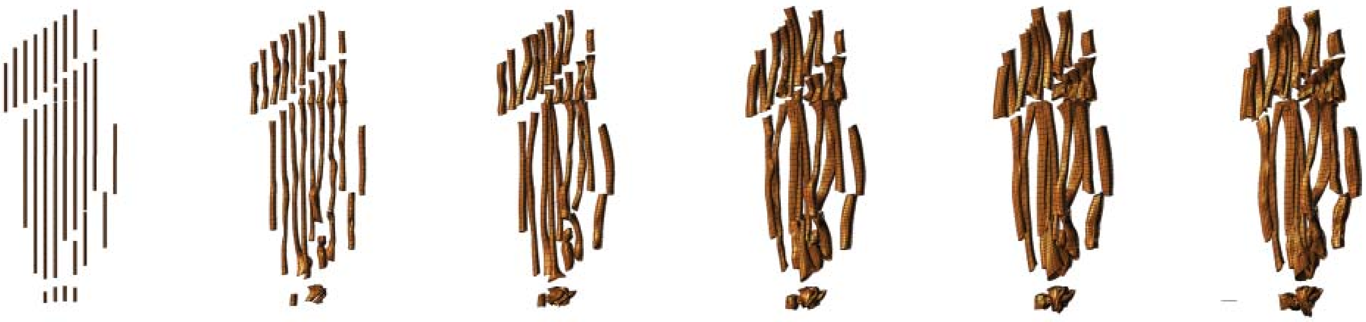
The center's exhibition space displays a regional history, consisting of small artefacts to even large ships. Smaller items would be displayed indoor, while an outdoor exhibition area would be reserved for larger displays. Current research of the Bothnian Bay would be conducted by researchers that work in the building and thus would have easy access to archives and all of the historical material on the subjects. Through their work, the cultural center would become a hotspot for the research of the Bothnian Bay, since the auditorium space would offer a venue for seminars. The exhibition space could host all types of presentations of the living culture of the region. The building would combine the history, present and the future of the Bothnian Bay area under one roof.

The set up for the evolutionary design process

The design process begins with the formulation of the seed. The effects that the environmental forces of the building location have on a surface are highly influenced by the shape, size and location of the seed. After the analysis of different test seeds, I came to the conclusion that, if I wanted a solution that could inspire or solve the visual morphology of the whole island, I could not use a seed based on a single object. On the other hand, I needed a seed that possessed the abilities to be able to describe the location and create a rough envelope for the future building. As the location of the building was not pre-defined, I intended its location to be found through the evolutionary process.

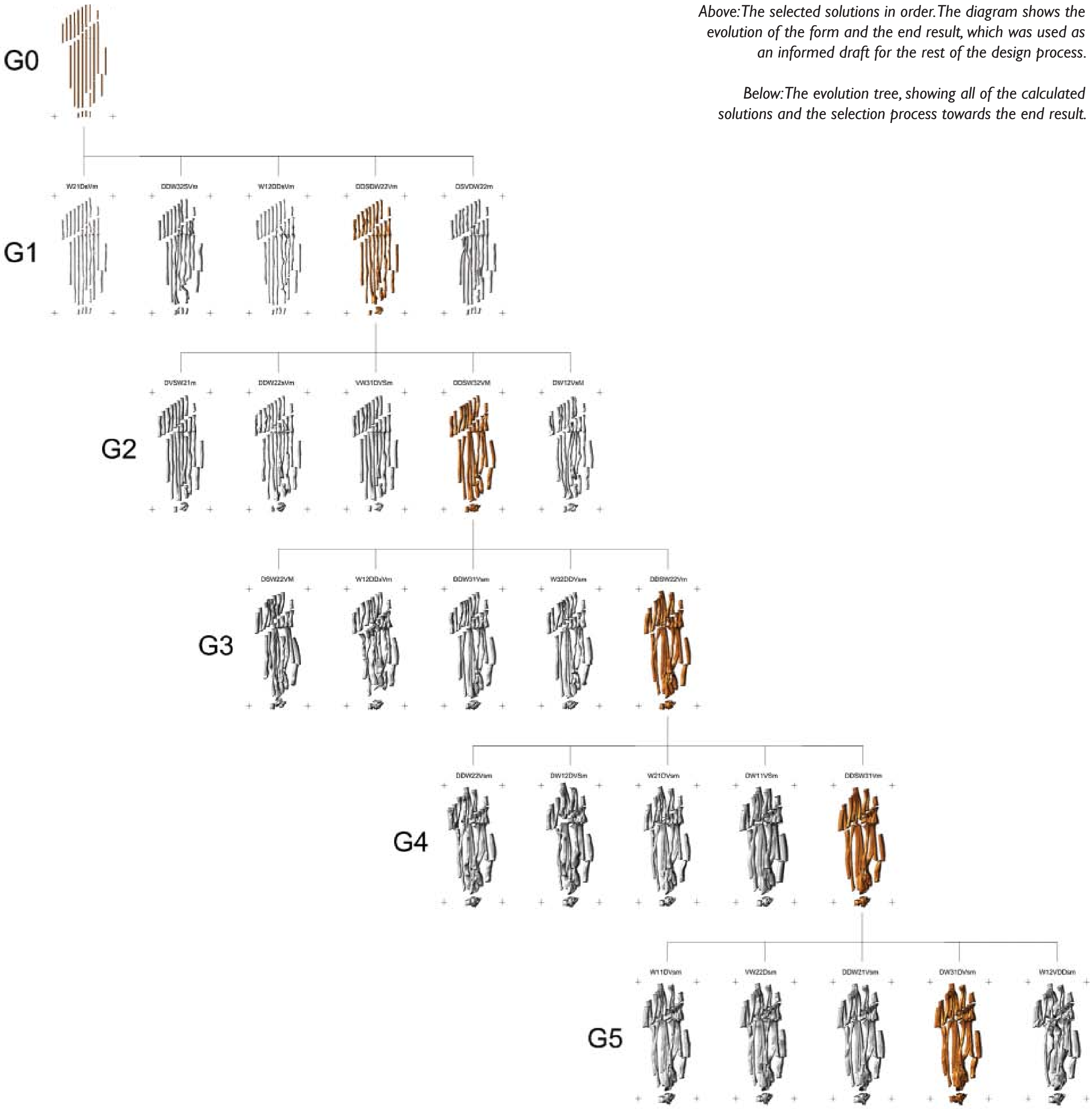
From these requirements, I designed a seed that consisted of several three-dimensional tubular objects that were situated on a North-South axis grid that loosely followed the shoreline of the islands. The tubes' lengths varied from 20 meters to 350 meters and their starting diameter was 6 meters. The density of the control points was calculated so that a ring of 8 control points were located on each object roughly 8 meters apart. This provided the resolution for the transformations.

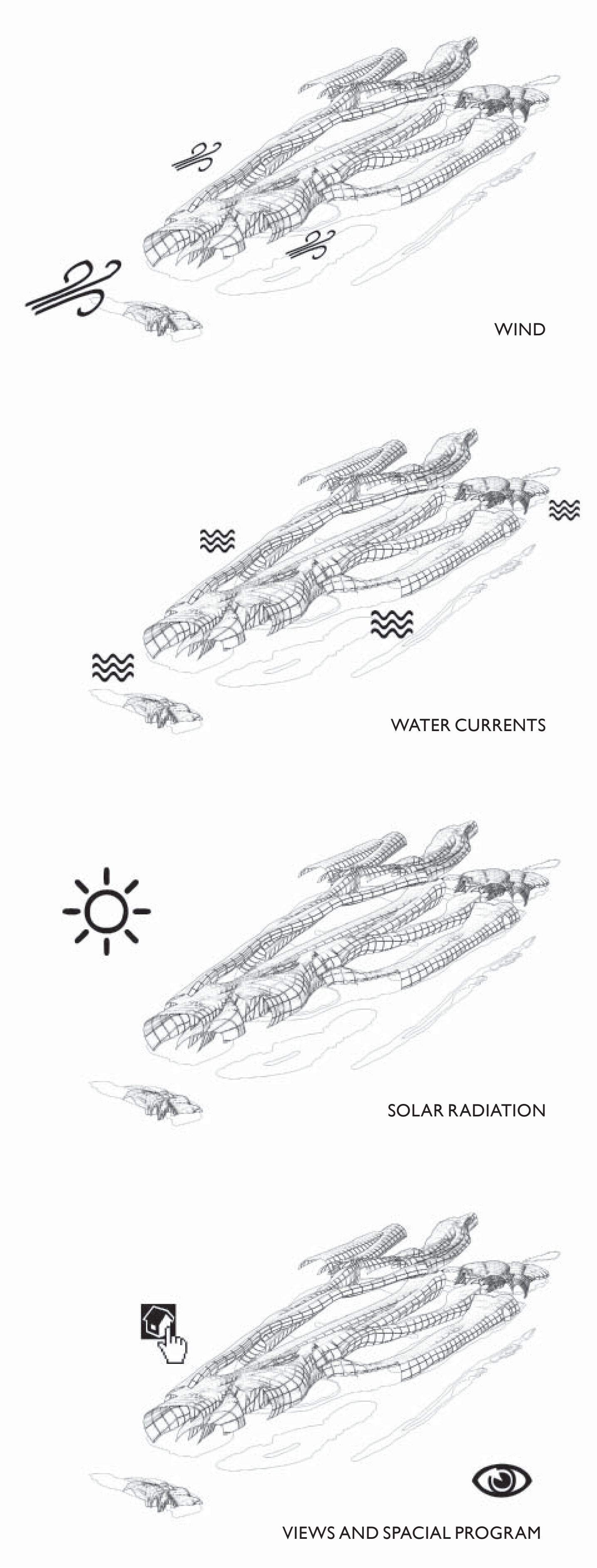




Above: The selected solutions in order. The diagram shows the evolution of the form and the end result, which was used as an informed draft for the rest of the design process.

Below: The evolution tree, showing all of the calculated solutions and the selection process towards the end result.





The influential external forces affecting the evolution.

During the making of the tools for the influential forces, I had already set up a digital environment for the building. This included the mapping of the orientation, general direction of the water flow and the prevailing wind directions. Other influential factors were mapped manually during the evolutionary process. As the building location was surrounded by water and with no significant obstacles affecting the simulation, there was no need to model the surroundings. As such, the only three dimensional representation in the digital environment is the seed. If I had chosen a location inside an existing city fabric, the modelling of the seed's surroundings would have been crucial, as it most certainly would have affected the solution

Visual evolution of the form

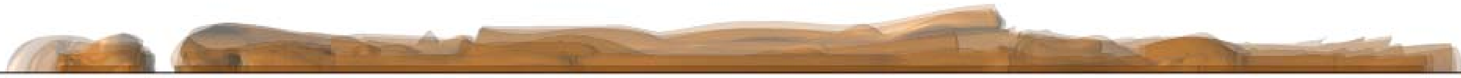
For the designed seed, I started to compute solutions with various settings which would influence the forces. The settings were picked randomly, but they varied enough for the solutions to differ. Through visual review of the different attributes of the solutions, I chose one that would be the seed for the next generation. The review was made on the grounds of aesthetic appearance and the formulation of three dimensional differentiations of form and space.

At start, the solutions that showed the formation of space with little or medium deviation from their horizontal axis were considered fitter in the visual analysis. Too rapid development of deviations in the form would have caused a highly differentiated result in the end, and that would have caused more disorganized forms. Some of the solutions showed more concentration in the middle sector of the main island; where as some solutions showed more even distribution.

From the third generation on, the formulation of space on the tip of the main island was becoming clearly visible. The solutions chosen emphasised that behaviour during the evolution. The area the formulated space took seemed to roughly match the area reserved for the spacial program of the building. I confirmed the solutions with the three dimensional representation of the spacial program and the solutions chosen worked in the sense, that they did not become too small or too large in their use of space.

The emergent curviness of the forms were influenced direct by the interaction of the forces of wind and water currents as they helped direct different parts of the form and in mainly opposite directions. The chosen solutions tended to evolve towards more relaxed curved forms. All of the decisions concerning the solutions were made after a visual review of the forms and their fitness to fulfil the desired building criteria as the building envelope, or as the guideline to the overall visual appearance of the island.

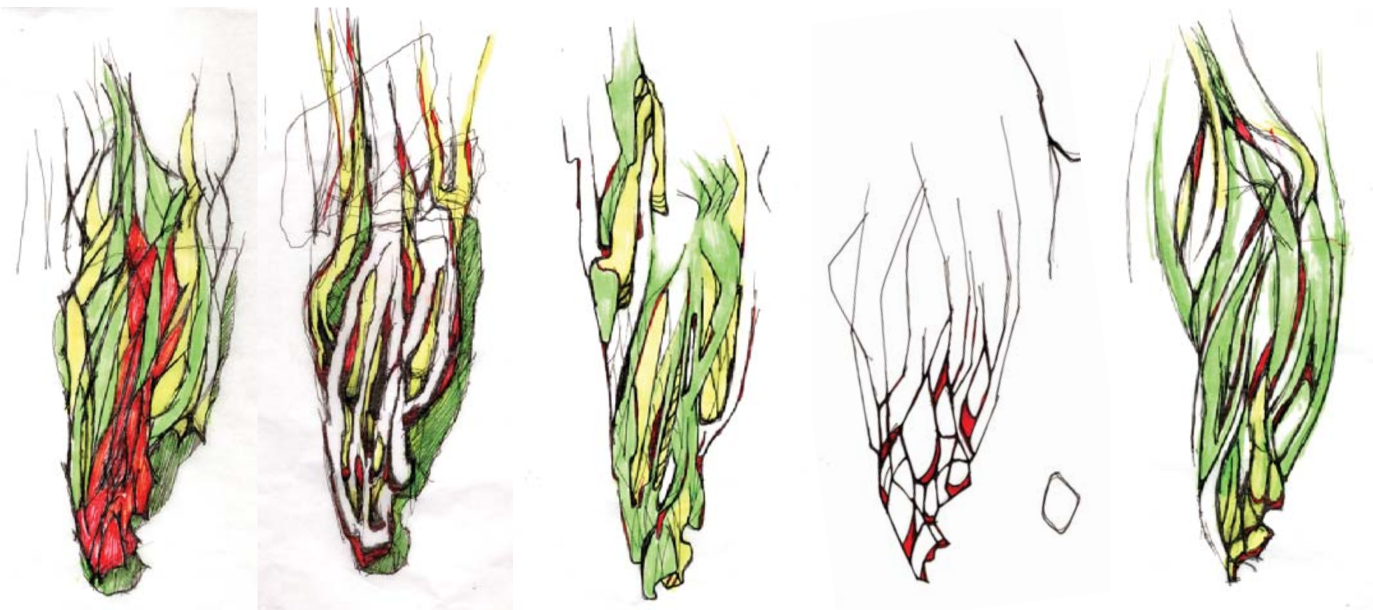
The different selected solutions of the evolutionary process overlaid on each other. Views from top and side.

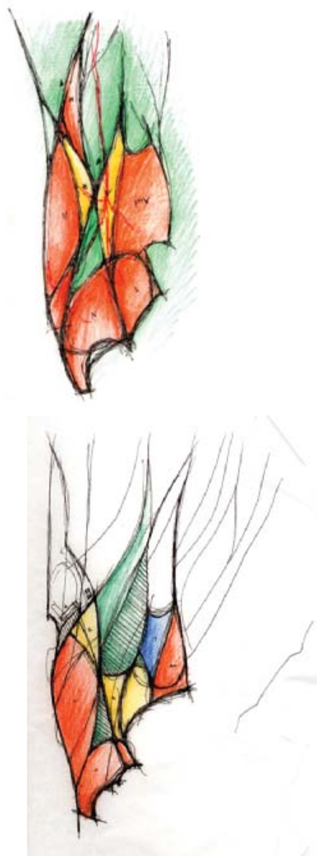


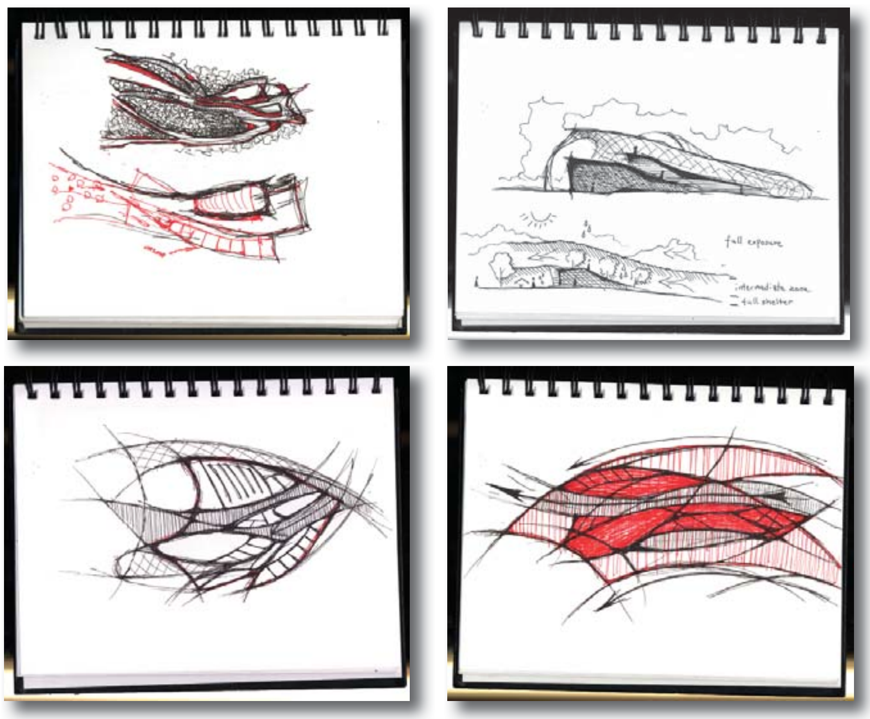
The informed draft

The final solution, which arose after five generations of visual evolution, acted as the basis for the design of the building. The solution created emergent space structure on the south end of the islands and curved forms through the island. The morphology of this solution would be used in the formulation of the building envelope and spaces. The solution acted as an informed draft for further development and design as it contained a rigorous analysis of the environment and its influential forces, but yet it was not able to determine something as complex as an entire building. The key was to be influenced and inspired by the informed draft and develop it further with the intelligence of the designer.

As a base for my hand drawn sketches, I used a two dimensional representation of the form and intersecting lines between the form and the base plane of the island to search for the final shape of the design. The sketching process was a very important phase in the design process as it enabled me, as the designer, to locate the key elements and identify beneficial factors of the informed draft. Through the sketching process, I was able to find the final form of the design. It was an

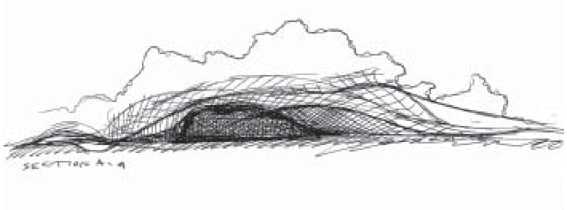






integration of the final solution, its intersection lines and the hand drawn sketches.

To achieve the room layout, I created relationships between the different spaces and used their effective radius to shape the spaces in the form of the overall design. I added the height requirements of the different spaces and transformed their forms to more suit the overall design. Using the final solution of the evolutionary process as my guide, I designed the envelope of the building and its canopies to better reflect the form of the solution.



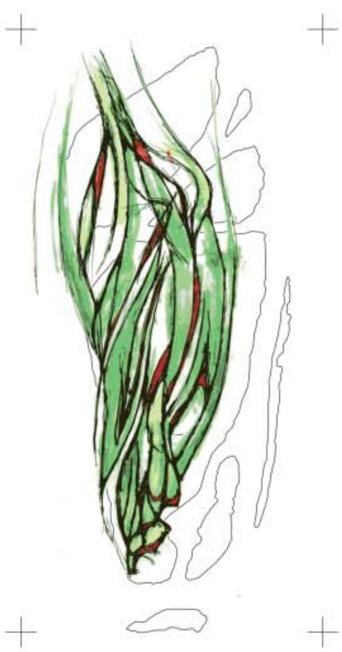
Opposite page: Hand drawn sketches of the visual and spatial appearance of the design.

Above: Hand drawn sketch of a section of the design.

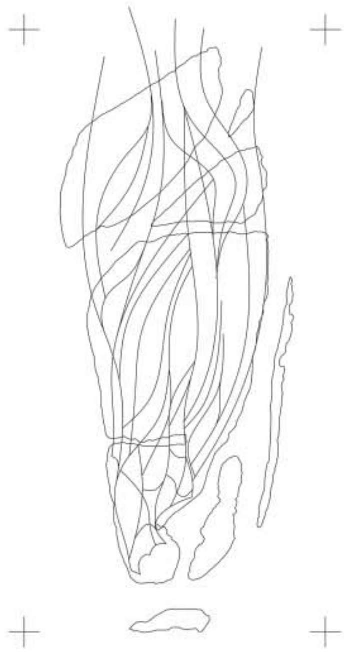
Below: The sketching process entailed the use of the final solution and its intersecting lines with the base plane. Using these and the hand drawn sketches, the final design was made.

The final solution.

The intersecting lines of the final solution and the base plane of the island.



The hand drawn sketch.



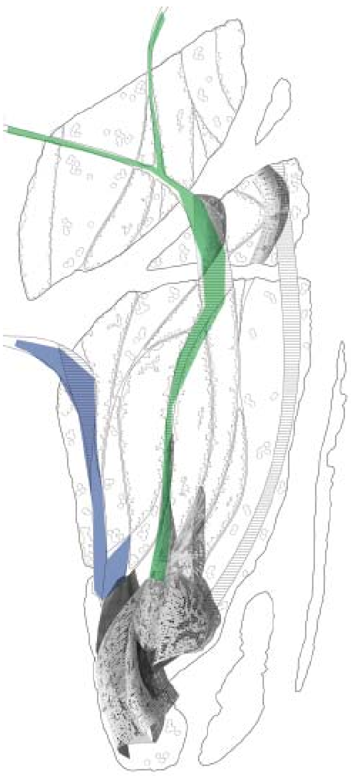
The final design lines.

Refining the draft

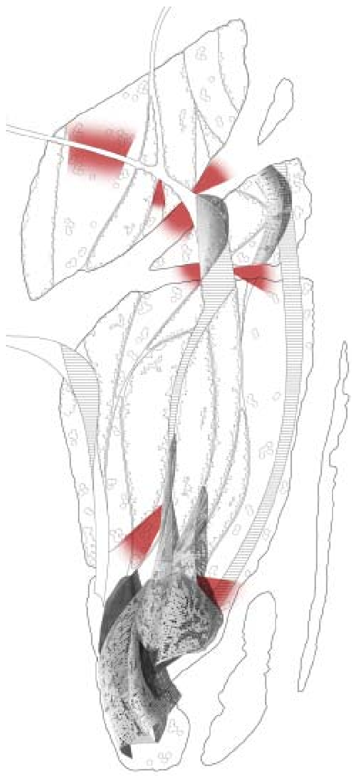
Just as important as the building, is the design of its surroundings. The methods used in the design of the area were inspired by nature and thus should be reflected in the design. The building is a representation of nature and acts as if natural forces had carved the form on location to fulfil the need of sheltered space. The shift from natural environment to built environment should be gradual and hold a variety of open and closed views, spaces and shading. There should be no distinct line between where nature seizes to exist and the man-made environment begins. To accommodate this, I created the approach towards the building through the forest and opened up views towards the surroundings. It offers a glimpse to the islands natural ecosystem and an exciting route towards the building. The amount of built structures and the shade the canopy offers, gradually increase, making the transition pleasant and inconspicuous.

The idea of the building itself is a kind of primitive cave, that the visitors finally enter as they have wandered through the rich flora. The cave effect is emphasized through the horizontal lines which the wooden wall construction produces. It is a representation of flowing water that has carved the space. The views from the building are limited and most of the light is received indirectly through the intertwining structures. It is not richly defined as the overall appearance and mood is more important than the single stylistic details.

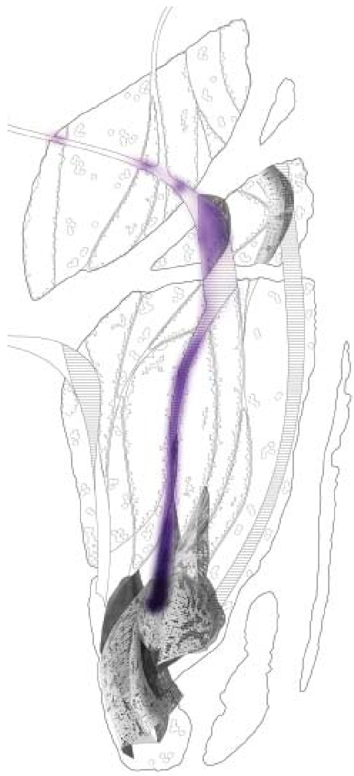
All of the different spaces are connected to each other and are accessible through the lobby. This allows the spaces to be used independently from one another as some spaces can remain off limits through closed partition walls. It also enables the building to be used for a variety of different occasions. The pedestrian entry to the cultural center is from the northern bridge and along the pathway. The maintenance route is from the southern road and it is separate from the main pedestrian walkways.



Patway to the building.
Green: pedestrian
Blue: maintenanace

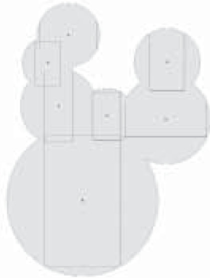


Views along the path.

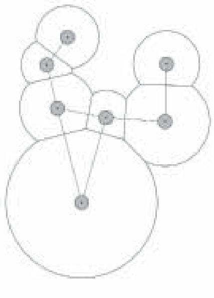


Amount of shadow along the path.

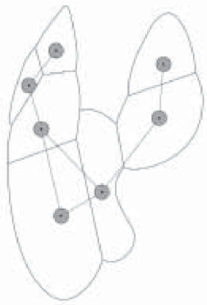
The spacial program overlaid on the design lines. The boxes represent the space needed and their distribution in relations to each other. The spacial program boxes were used to map their effective range for a rough plan to emerge.

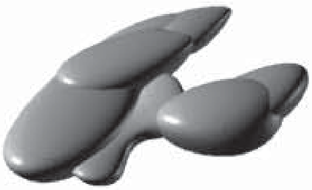


The connections of the different spaces. All functions go through the lobby and other necessary connections are made. This plan is then transformed to a three dimensional model.

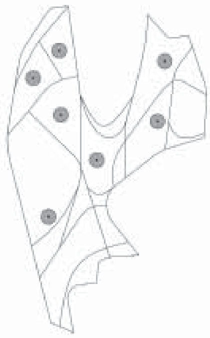


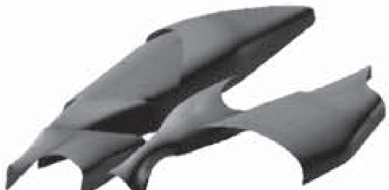
The two dimensional plan is approximated with the design for a more correct representation of the plan. Distinct shape starts to gradually emerge. The spaces of the three dimensional model are translated through their distinct height requirements.





Mode detailed study of the plan and the model. The final shape of the design is already visible in both representations. Details to the plan were derived through the sketching process as the model's outlook was made to more match the appearance of the final evolutionary solution.

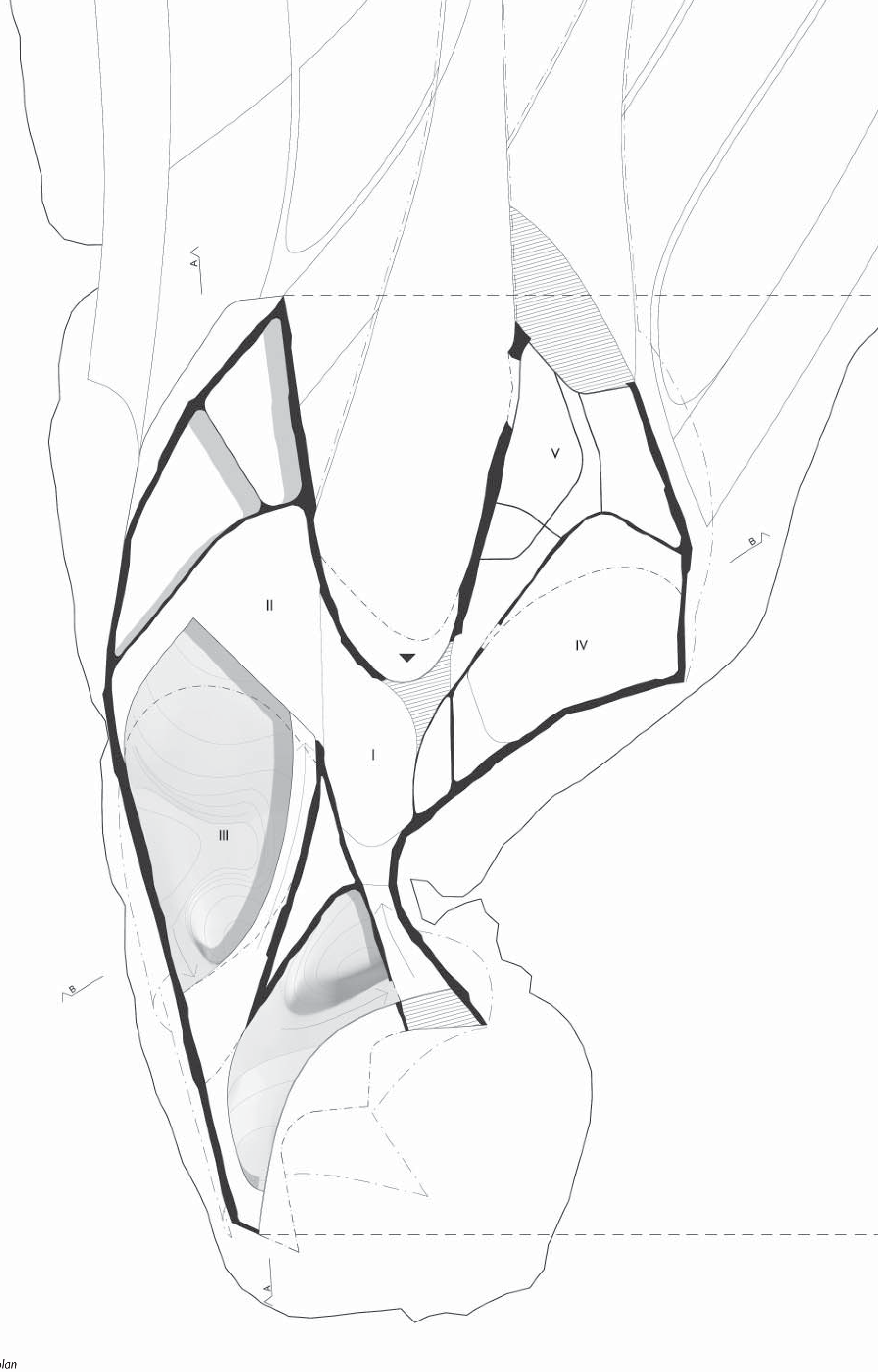




The final design.

2D REPRESENTATION

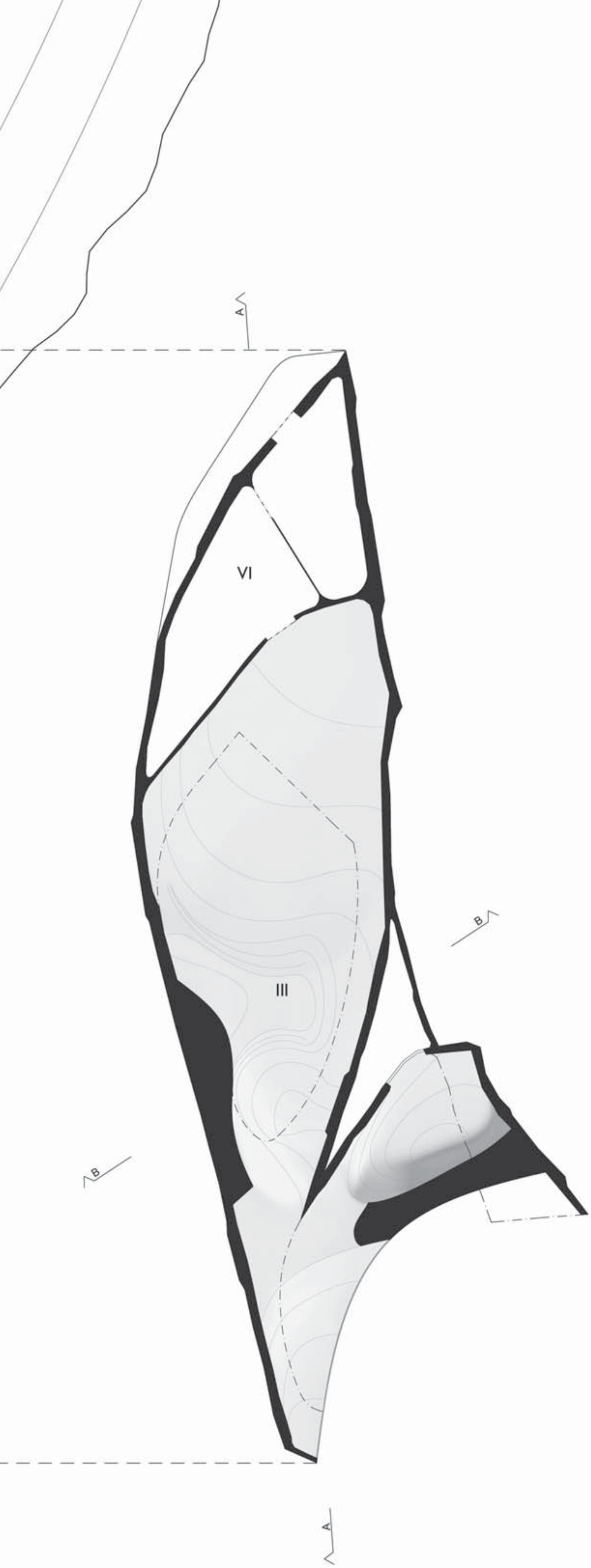
3D REPRESENTATION



Ground level plan

The design

The case results of this diploma work can be viewed as formalistic, as the whole process drifts towards a formal representation of a buildings form, without the systematic review of structural performance or functional aspects. But as it is, the destination is not the form for its own sake. The final form of the building is not the starting point for the design process, but merely the end result. It is the well-thought-out, analysed and dissected outcome of a process that encapsulates ecological forces, evolution, as well as the designer's whimsical decisions.

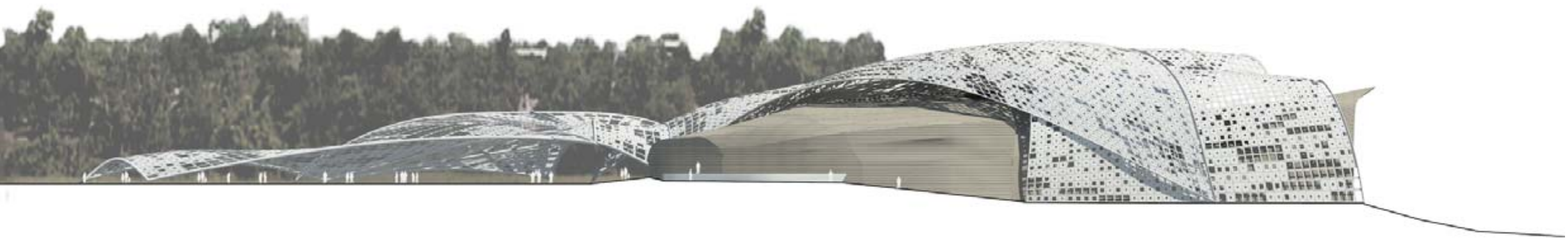


I. lobby
II. restaurant
III. exhibition space
IV. auditorium
V. employees and researches (technical space)
VI. maintenance and storage (technical space)

0 25 50 meters

-1 level plan (exhibition and maintenance)

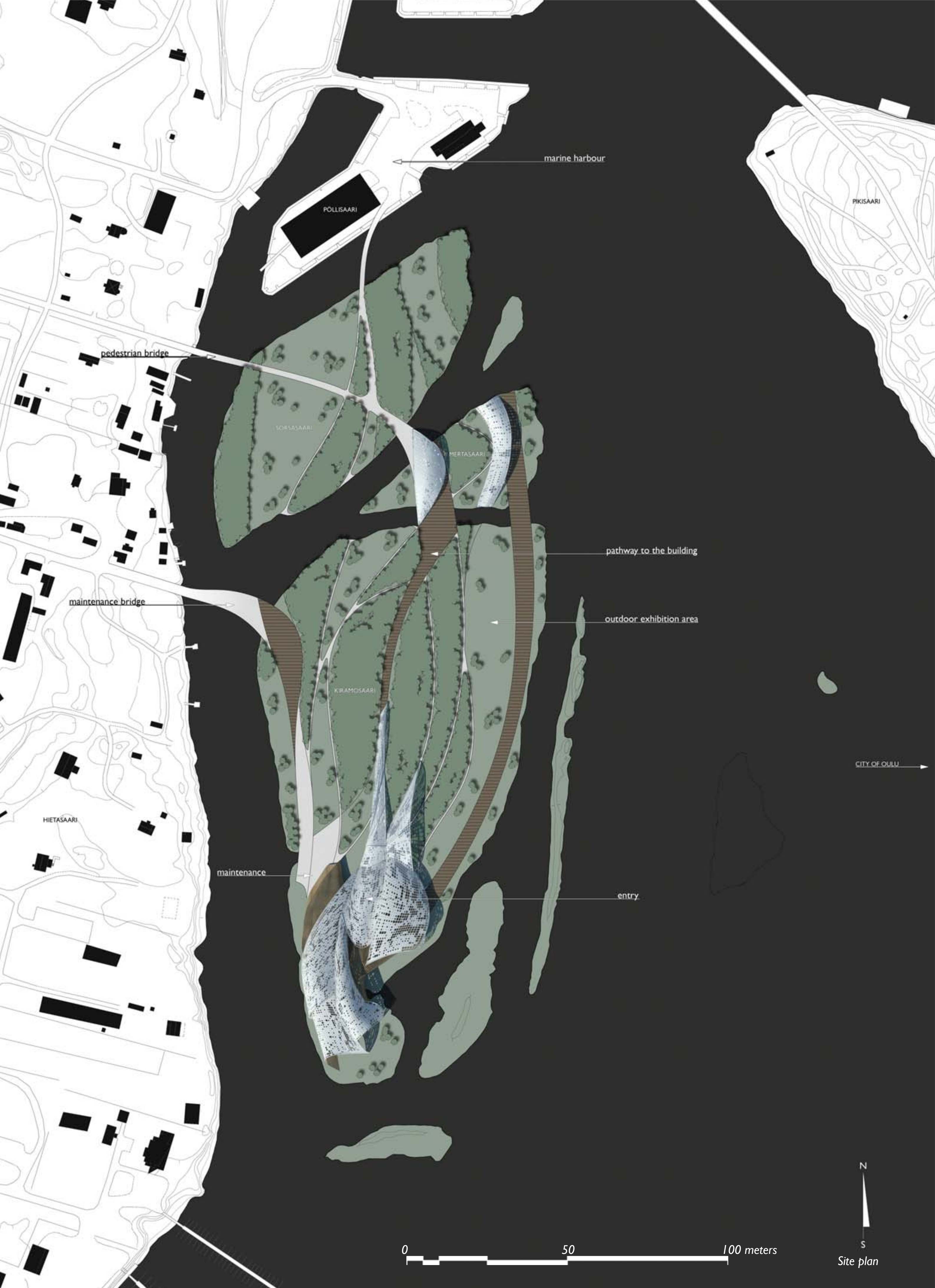
Elevations to South and North



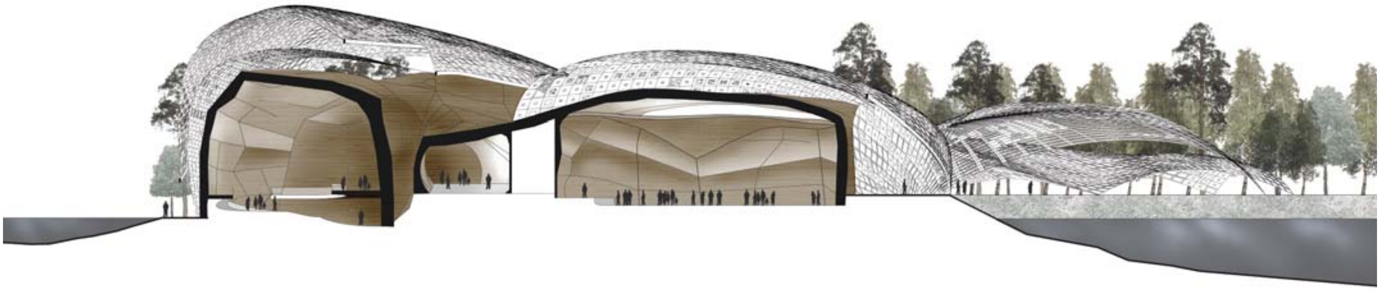
Elevation to West

Elevation to East

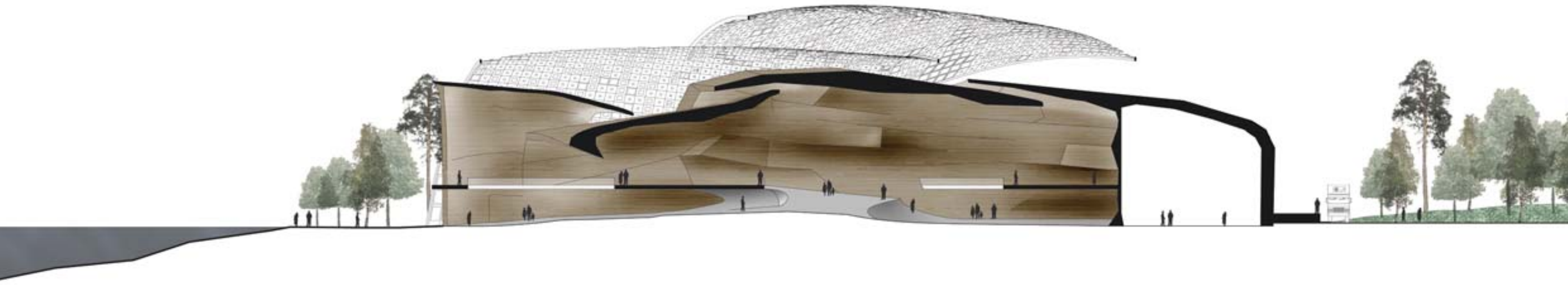
0 25 50 meters


marine harbour
PÖLLISAARI
PIKISAARI
pedestrian bridge
SORSASAARI
MERTASAARI
pathway to the building
maintenance bridge
outdoor exhibition area
KIRAMOSAARI
CITY OF OULU
HIETASAARI
maintenance
entry
N
S
0
50
100 meters

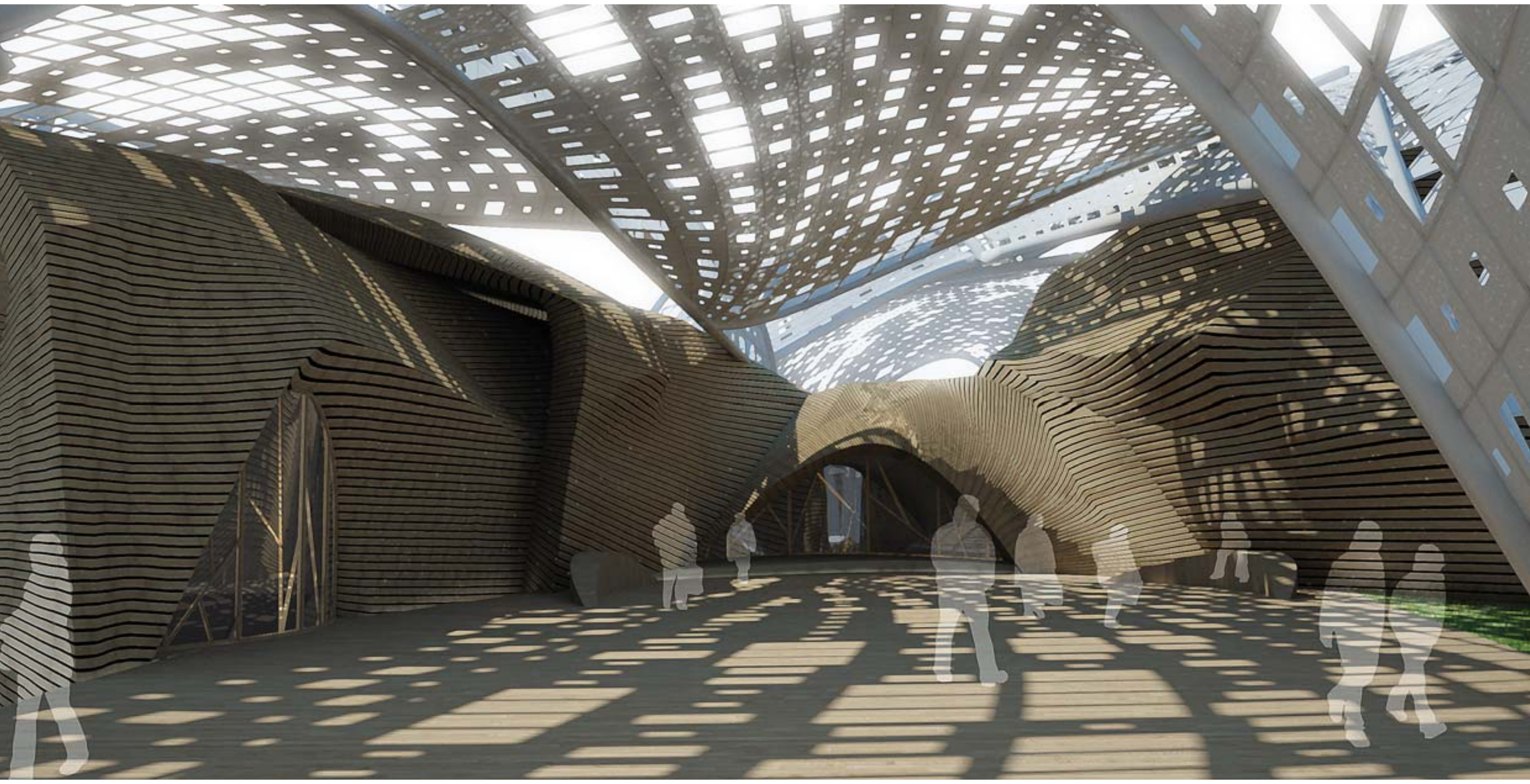
Site plan

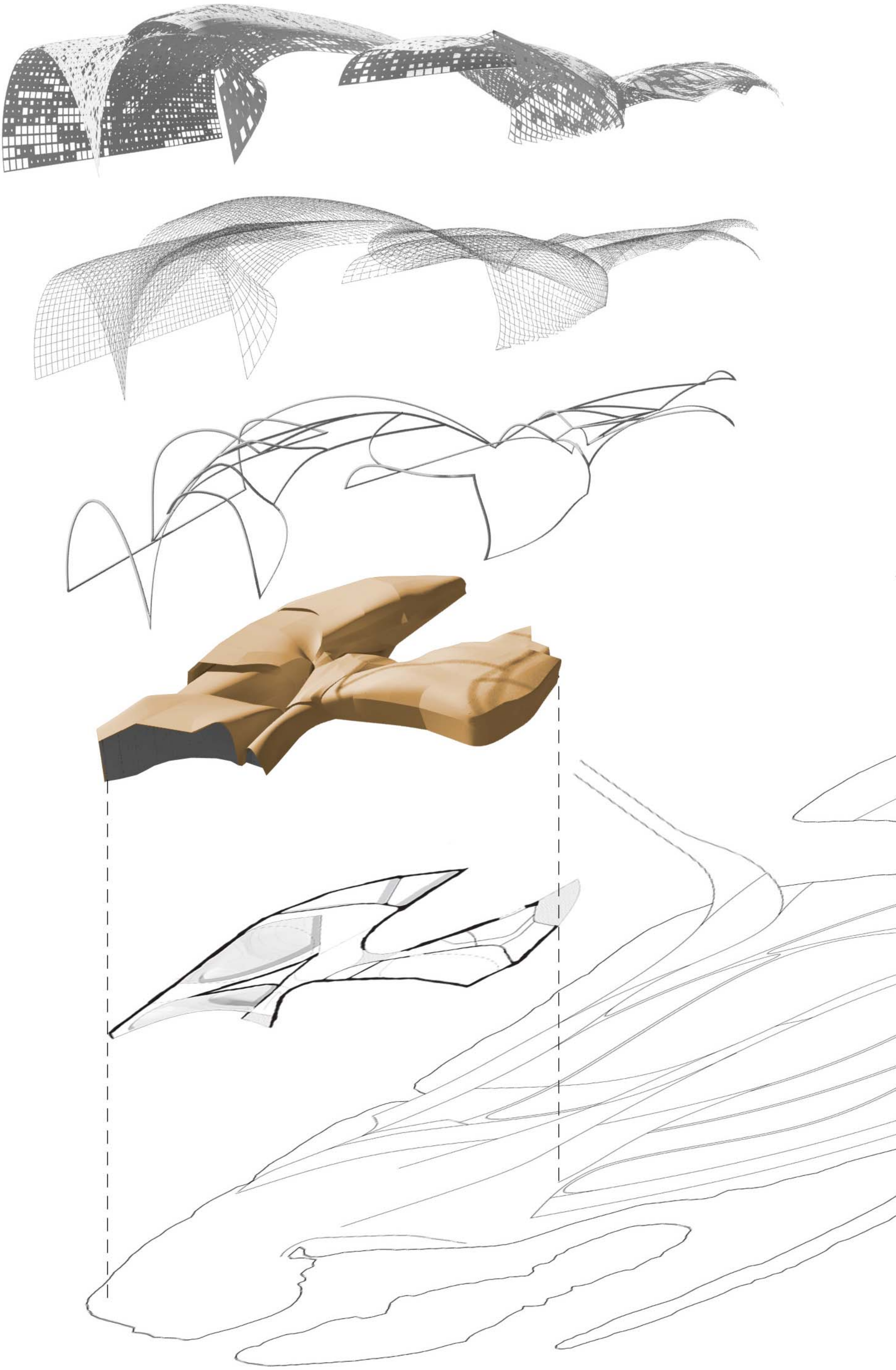


Section B-B



Section A-A





The canopy openings.

The structural grid.

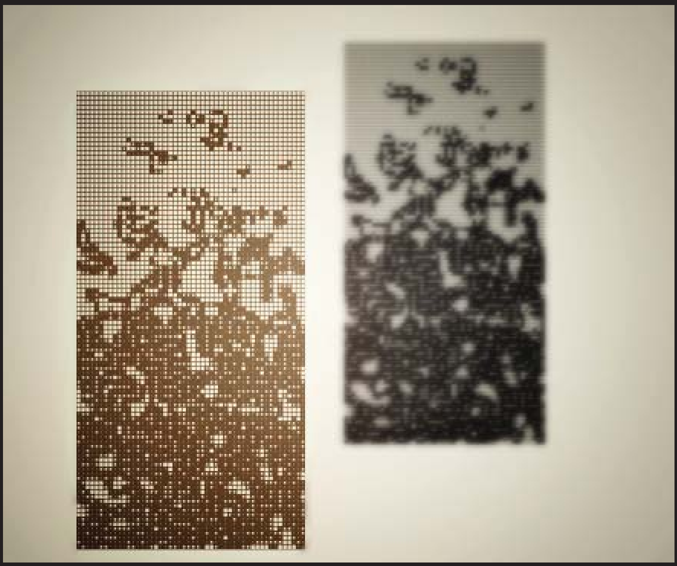
The canopy main frame.

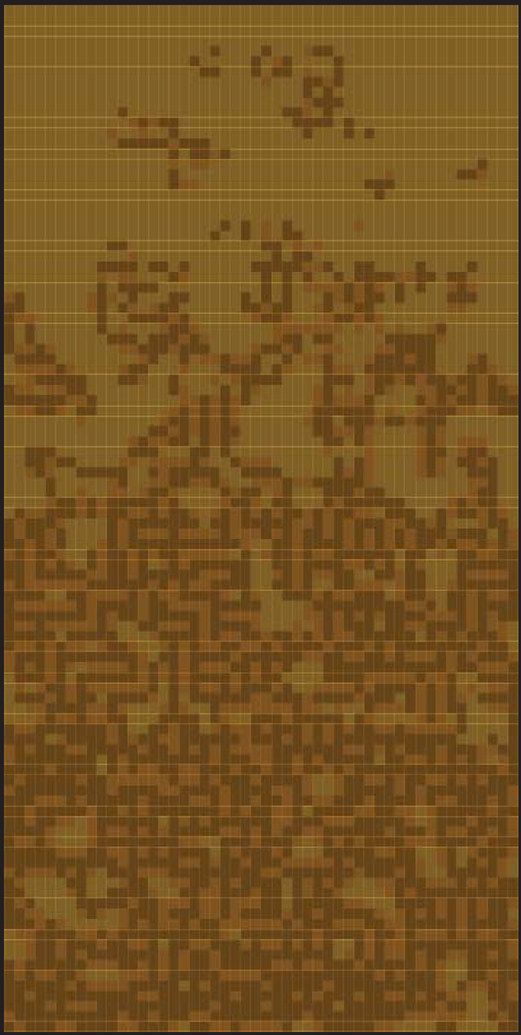
The building envelope.

The building plan.

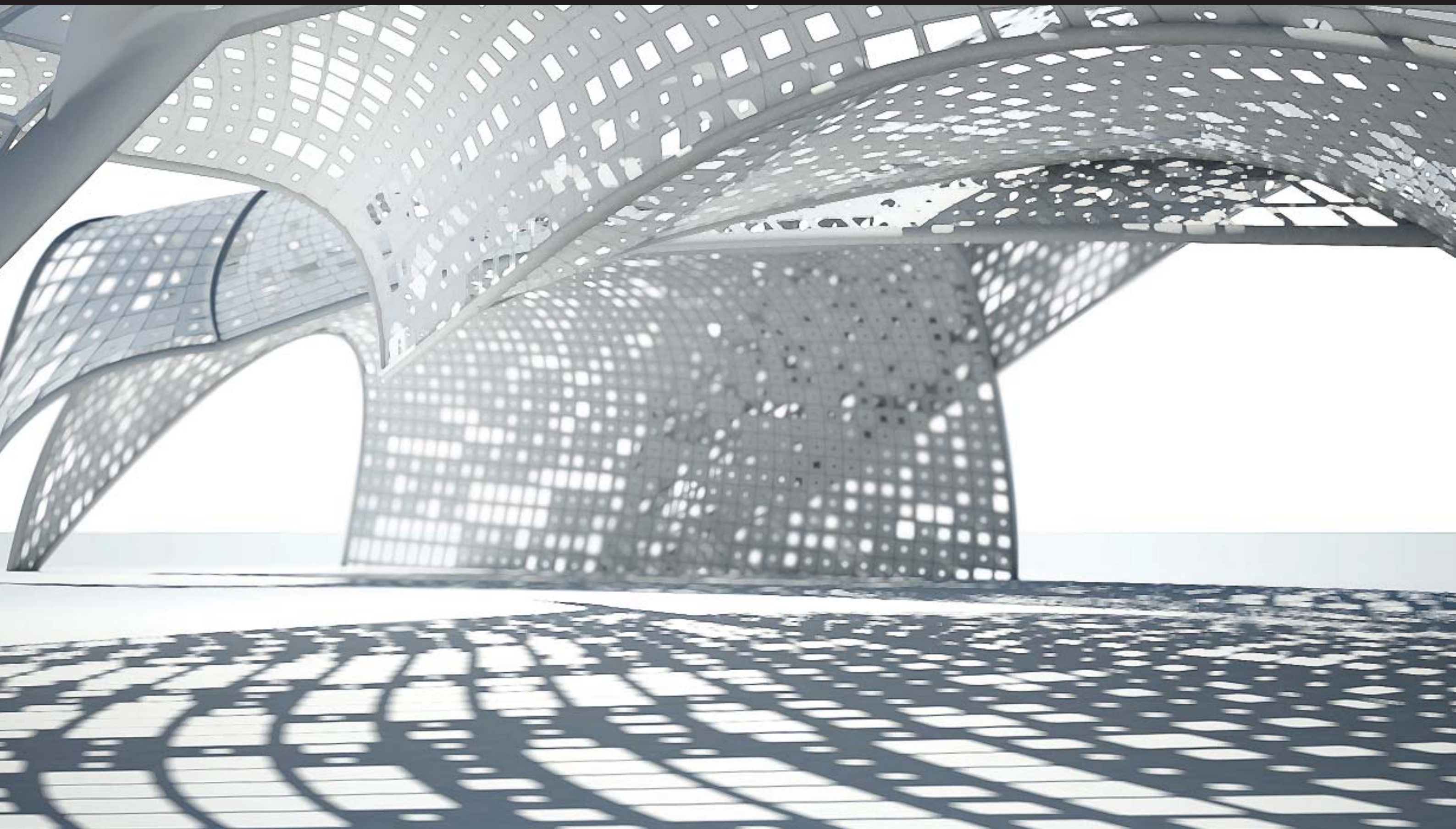
The island and site plan.

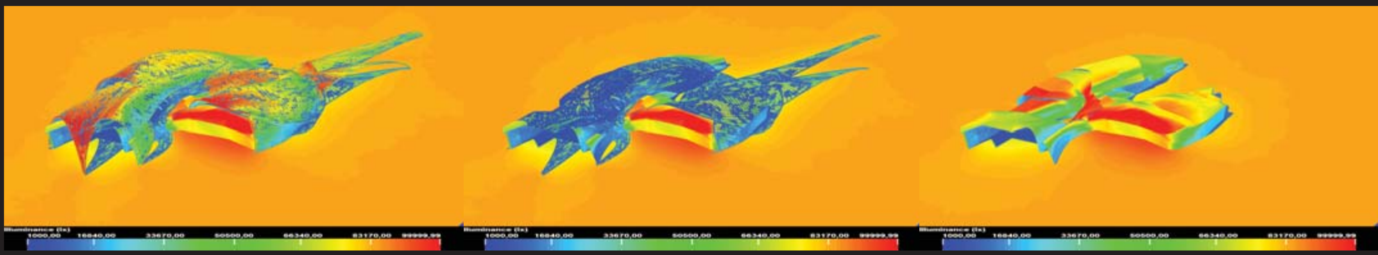
Structural layers





The pathway towards the building is partially covered by a perforated canopy. The purpose of this canopy is to provide different shading conditions and to gradually shift the environment from being totally natural to being totally man-made. The perforation patterns on the canopy create organic shadows which mimic the shadows cast by the natural foliage of the island. The perforations get smaller towards the entrance of the building, creating a gradient shading along the path. The canopies provide shelter and thus cool down the microclimate that they host.



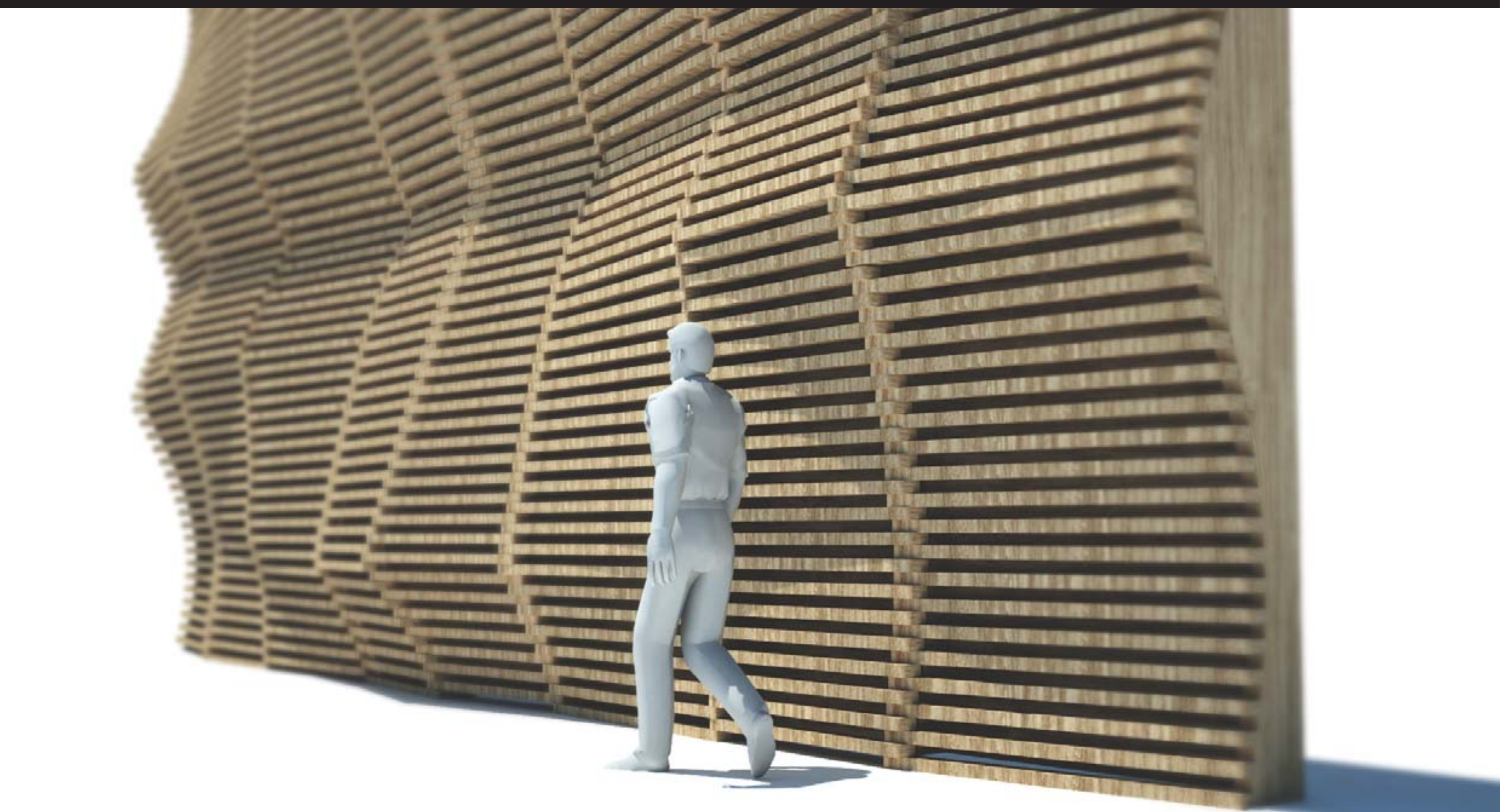


Above: Pseudocolor rendering showing the effect the canopy has on luminance. On the left is the luminance of the canopy and the building. Center picture shows the luminance values of the shadow of the canopy and on the right is the building without the shading of the canopy.

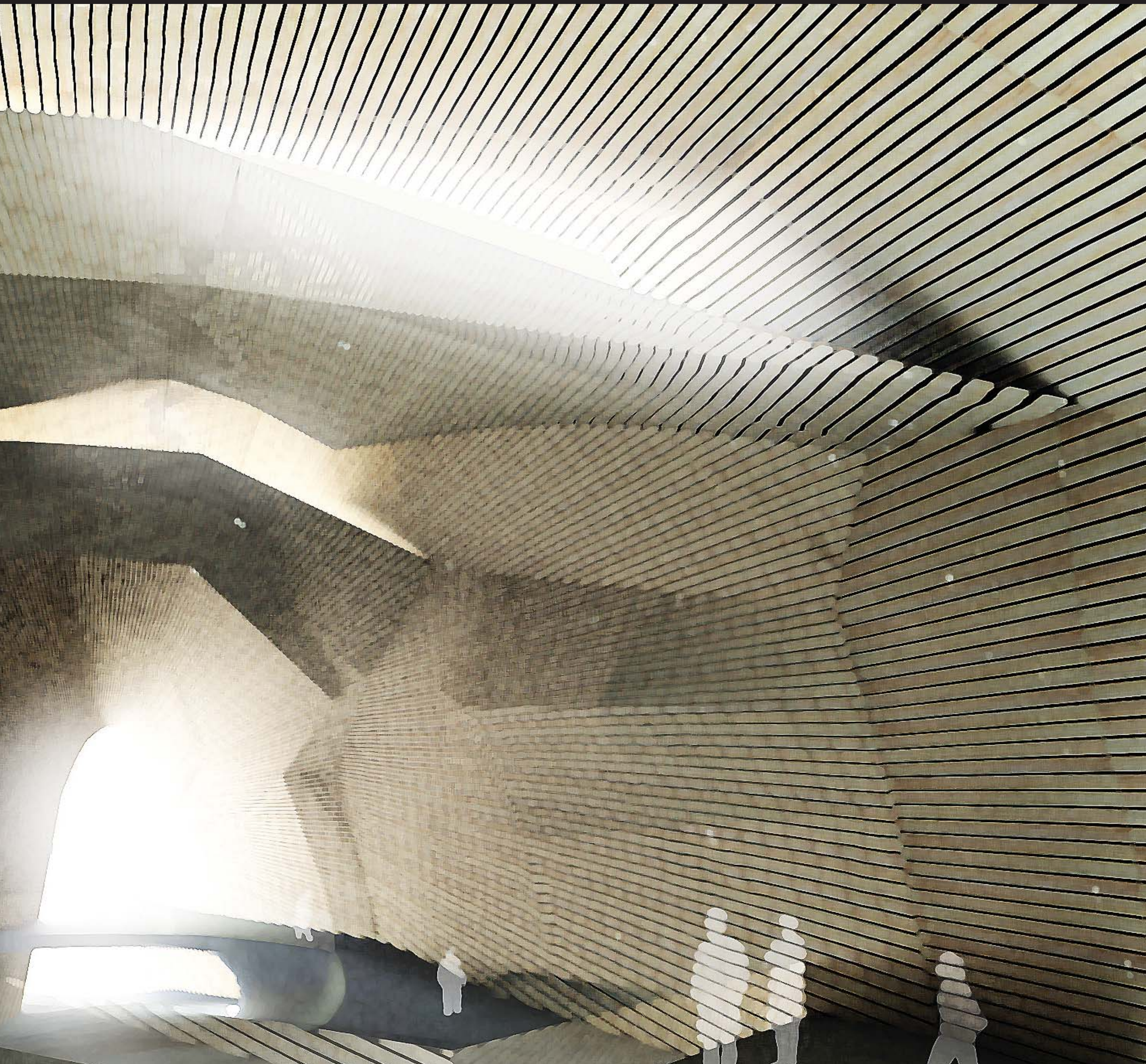
Left: Pictures showing the 3 distinct states of the cellular automata calculations and the emergent shading pattern it creates when mapped as various sized openings on a planar surface.

Below: Axonometric projection of the perforated canopy construction. The colours correspond with the colours of the picture on the previous page; they have been mapped to varying sized openings.

The distribution of the openings on the canopies are based on cellular automata with dynamically varying rules in relation to a distance parameter. The cellular automata has 3 different states which were then mapped onto the canopies as varying sized openings. The distance is measured to the entrance of the building and farther the cell is located from the entrance the more likely it is not to survive, thus eventually mapping that cell as a large opening on the canopy.



The principle of the cladding of the wall structure.



05. DISCUSSION

This diploma work employs the possibilities of algorithmic design methods in a design process that uses natural phenomena as the basis for its architectural morphology. It implements digital morphogenesis in reaction to ecology and the influential forces of the building environment. The resulting design of this process is a combination of the application of the forces and the use of traditional design methods. With the help of algorithmic design methods, my goal has been to find new techniques and inspiration in the aid of architectural design. The use of computational methods in architecture have the ability, not just to aid in the design, but to aid in the search for the inspiration for the design as well.

The motivation for this diploma work was to study the possibilities of how algorithmic aided design could develop the process of architectural design. Rather than just being used as tools for execution, they can be used to find inspiration from the forms created by mathematical equations, simple algorithms or in this case, from the simple simulation of natural phenomena. The simulation is not an actual representation of the physical real-world forces, but even as such, offers new means to comprehend environmental forces. My intention was not to get a final and definitive answer to the design problem just by making the tools and then pressing a button; the methods used in this diploma work offer more soft-touch integration of computational methods as an extension to our inspiration and sketching processes. And as such, these methods do not rule out or shift any of our decisive factors onto the computer, but rather expands the design possibilities we have. Algorithmic design methods offer new ways of searching intelligent information and motivation to reinforce our design intentions.

The final case design is a digital representation of an organic architectural form. I have avoided the use of pre-learned mannerisms and direct references to existing solutions. This offered the possibility to be inspired by the location, its ecology and the design problem itself, rather than just looking into recent architectural publications as a source for inspiration. These new techniques offered me a way to break free from the limiting chains of my own mind, and truly search for alternative solutions through the inspiration of nature. If I had continued on with the traditional design process, the design would have been a collage of different works of other architects as I would have undoubtedly been influenced by architectural publications.

The benefits of this new process in conjunction with my own design methods, have been vast, especially in the formulation of the general starting draft. Typically, I tend to ponder between many different solutions, with great difficulties in choosing the final design. The original idea was to implement natural environmental forces in the formulation of a building envelope; I expanded the idea to cover the design of the whole area. The resulting case design is still a draft and it would certainly go through some alterations if I would continue refining the design process. However, I am very pleased with the outcome of the design, as it is the integration of nature's unpredictability and my own aspirations as a designer. The resulting design is truly my own but with the help of computational methods. I have been able to create something I would not have been able to imagine otherwise.

In the work and time frame of this diploma, there were still many factors not utilized in the design that I would have liked to experiment with. These factors still remain in my future aspirations as I test and learn new methods of architectural design. One of these factors is the integration of true physical optimization into the design process such as structural, aerodynamic and solar optimization. This would create the possibility that while the morphology of the design follows natural processes, the shape could be optimised to be resistant to physical forces and as such offer the best local environment for its function.

Other topics for personal future research would be to refine the use of evolutionary methods and the ability to harvest true genetic algorithms in the aid of architectural design. The problem with genetic algorithms in architectural design is that as genetic algorithms search for an optimised solution, it is very difficult to determine "the best" solution in architecture. The influential factors in architecture are too numerous and vague to be able to simplify as instructions for computation. One possible solution could be something similar to what I have done in this diploma work; to search for an informed draft and continue onward from that point with the intelligence of the designer.

The creation of this diploma work has been an educational process; I've been able to deepen my knowledge in genetic and evolutionary processes, environmental forces, algorithmic design methods and new architectural theory. Looking back, the importance of this diploma work seems minuscule to the importance of the experience I've gained by doing it. And I believe that is a good sign that it has fulfilled its purpose.

Endnotes

1. Michael Hensel and Achim Menges have coined the term *morpho-ecologies* to explain the new framework for architectural design that is rooted in the biological paradigm and combines the concepts of morphology and ecology. See Hensel, Michael & Menges, Achim. (2008). (edit.) *Morpho-Ecologies – Towards an Inclusive Discourse on Heterogeneous Architecture*. London: Architectural Association (second. edit., first. published 2006). p. 20.
2. Ibid p. 16.
3. The dissertation was written in Finnish, but the title was later translated by Aulikki Herneoja.
4. Kostas Terzidis is Associate Professor at the Graduate School of Design, Harvard University, USA and has written books on the use of algorithms in design.
5. See Terzidis, Kostas.(2006). *Algorithmic architecture*. Amsterdam: Elsevier
6. See Suomen rakennustaiteen museo. (1985). *PIETILÄ – Modernin arkkitehtuurin välimaastoissa*. [Intermediate Zones in Modern Architecture]. Helsinki: Martinpaino. [Exhibition Publication]. See also Suomen rakennustaiteen museo. (2008). *raili ja reima pietilä - modernin arkkitehtuurin haastajat*. [challengers of modern architecture]. Lahti: Aldus Oy. [Exhibition Publication].
7. See *Arkkitehti*. [Finnish architectural review]. 11-12/1966. pp.152-159.
8. Interview with Reima Pietilä. See Suomen rakennustaiteen museo. (1985). *PIETILÄ – Modernin arkkitehtuurin välimaastoissa*. [Intermediate Zones in Modern Architecture]. Helsinki: Martinpaino. [Exhibition Publication]. p. 14.
9. Introduction to the book by Michael Weinstock. See Hensel, Michael & Menges, Achim. (2008). (edit.) *Morpho-Ecologies – Towards an Inclusive Discourse on Heterogeneous Architecture*. London: Architectural Association (second. edit., first. published 2006). p. 12.
10. See Terzidis, Kostas.(2006). *Algorithmic architecture*. Amsterdam: Elsevier. Prologue. p. xi-xii.
11. Ibid. p. 39.
12. Terzidis states a difference between the terms planning and design. He describes planning as the act of devising a scheme, program, or method worked out beforehand for the accomplishment of an objective, as design is a conceptual activity of formulating an idea intended to be expressed in a visible form or carried into action. Design is about conceptualization, imagination, and interpretation. In contrast planning is about realization, organization, and execution. See Terzidis, Kostas.(2006). *Algorithmic architecture*. Amsterdam: Elsevier. p. 1.
13. Ibid. p. 25.
14. Ibid. Prologue. p. xii.
15. Ibid.
16. See Achim, Menges. (2006). *Instrumental geometry*. Architectural Design. Vol 76 No 2. John Wiley & Sons Ltd. pp. 42-53.
17. See Hensel, Michael & Menges, Achim. (2008). (edit.) *Morpho-Ecologies – Towards an Inclusive Discourse on Heterogeneous Architecture*. London: Architectural Association (second. edit., first. published 2006). See also Frazer, John. (1995). *An Evolutionary Architecture*. London: Architectural Association.
18. See Terzidis, Kostas.(2006). *Algorithmic architecture*. Amsterdam: Elsevier. p. 19.
19. Genetic algorithm is a computational search technique for finding exact or approximate solutions for optimization and search problems. Cellular automaton (plural Cellular Automata) consists of a grid of cells, each in a distinct state, for instance "on" or "off". Through calculation of the states of the cell's neighbours, the cell's state is re-evaluated. For more information on genetic algorithms, cellular automata and voronoi-diagrams, see for example Coates, Paul. (2010). *programming.architecture*. New York: Routledge.
20. See Estévez, Alberto T.; Puigarnau, Alfons… (2003). *Genetic Architectures*. Barcelona: Lumen, Inc. p. 9.
21. See Achim, Menges. (2006). *Polymorphism*. Architectural Design. Vol 76 No 2. John Wiley & Sons Ltd. pp. 78-87.
22. See Pietilä, Reima. (1958). *Morphology of Expressive Space*. Le Carré Bleu 1/58.
23. See Hensel, Michael. (2006). *Computing Self-Organisation: Environmentally sensitive Growth Modelling*. Architectural Design 76 (2), pp. 12-17.
24. See Hensel, Michael & Menges, Achim. (2008). (edit.) *Morpho-Ecologies – Towards an Inclusive Discourse on Heterogeneous Architecture*. London: Architectural Association (second. edit., first. published 2006). p. 16.
25. See Hensel Michael. (2006). *(Synthetic) Life Architecture: Ramifications and Potentials of a Literal Biological Paradigm for Architectural Design*. Architectural Design 76 (2), pp. 18-25
26. Ibid.
27. See Frazer, John. (1995). *An Evolutionary Architecture*. London: Architectural Association.
28. See Hensel Michael. (2006). *(Synthetic) Life Architecture: Ramifications and Potentials of a Literal Biological Paradigm for Architectural Design*. Architectural Design. Vol 76 No 2. John Wiley & Sons Ltd. pp. 18-25
29. Ibid.
30. "Behaviour is an observable action or response to an organism or a species to environmental factors. This involves: first, a stimulus, in other words, an internal or external agent that produces a reaction or change in an organism; second, sensibility, which is the capacity to perceive a stimulus; and third, sensitivity, the capacity to respond to that stimulus. " See Hensel, Michael & Menges, Achim. (2008). (edit.) *Morpho-Ecologies – Towards an Inclusive Discourse on Heterogeneous Architecture*. London: Architectural Association (second. edit., first. published 2006). p.54.
31. See Pugnale, Alberto & Sassone, Mario. (2007). *Morphogenesis and structural optimization of shell structures with the aid of a genetic algorithm*. Journal of the International Association for Shell and Spatial Structures: J. IASS. Vol 48 No 3. pp. 161-166.

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pp. 14-15. Photographs and plan by Reima Pietilä and Raili Paatelainen. See Pietilä, Reima & Paatelainen, Raili. *Kalevan kirkko.* [Kaleva Church]. Arkkitehti. [Finnish architectural review]. 11-12/1966. pp. 152-159.

p. 20. Photographs by Eero Lundén.

p.21. Photograph by Suomen rakennustaiteen museo. See Suomen rakennustaiteen museo. (1985). *PIETILÄ – Modernin arkkitehtuurin välimaastoissa*. [Intermediate Zones in Modern Architecture]. Helsinki: Martinpaino. [Exhibition Publication].

p.22. Photographs by Wikipedia Commons (http://commons.wikimedia.org/wiki/File:USA_10150_Antelope_Canyon_Luca_Galuzzi_2007.jpg; http://commons.wikimedia.org/wiki/File:Wind-blown_tree_Ka_Lae_Hawaii.jpg)

p.25. Aerial photograph by city of Oulu (http://kartta.ouka.fi/photos/ilmakuva_oulu_1947.htm)

All other pictures by the author.

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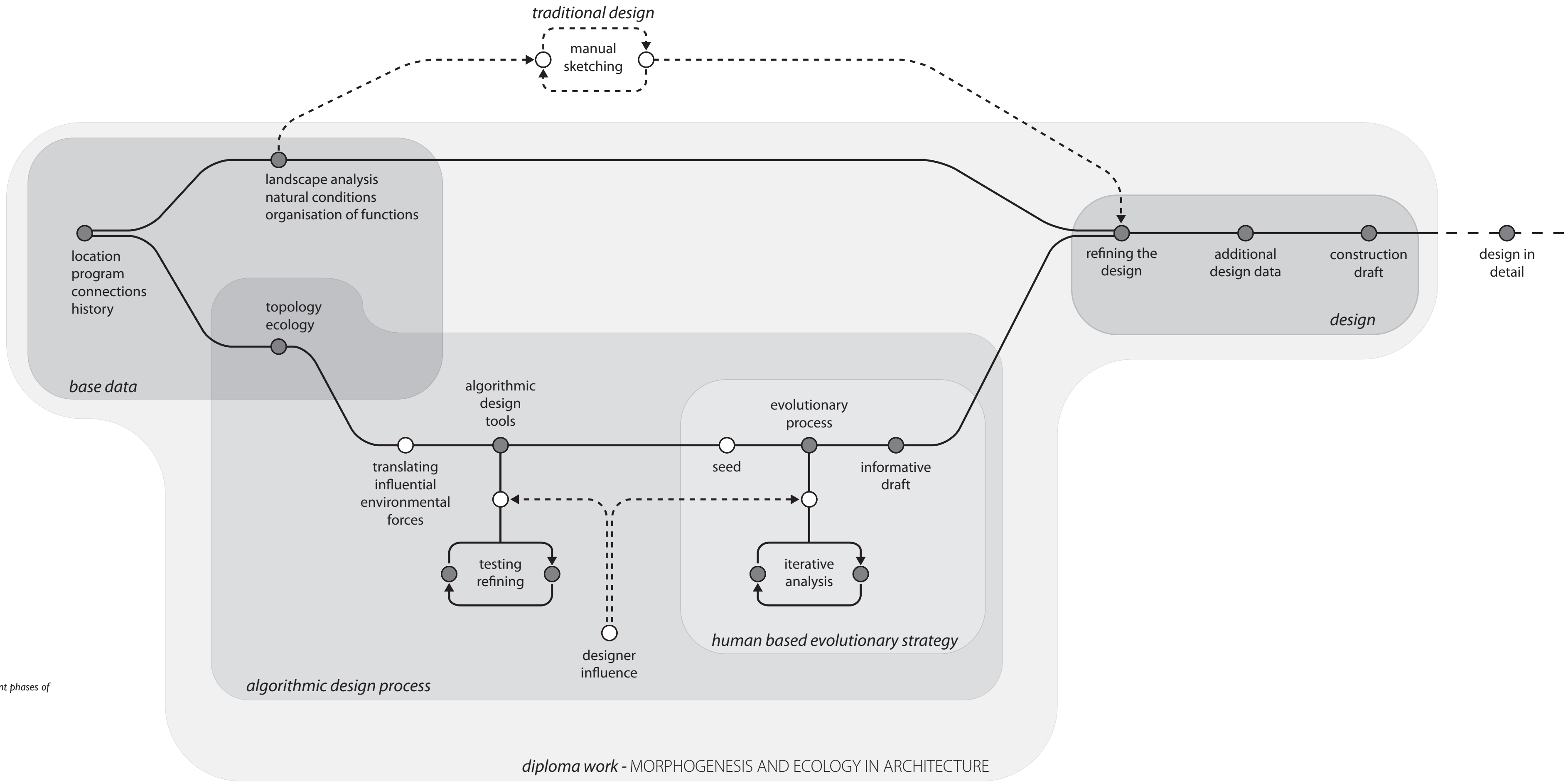
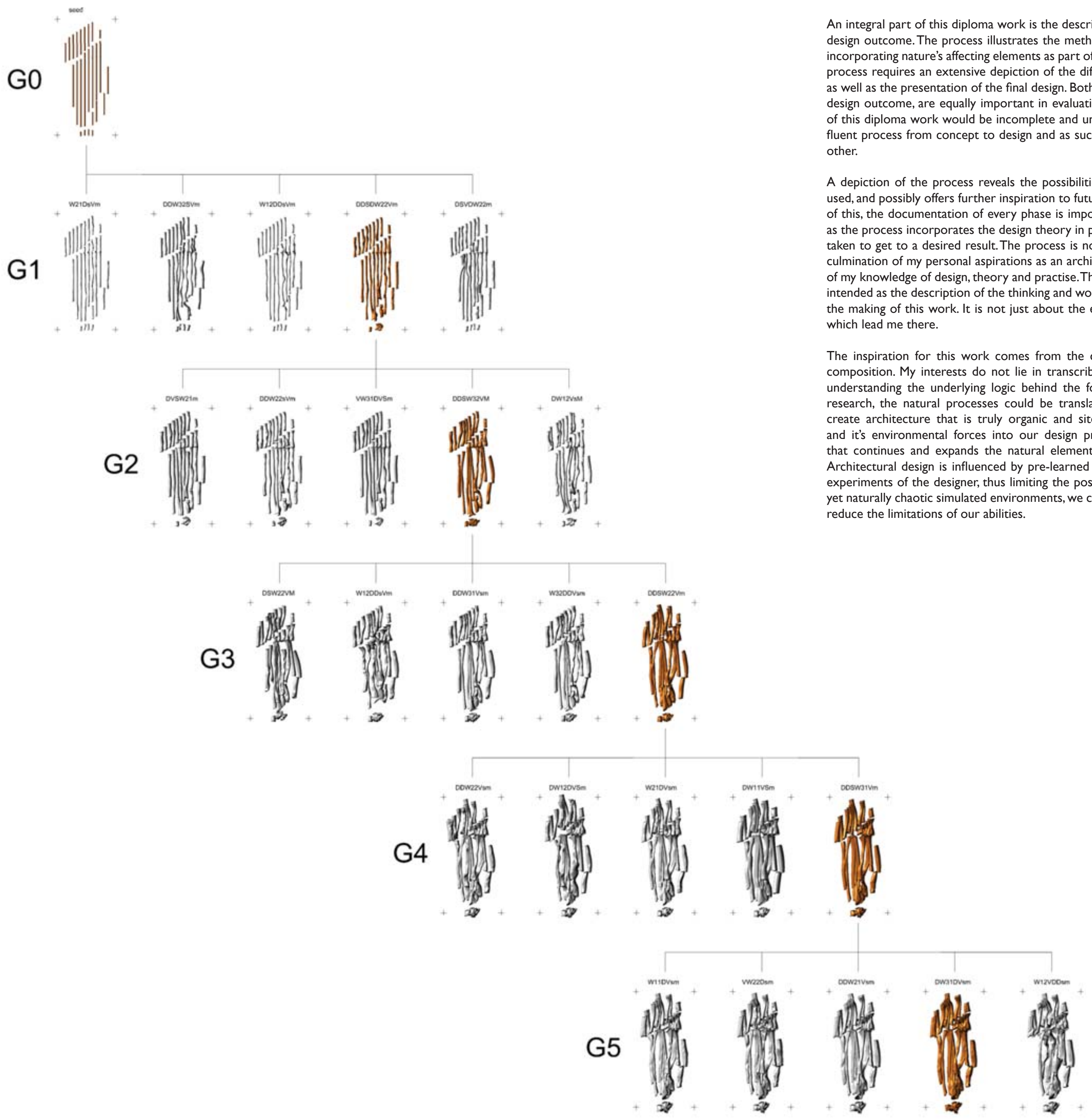


Diagram demonstrating the different phases of the design process.

The evolution tree, showing all of the calculated solutions and the selection process towards the end result..



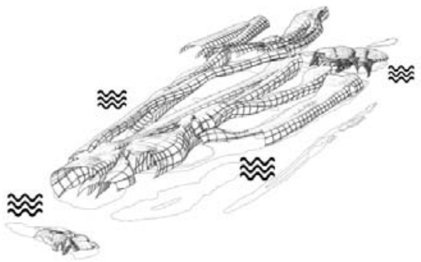
An integral part of this diploma work is the description of the process that leads to the design outcome. The process illustrates the methods used and the thinking involved in incorporating nature's affecting elements as part of the creative task. A description of the process requires an extensive depiction of the different phases included in the method as well as the presentation of the final design. Both, the depiction of the process and the design outcome, are equally important in evaluating this work. Without one, the result of this diploma work would be incomplete and uninformative. Together they describe a fluent process from concept to design and as such, the distinctive parts complete each other.

A depiction of the process reveals the possibilities of these novel tools and methods used, and possibly offers further inspiration to future developments in this area. Because of this, the documentation of every phase is important for a coherent path to emerge, as the process incorporates the design theory in practise and illustrates the steps I have taken to get to a desired result. The process is not a result of a haste decision but the culmination of my personal aspirations as an architect and therefore represents a range of my knowledge of design, theory and practise. This description of the design process is intended as the description of the thinking and working process which took place during the making of this work. It is not just about the end result but also about the journey which lead me there.

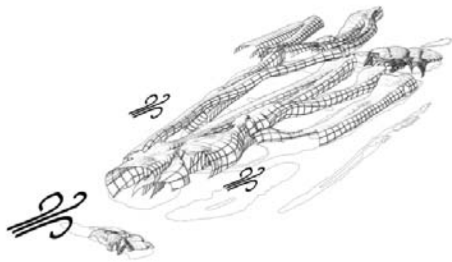
The inspiration for this work comes from the complexity of nature and its organic composition. My interests do not lie in transcribing or copying its visual form but in understanding the underlying logic behind the formulation of the form itself. Trough research, the natural processes could be translated into simulations and this would create architecture that is truly organic and site-specific. If we incorporate ecology and it's environmental forces into our design processes, we can create architecture that continues and expands the natural elements of the location in it's morphology. Architectural design is influenced by pre-learned formal languages and the past design experiments of the designer, thus limiting the possibilities. Through designer-controlled, yet naturally chaotic simulated environments, we can expand our range of influences and reduce the limitations of our abilities.

The selected solutions in order. The diagram shows the evolution of the form and the end result, which was used as an informed draft for the rest of the design process.

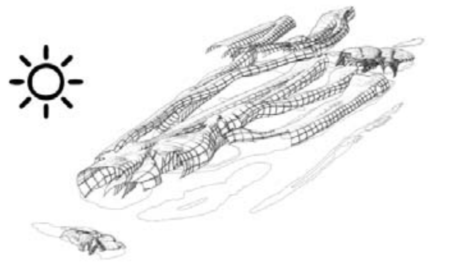
The influencial external forces affecting the evolution.



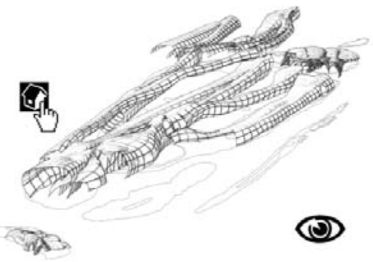
WATER CURRENTS



WIND



SOLAR RADIATION



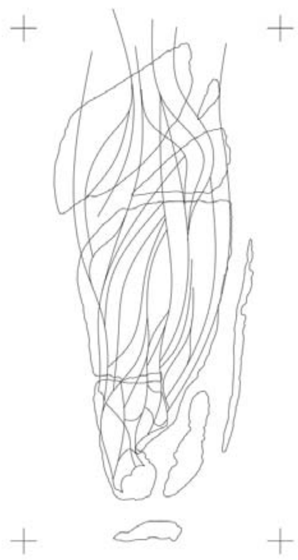
VIEWS AND SPACIAL PROGRAM

The sketching process entailed the use of the final solution and its intersecting lines with the base plane. Using these and the hand drawn sketches, the final design was made.

The final solution.

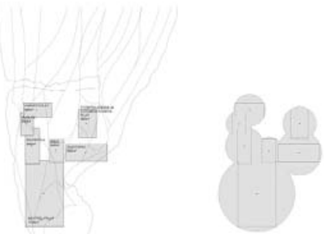
The intersecting lines of the final solution and the base plane of the island.

The hand drawn sketch.

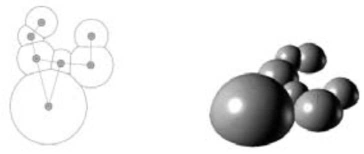


The final design lines.

The spacial program overlaid on the design lines. The boxes represent the space needed and their distribution in relations to each other. The spacial program boxes were used to map their effective range for a rough plan to emerge.



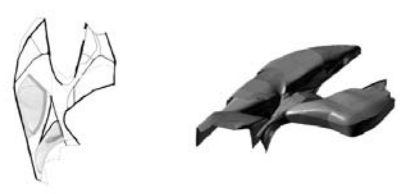
The connections of the different spaces. All functions go through the lobby and other necessary connections are made. This plan is then transformed to a three dimensional model.



The two dimensional plan is approximated with the design for a more correct representation of the plan. Distinct shape starts to gradually emerge. The spaces of the three dimensional model are translated through their distinct height requirements.

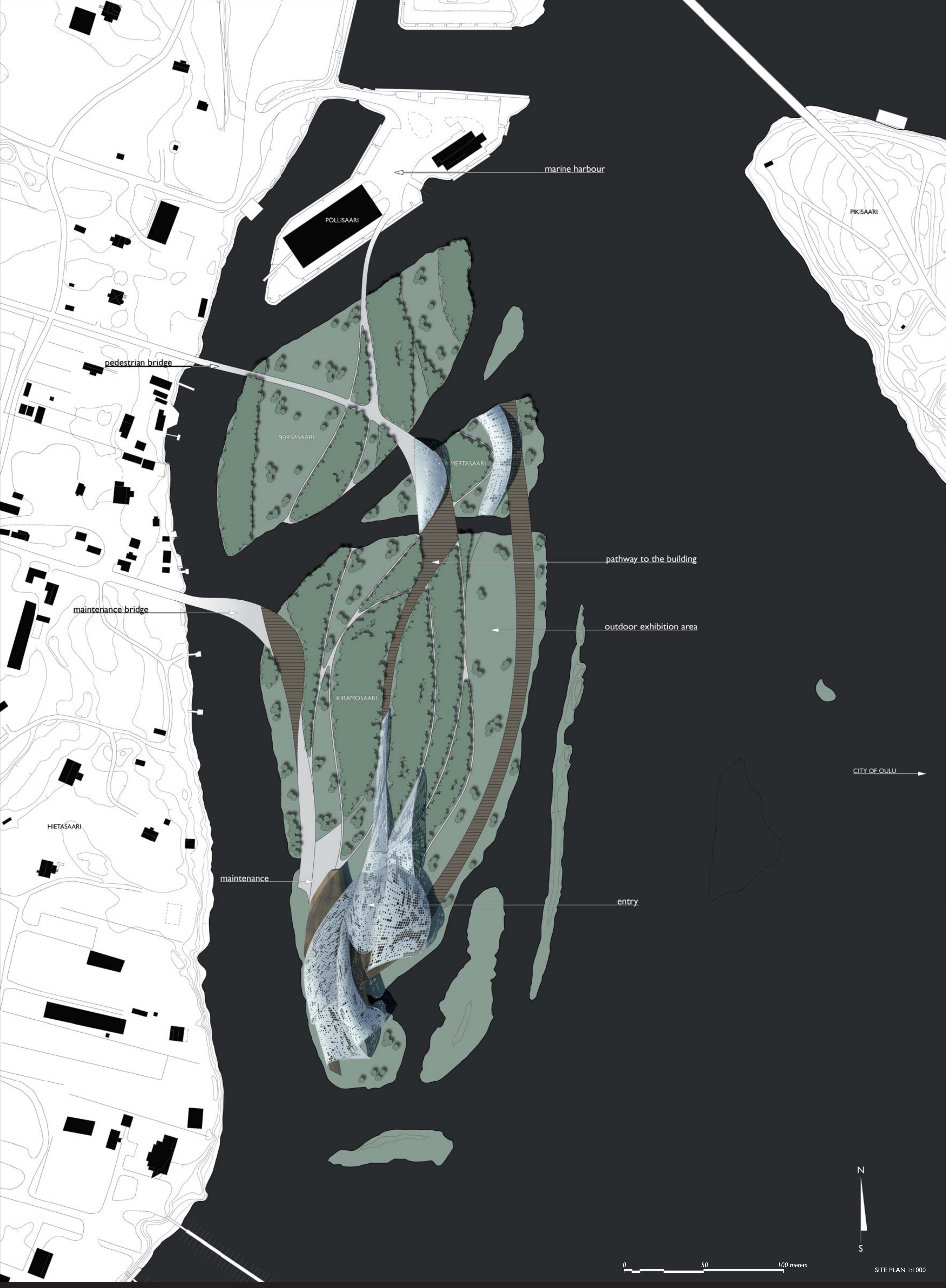
Mode detailed study of the plan and the model. The final shape of the design is already visible in both representations. Details to the plan were derived through the sketching process as the model's outlook was made to more match the appearance of the final evolutionary solution.

The final design.



2D REPRESENTATION *3D REPRESENTATION*

METHODS FOR MORPHOGENESIS AND ECOLOGY IN ARCHITECTURE - CASE: DESIGNING BOTHNIAN BAY CULTURAL CENTER | 2/8
DIPLOMA WORK | UNIVERSITY OF OULU, DEPARTMENT OF ARCHITECTURE | 28.4.2010 | TONI ÖSTERLUND |
SUPERVISOR: PROFESSOR RAINER MAHLAMÄKI | INSTRUCTORS: AULIKKI HERNEOJA, JUKKA LAAKSONEN



METHODS FOR MORPHOGENESIS AND ECOLOGY IN ARCHITECTURE - CASE: DESIGNING BOTHNIAN BAY CULTURAL CENTER | 3/8

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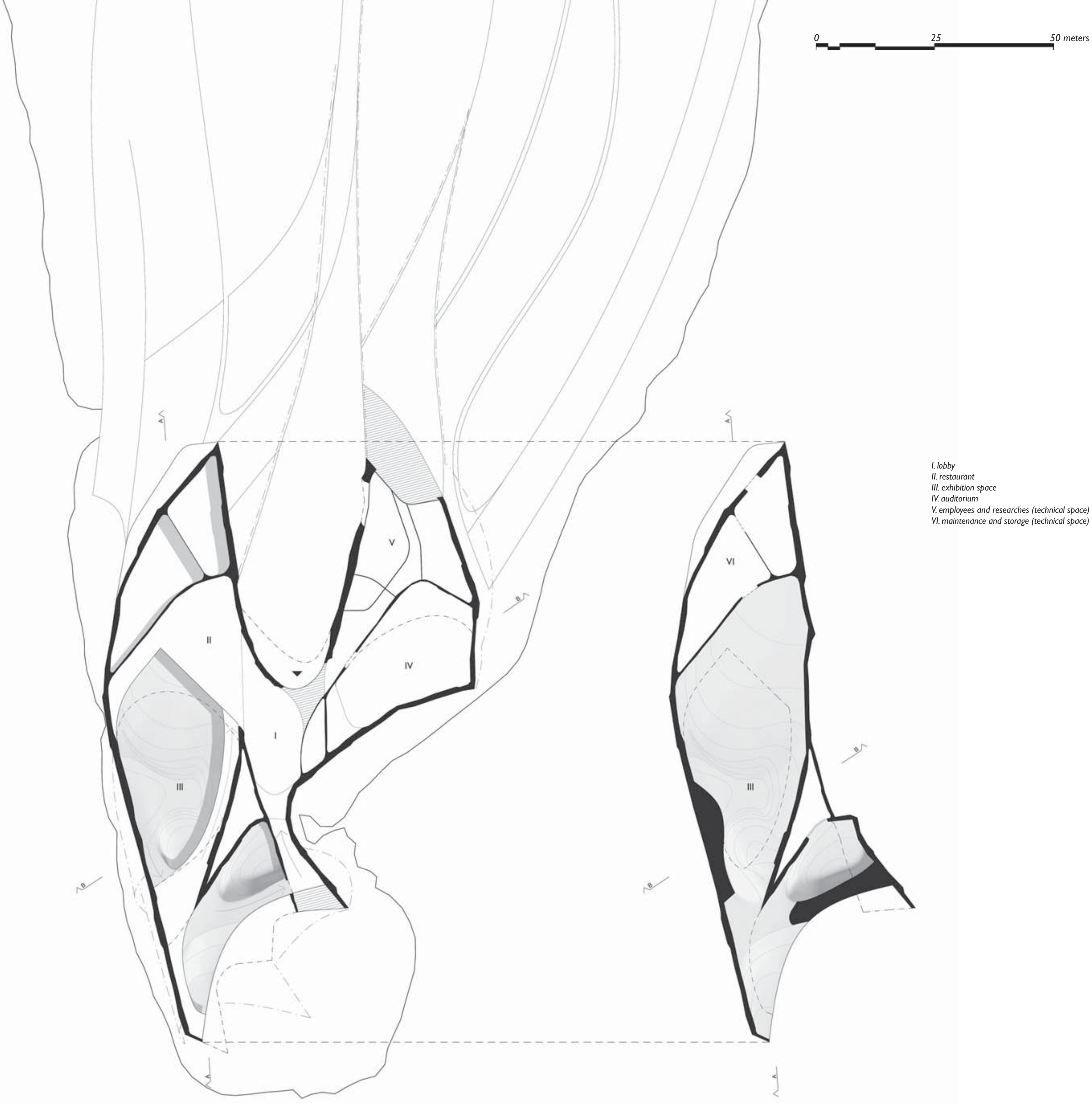
SUPERVISOR: PROFESSOR RAINER MAHLAMÄKI | INSTRUCTORS: AULIKKI HERNEOJA, JUKKA LAAKSONEN



GROUND LEVEL PLAN 1:500

-1 LEVEL PLAN 1:500

METHODS FOR MORPHOGENESIS AND ECOLOGY IN ARCHITECTURE - CASE: DESIGNING BOTHNIAN BAY CULTURAL CENTER | 4/8

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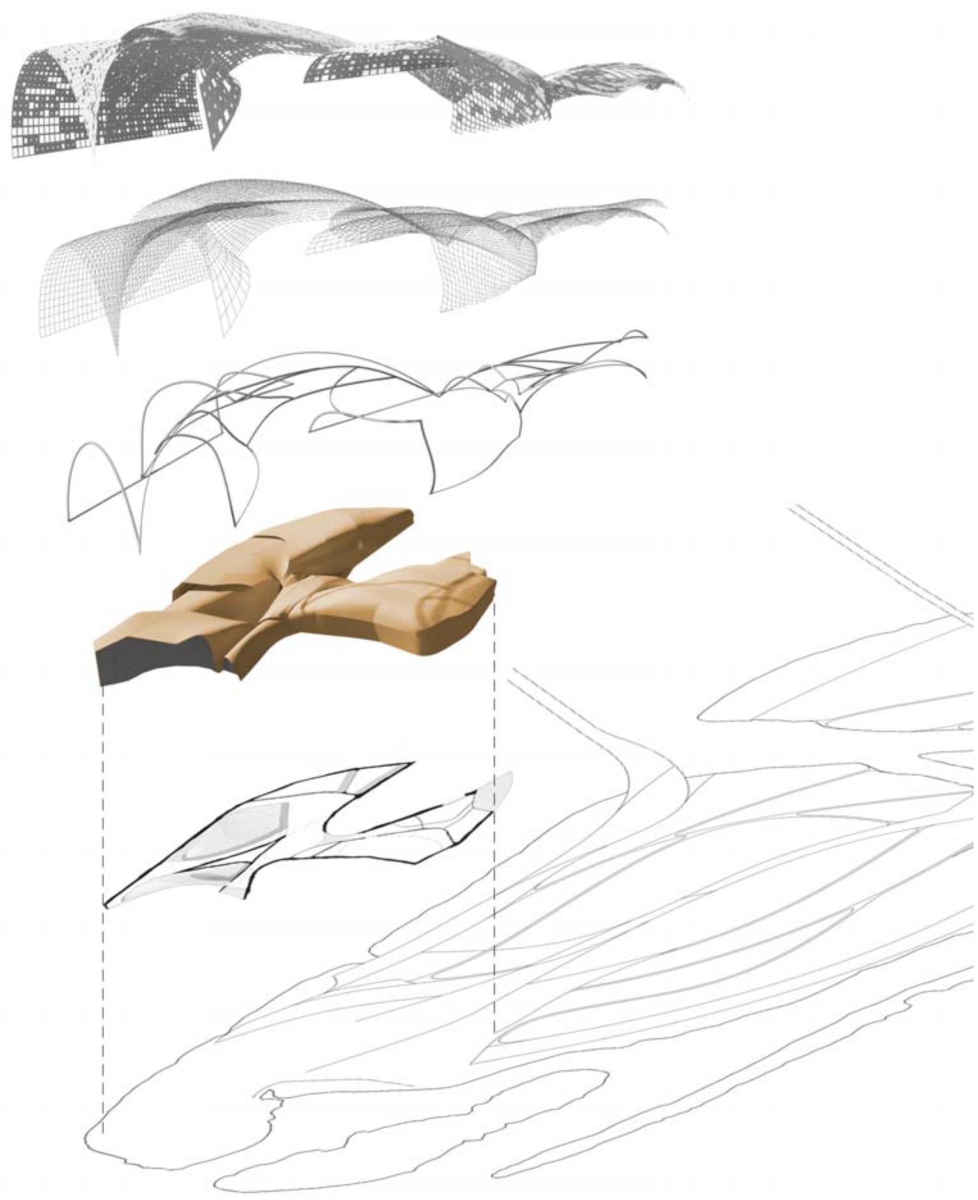
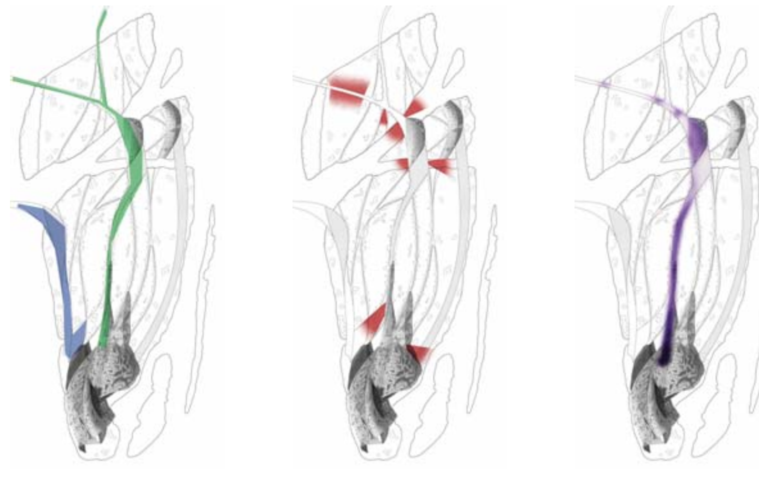


STRUCTURAL LAYERS



Patway to the building.
Green: pedestrian
Blue: maintenanace

Views along the path.

Amount of shadow along the path.

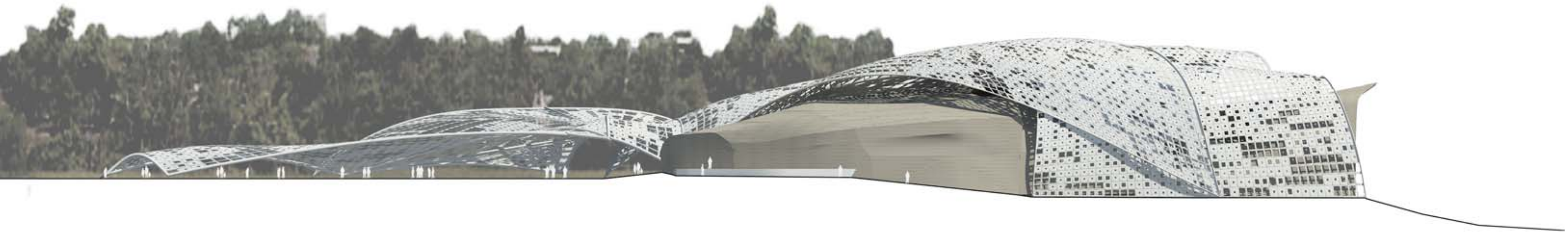
This diploma work employs algorithmic design methods in a design process that uses natural phenomena as the basis of its architectural morphology. It implements digital morphogenesis in reaction to ecology and the influential forces of the building environment. The resulting design of this process is a combination of the application of these forces and the use of traditional design methods. With the help of algorithmic design methods, my goal has been to find new techniques and inspiration in the aid of architectural design. The use of computational methods in architecture have the ability, not just to aid in the design, but to aid in the search for inspiration for the design as well.

The motivation for this diploma work was to study the possibilities of how algorithmic aided design could develop the process of architectural design. Rather than just being used as tools for execution, they can be used to find inspiration from the forms created by mathematical equations, simple algorithms or in this case, from the simple simulation of natural phenomena. The simulation is not an actual representation of the physical real-world forces, but even as such, offers new means to comprehend environmental forces. My intention was not to get a final and definitive answer to the design problem just by making the tools and then pressing a button; the methods used in this diploma work offer more soft-touch integration of computational methods as an extension to our inspiration and sketching processes. And as such, these methods do not rule out or shift any of our decisive factors onto the computer, but rather expands the design possibilities we have. Algorithmic design methods offer new ways of searching intelligent information and motivation to reinforce our design intentions.

0 25 50 meters

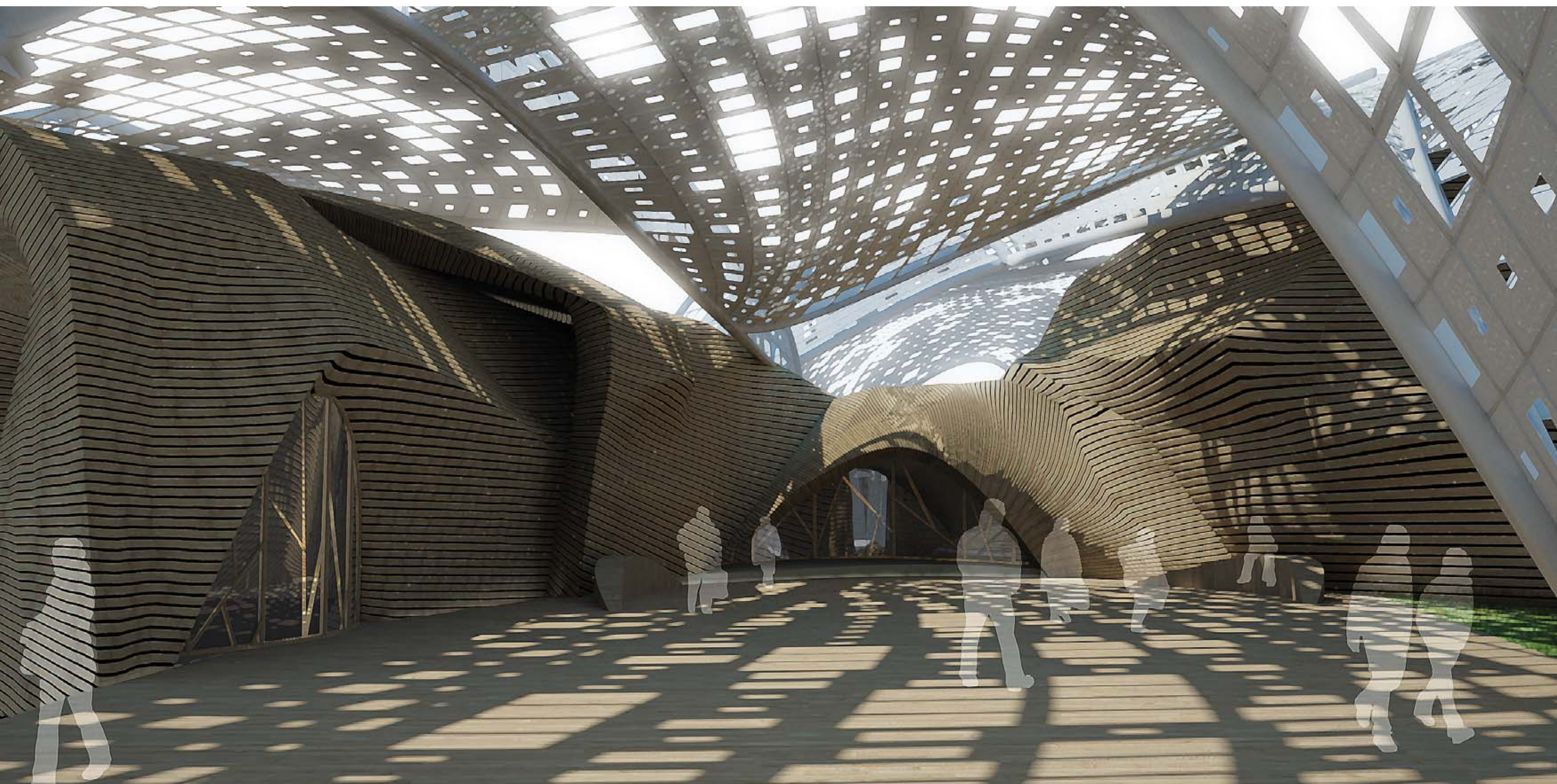

Elevations to North and South

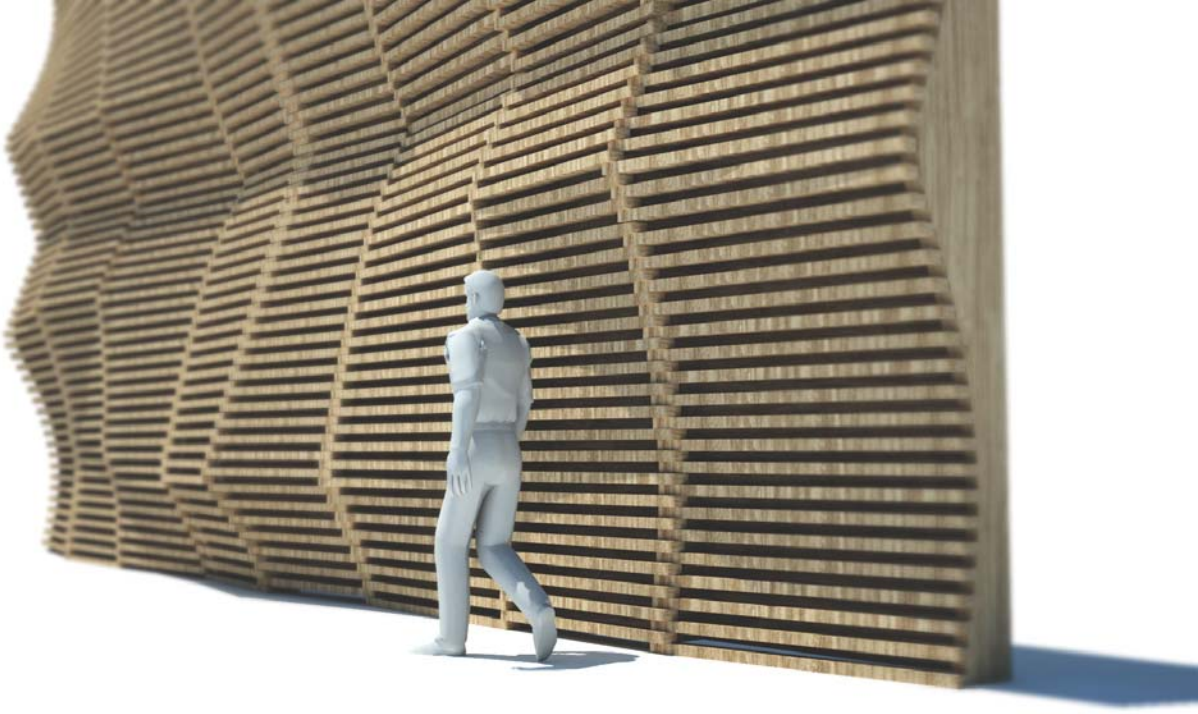
Elevation to East



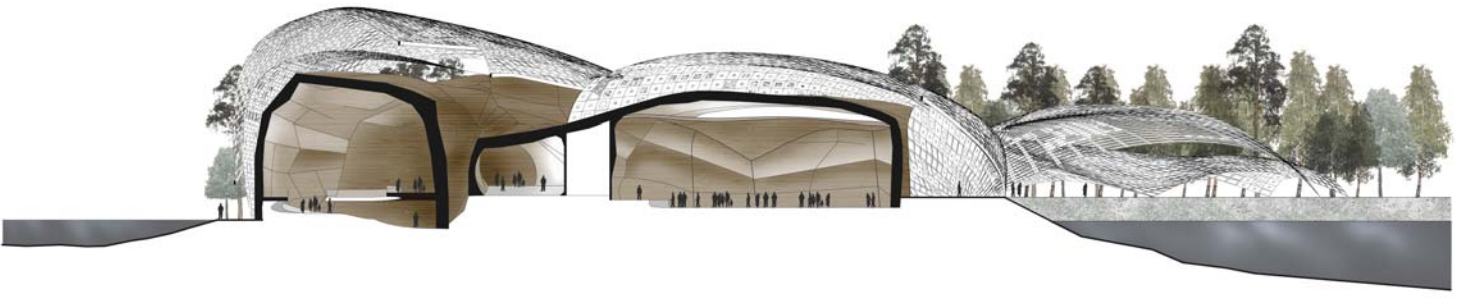
ELEVATIONS 1:500

Elevation to West

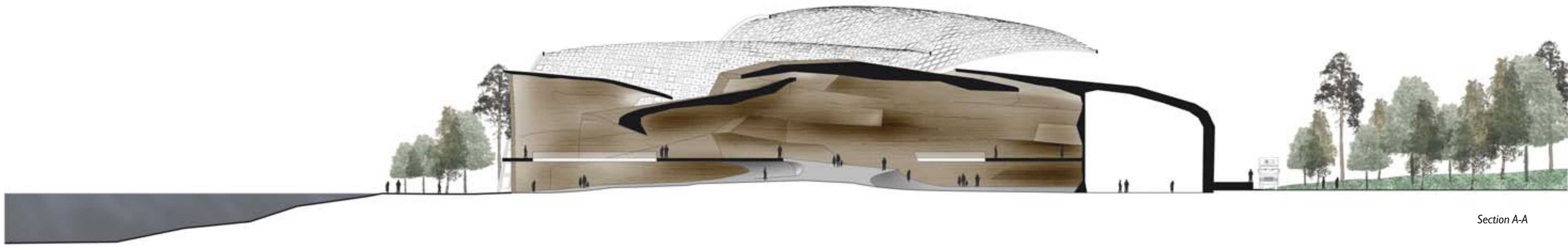




THE PRINCIPLE OF THE CLADDING OF THE WALL STRUCTURE.



Section B-B



Section A-A

SECTIONS 1:500

0 25 50 meters

METHODS FOR MORPHOGENESIS AND ECOLOGY IN ARCHITECTURE - CASE: DESIGNING BOTHNIAN BAY CULTURAL CENTER | 7/8

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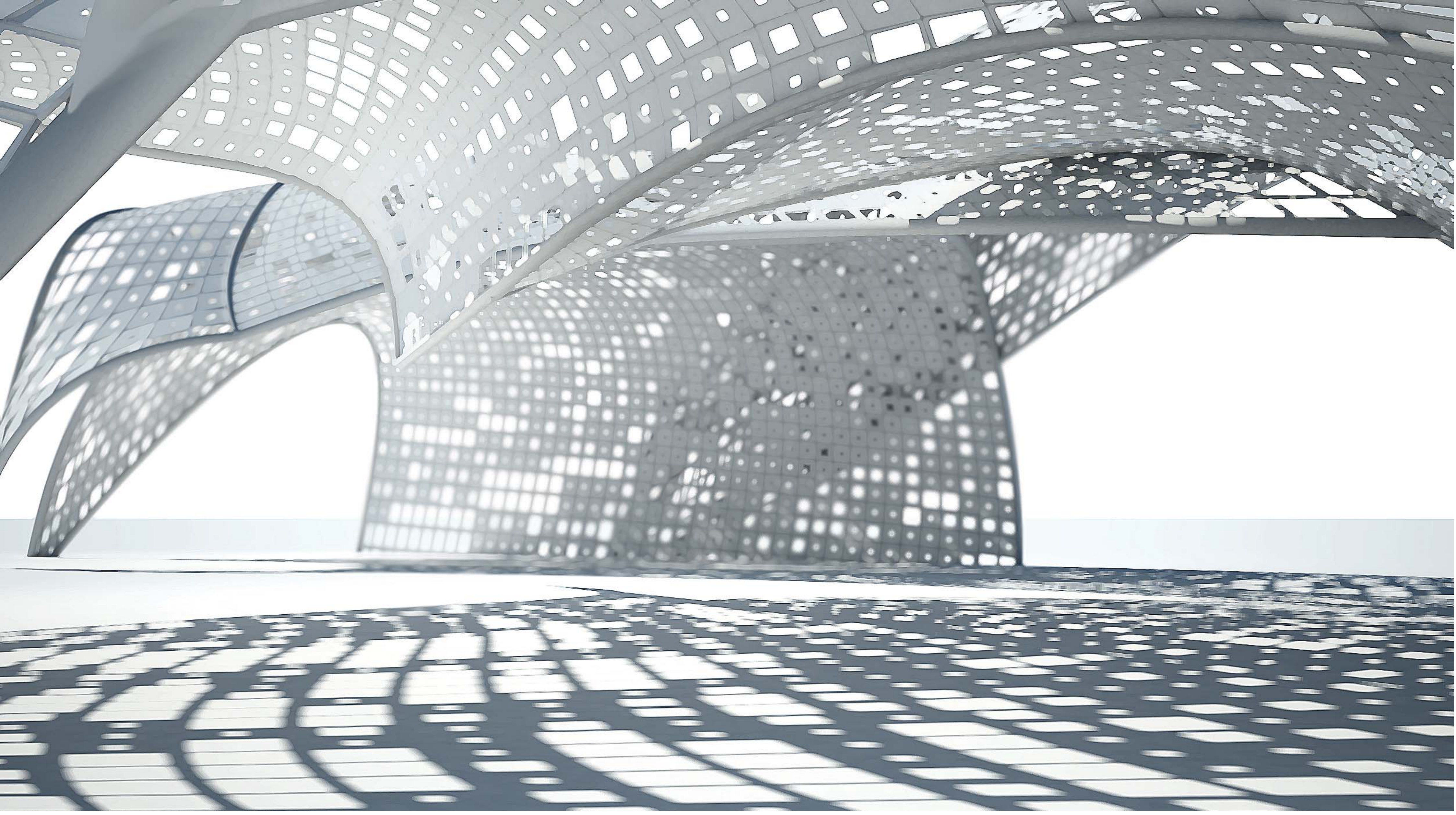
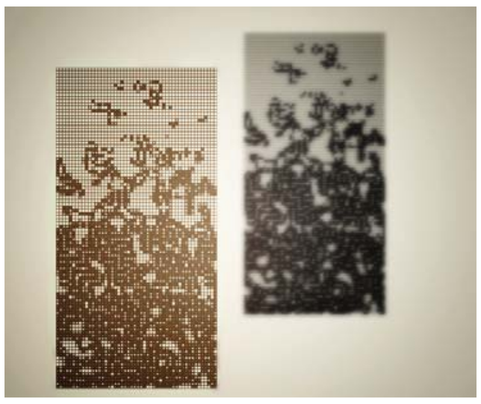
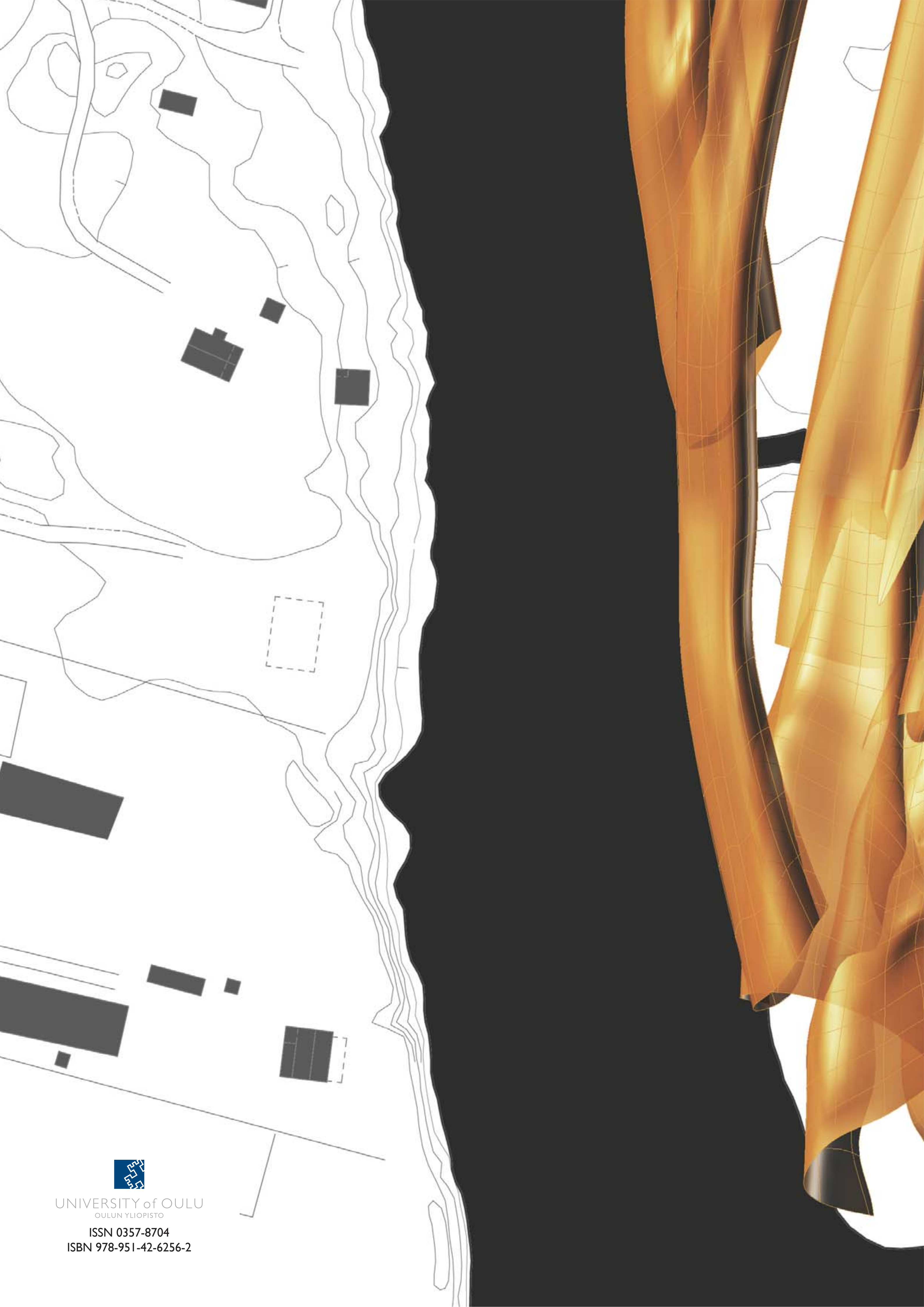


Pictures showing the 3 distinct states of the cellular automata calculations and the emergent shading pattern it creates when mapped as various sized openings on a planar surface.



The pathway towards the building is partially covered by a perforated canopy. The purpose of this canopy is to provide different shading conditions and to gradually shift the environment from being totally natural to being totally man-made. The perforation patterns on the canopy create organic shadows which mimic the shadows cast by the natural foliage of the island. The perforations get smaller towards the entrance of the building, creating a gradient shading along the path. The canopies provide shelter and thus cool down the microclimate that they host.

The distribution of the openings on the canopies are based on cellular automata with dynamically varying rules in relation to a distance parameter. The cellular automata has 3 different states which were then mapped onto the canopies as varying sized openings. The distance is measured to the entrance of the building and farther the cell is located from the entrance the more likely it is not to survive, thus eventually mapping that cell as a large opening on the canopy.



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