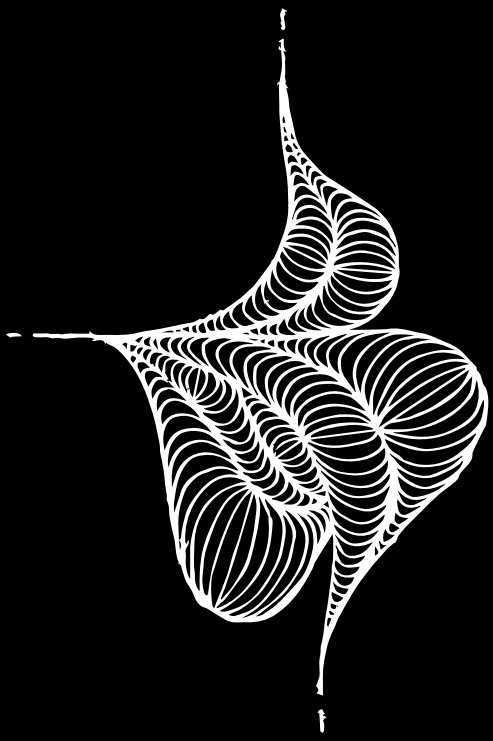

I

Beyond Thermal Comfort

Architecture according to neurophysiology

MSc04 - master thesis by Zakaria Djebbara. Aalborg University

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ABSTRACT

In pursuit of a new and interdisciplinary approach to architecture, the following theoretical framework is the first part, consisting of two, developed for a Master Thesis. This first part aims to establish a list of applicable principles for an architectural project in the second part. To understand the consequences of a space, three existing theories are investigated by way of a neurophysiological approach. The aim is to apprehend architecture through the scope of sensory, specifically thermal sensory, and furthermore establish a theory, consisting, inter alia, of a list of principles.

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I PREFACE

As a young architect student, I find the field of affective architecture very interesting, as my interest has always been scientific explanations. Reading on atmospheres and complexity in general in architecture, I was not too sure about the abstract explanations attached to these respective theories. When Pallasmaa expresses himself about the phenomenal human reaction when experiencing space, almost identical to Zumthor's perception of atmospheres, something is triggered in my mind. I believe there is pattern of architectural pleasure, since their definitions converge. I myself have experienced dynamic architecture multiple times. I realized that when Lacan related the eyes to the mind and argued, human beings are enticed by the idea of a hidden message, solely because of human cognition (Lacan 1998, p. 107). Lots of scientists have argued that multistable and ambiguous art has to do with creating a meaning and hence a cognitive phenomenon. It has also been argued that architectural pleasure coincides with creating meaning, which makes me believe that the experience of ambiguity in architectural space may be related to the cognitive phenomena. There has to be a scientific explanation of how we understand this art of architecture, which is the main reason for my interest in neurology. I want to narrow the scope, as the field of ambiguity and architecture is rather broad, thus I will specifically focus on the body and mind. In other words; I will focus on the actual sense of thermal comfort and the visual representation of the world in the mind, and further introduce a hypothesis which may solve an issue of thermal comfort.

"The poet of the vague can only be the poet of precision!" (Zumthor 2010, p. 30)

II METHODOLOGY OF THEORY

The paper will be separated into three parts; (i) theoretical base for hypothesis, (ii) substantiating hypothesis and (iii) ultimately conclude and form a list of principles. Throughout all the chapters of the paper, there will be subsets, which will both conclude and suggest an architectural aspect of the subject. The main method of writing the paper is Evidence Based Design, as defined by Pawson (2006). The model suggested by Pawson is a meta-analysis for systematic review process with the following protocol:

(i) **Identifying the question**

- When identifying the problem a larger number of questions are asked, and further boiled down to 1-2 core questions. The question(s) should be of both design and theoretical matter, searching for design principles and theoretical relation.

(ii) **Searching for primary studies/Collecting evidence**

- Using electronic libraries and common libraries to find evidence or hypotheses that are related to the core question(s). As much literature as possible.

(iii) **Qualitative appraisal**

- The literature found is reviewed for quality, as the final paper should not be based on unreliable studies, with lower methodologic standards.

(iv) **Extracting the data**

- Reading closely and deeply the studies found, and extracting the points which solve the questions asked. This could be done in various ways, as an interesting point of the studies can occur during result, discussion or even procedure.

(v) **Synthesize the data**

- Extracting the meaning and point of several studies should

be synthesized into a higher meaning and/or lead to creating a new (possibly improved) hypothesis.

(vi) **Dissemination**

- Finally, the paper should advertise findings and conclude, by for instance develop a list of principles.

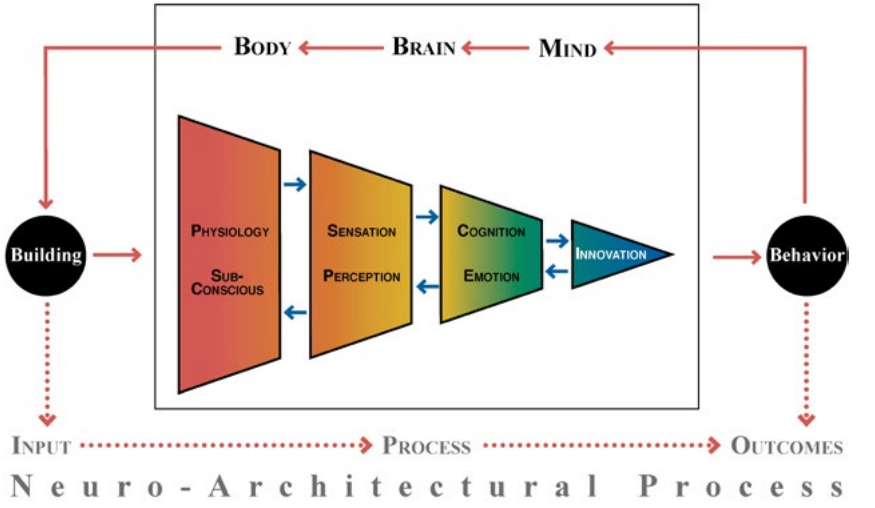
This paper uses this specific method as it is the most suitable for merging neurophysiology, psychology and cognitive science with architecture.

Furthermore, this approach is fairly new, as stated by Edelstein (Neuro-architecture 2015), and can be described as a neuro-architectural process. The process, as described in **process diagram**, ensures an integrated and iterative process, giving weight to scientific research, linking input, response and output.

In using highly precise neuroscientific instrumentation, the user's ability to articulate cognitive, emotional and sensory response to design, is made measureable, and can thus be used to inform the design process. The research made can then be used to develop critical principles advocating the desired experience. In design involving health and care, this process becomes vital, as psycho-physiological impact can reduce harm and advocate healthy environment.

"Psycho-physiological responses are considered in terms of their ability to support the quality of care, as well as the quality of work and creativity" Eve Edelstein (Neuro-architecture 2015)

The scientific research is used to develop design principles, which advocate the conclusion of the research. In similar manner, this paper seeks to use EBD-method to synthesize the data and further disseminate the findings into a list of design principles, which automatically advocates thes cientific research.



Process diagram - A neuro-architectural design process

III INTRODUCTION

"The discrepancy between physical fact and psychic effect [...] is the origin of art"- Josef Albers (Venturi 1966, p. 27)

When reading and collecting architectural theory on ambiguity and multi-stable architecture, it was discovered that many theorists have strong statements about the contradictory and apparent ambiguity occurring in architecture, although the subject is subtly discussed. However most theories discussing ambiguity only considers it according to visual appearance or functionality, in perfect accordance to Pallasmaa (2014, p. 32) when suggesting that the visual sense is the modern dominating sensory. Venturi (1966) dedicates his book, Complexity and Contradiction, to subtly discussing ambiguity and contradictions in architecture and the dynamic experience, while other theorists, such as Koolhaas (Nielsen 2004, p. 52-61), are inspired by the skyscrapers ultimate function of housing unrelated functions in the same architecture. In search of how ambiguity is established or interpreted in architecture, linguistics seem to have played a central role as poets, such as Shakespeare, were the first supreme ambiguists, creating metaphors by words (Empson 1966). However, architecture is merely but a metaphor at all times, depicting what the artist of the architecture has intended to be reflected through experience. 'Metaphor' has been the subject when discussing ambiguity and contradictions in architecture, in terms of functions and form, although metaphor and ambiguity are not exactly the one and same concept. As suggested by Stadler and Kruse (1995), the main difference between ambiguity and metaphor, at least in the case of multistability, a spontaneous reversion of the perception, leading one from one order to another, without increasing the level of order, is an ambiguous perception. However, if the perception changes due to instability and increases the level of order (usually through prior knowledge), it can be grasped as a metaphor:

Spontaneous reversion:	$Order_1$	⟶	*Instability*	⟶	$Order_2$
Evolution:	*Order*	⟶	*Instability*	⟶	*Higher order*

(Stadler and Kruse 1995, p. 6)

Expressive functionalism has been the precursor of expressing functions through form, and disregard metaphors of artistic depiction (Jencks 1988, p. 44). This can best be exemplified by Venturi (1977, p. 88) using the duck as an example of depicting the function. In other words, the signifier, being the form, uses overlapping aspects of the signified, being the content (Jencks 1988, p. 45). The Sydney Opera (**Figure A**), Australia by Utzon, built in 1957-74, has been discussed to be an ambiguous architecture, as the form evokes metaphoric responses, for instance, it is associated with inter alia sea shells from the local coast, waves/splashes from the shore, white sails in the harbor and even turtles making love (Jencks 1988, p. 43). Interestingly, the interpretation of architecture is more elastic than the metaphor of words, so how is that coherent with what Venturi stated? How appropriate are metaphors to the buildings function? Considering the Sydney Opera, it is not possible to perceive the restaurant, the music hall or any other function through the shells; does the form have an erratic signification? Jencks (1988, p. 45) asks similar questions, and discovers that emotions are being heightened as an end in themselves and there is not one converging answer of these metaphors, which ultimately results in greater drama. "[…] the more metaphors, the greater drama, and the more they are slightly suggestive, the greater the mystery" (Jencks 1988, p. 45). There are many examples of metaphoric architecture who are related to their function, such as Eero Saarinen's TWA Building (**Figure B**), Le Corbuiser's Ronchamp Chapel (**Figure C**), and Cesar Pelli's Pacific Design Center (**Figure D**) and so on. For instance the Ronchamp Chapel by Le Corbusier depicts praying hands or the chapeaux of a priest, see figure E. The interpretation is highly influenced by the function and the context of the architecture. However, using the duck example again, there exists architecture that does not need higher cognitive association to grasp. There exists architecture, such as a hotdog stand formed as a hotdog that needs merely to be within the visual perception to understand. So what is the difference here; how is some architecture merely understood when perceived and other need to be further associated with prior experience or personal visual dictionary? What are the processes behind the choice of perception? Under any circumstances, the process of making meaning of words and the process of making meaning of architecture are in many aspects very similar, although architecture is more plastic in interpretation than linguistics. Considering

Figure A - Sydney Opera by Utzon

Figure B - TWA Building by Eero Saarinen

Figure C - Ronchamp Chapel by Le Corbusier

Figure D - Pacific Design Center by Cesar Pelli

symbols used in architecture, Baumberger (2009) have suggested a model using Goodmanian symbol theory to interpret ambiguity in architecture, although such analysis lies beyond the scope of this paper. Ultimately, the metaphoric meaning ascribed to architecture depends on both social and physical analysis. However, such analysis is not necessary to establish metaphoric meaning, but it outputs a proper candidate as prior knowledge is a major influence (Jencks 1988, p. 54).

To investigate ambiguity in general, and understand the core of such phenomenon, which is what Semir Zeki, a neurologist and precursor of neuro-aesthetics, has been doing, one needs to investigate multistable pictures. Ambiguity as defined in the Oxford English Dictionary (2015): "The quality of being open to more than one interpretation" is ambiguous itself. When investigating the spontaneous reversion of ambiguity, such as The Kanizsa cube, illustrated in **Figure E**, it presents the issue of equally valuable interpretations. The cube is either read from left to right and is interpreted to be facing towards the perceiver, or it is read from right to left, viewing the cube from a higher perspective. This is true ambiguity as no solution is more plausible than the other, leaving the brain to treat them equally. This means, as Zeki noticed, the neurological definition of ambiguity is opposite of the one in the Oxford English Dictionary, as ambiguity is a certainty of equally plausible interpretations (Zeki et al. 2006, p. 245). What is interesting to notice in the case of the cube is that the two interpretations are of the same category; both interpretations represent a cube, and therefor imply a simple kind of ambiguity. Escher Stairs, in **Figure F**, is widely known for the ambiguous direction of the stairs. The directions are interpreted equally as the context in parts of the picture is in question. Now, these ambiguous figures capture the core of ambiguity, as they leave out an immense amount of perspective information and can be conceived as explanatory diagrams. However the surrealist Rene Magritte seem to have investigated ambiguity and manages to translate the simple explanatory ambiguity into spatial ambiguity, involving more than diagrammatic lines that excludes depth. For instance, when considering **Human Condition III** by René Magritte, the question of ambiguity becomes part of knowledge and prior experience, as well as context, since the "real" landscape and the painting of the landscape are both two-dimensional, the perception of reality becomes questioned. If observed closely, there emerges a

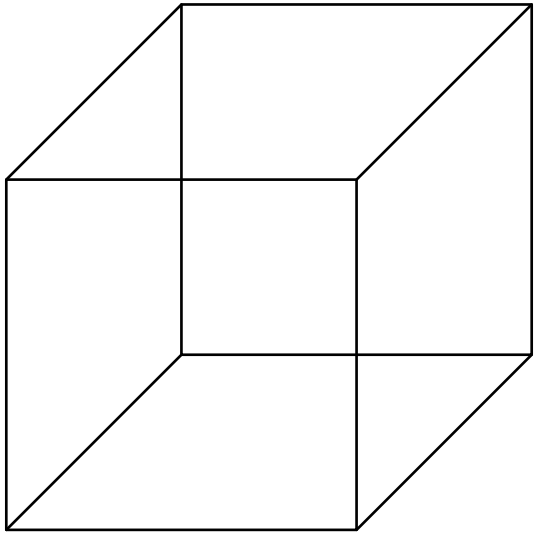


Figure E - The Kanizsa Cube

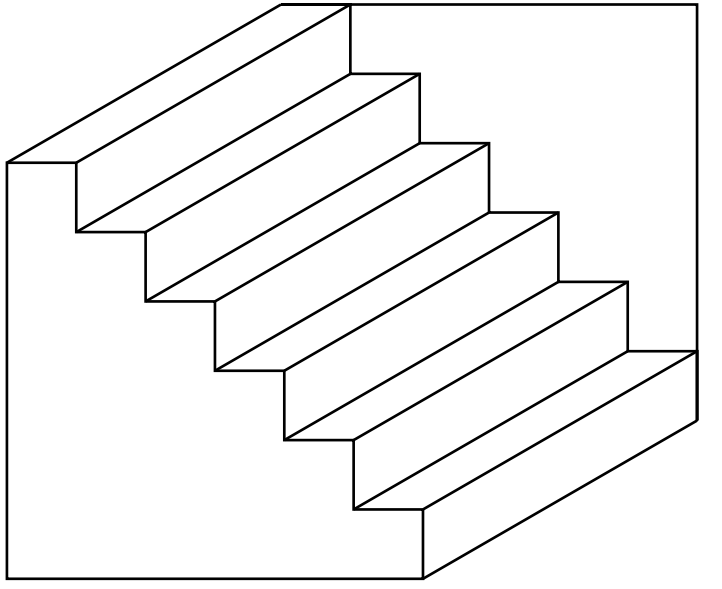


Figure F - MC Escher Stairs

picture frame in the middle of the view. The view could be real or illusory; both interpretations are equally plausible. Magritte's **The Childhood of Icarus** further creates an ambiguity of the inside and outside (Gorlin et al. 2004, p. 105).

Magritte managed to create ambiguity amongst concepts and not merely multistable visual stimuli by ambiguous spaces, although these might be interpreted very similar by the brain. The ambiguous spaces occurs in much modern architecture for instance the **Pavilion de l'Esprit Nouveau** by Le Corbusier, where he strategically removes one wall towards the foliage, creating a scene with the outdoor stretched like a painting across of a two-story opening (Gorlin et al. 2004, p. 106). What seems to be interesting, in ambiguous composition, is not only the fact that it raises basic geometrical questions, but also the translation from a specific view to an architectural space, and how the outside is differently grasped from the inside, and vice versa. The subject of relating the interior to the exterior is not unfamiliar. The interest in the ambiguous and relaxed relation of the two oppositions mainly is how they can create dynamic and attractive articulations which for peculiar reasons evoke a certain sense of consciousness (higher cognitive process). Theorists have argued this subject to be of epistemological implications (Zimmer et al. 1995, p. 106). The living room in **Can Lis** built in 1972 by Utzon has a fluent relation between the inside and the outside, creating an ambiguous environment. The word articulation comes to mind when noticing the three big deep windows with a view of the shore, and plants growing along the building, while a tiny gap in the wall allows light to cast a ray, resulting in a dynamic environment by virtue of both the ambiguous relation of inside and outside and the endorsed ray of light. The indoor is accompanying the outdoor, whilst intertwining within it. Although some of the mentioned metaphoric architecture projects are rather complex, involving social, functional and physical analysis, the main concept they all have together is the fact that they can be interpreted differently, depending on the user/investigator. As presented, metaphor and architecture is a great field which cannot be fitted into the scope of this paper. Thus it has been limited to a certain dichotomy, namely the inside versus the outside. Specifically this dichotomy has been chosen to be investigated as it is a popular subject in architecture, which has led many architects and theorists to investigations and state-

Figure G - Human Condition III by Rene Magritte

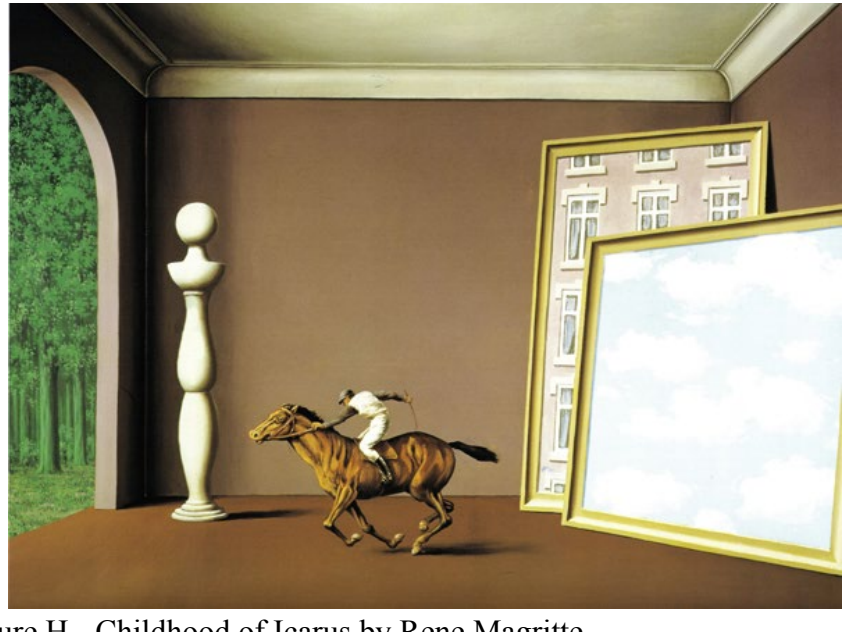


Figure H - Childhood of Icarus by Rene Magritte

Figure I - Pavilion de l'Esprit Nouveau by Le Corbusier

Figure J - Can Lis by Utzon

ments. Interestingly, the very first task for architecture was separating the outside from the inside, which is still a current problem, considering energy frames and global sustainability. As Arnheim (1997, p. 92) pointed out perfectly: "Perceptually and practically, the worlds of outside and inside are mutually exclusive". It is impossible to be in both worlds at once, physically, yet these two worlds have nothing more than a thin door to separate. The architecture from outside is always in context, and it is the context that describes what the architecture is; whether it is small, or harmonious or out of step. From outside one is able to compare the architecture. The interior on the other hand is a world of its own. Even though when from the inside one perceives the outside, one does not acknowledge another space, but rather grasps it as a part of the interior. From the inside, it is only possible to compare through memory or anticipation (Arnheim 1997, p. 94).

The many questions have been boiled down to a statement of problem which has been formulated as following:

There have been multiple respective theories who have alleged that the perception of ambiguity is related to consciousness. Does ambiguous meaning, and composition, between the relations of inside and outside, in architecture evoke certain senses in human beings, resulting in comfort? Is it possible to establish a list of principles or guidelines through neurophysiological approach, to ensure the evoked senses, in a design process? This thesis aims to examine theories in order to create a hypothesis, defining the levels of ambiguity, how humans interpret these and how the interpretation is linked to consciousness and pleasure, and further investigate how these can be included in the design process. The goal is to investigate how ambiguity can renew the subjects of comfort and pleasure in architecture, and further introduce a new aspect of architecture and sensory.

IV ULTIMATE AIM

The growing issue of building sustainable and the tight energy frames limiting the architectural experiences needs a review in order to not create competition between the two different processes, but rather reach convergence, which is believed that a neurophysiological approach might evidence. The paper does not necessarily provide an answer to what neurophysiology and architecture, including thermal comfort, might turn out to be, but rather the paper investigates the possibilities of adding information or aspects to thermal comfort through neurophysiology. Future work within these areas will be suggested during the paper.

The ultimate aim is to use neurophysiology to influence the design process and to present a new aspect of architecture; the convergence between the former and the latter. Furthermore, while acquiring knowledge of different fields in neurophysiology there will be presented an architectural aspect of the chapters in the form of a subset, which allow a continuous suggesting of design principles. The paper will be limited to only investigate the neurophysiological dichotomy of inside and outside in terms of visual stimuli and thermal comfort. However, the paper will introduce, when possible, the possibilities of broader cross-activations than thermal comfort and visual stimuli.

A final aim is to establish the list of principles as experimental variables, allowing the variable to be form-decisive.

Part I

Reality versus Actuality

Within Part I certain neurophysiological and psychological processes will be reviewed, further investigated and ultimately used to form a hypothesis related to architecture.

1.1 LAWS OF GESTALT

"The whole is greater than the sum of its parts" - Koffka (Koffka 1935)

Before introducing the ambiguity in architecture, certain laws of perception, which are widely acknowledged, is the psychology of the laws of Gestalt. These laws were first introduced by Max Wertheimer, Kurt Koffka and Wolfgang Köhler (Lauring, J.O., 2014, p. 19), and were a result after a certain amount of experiments of perceptual organization. The main idea of Gestalt theory is the simplification of perception and how organization occurs. Gestalt psychology takes origin in believing that the perceptual organization, order and form are the outcome of the subject's commitment to the visual input, meaning the receiver is not passive, but rather an active receiver. This implies that the receiver actively is striving to create meaning of the perceived. They also regard the perceptual experience to be related to the physiological processes through isomorphic relations. Created by the stimuli, electric fields would occur and cooperate within itself throughout the brain, and finally converge at minimum energy, was their explication of how perception was simplified, which is in contradiction with standard neurophysiology (Lauring, J.O., 2014, p. 20).

The Gestalt laws are still valid in the theory of perception. When examining e.g. a painting, human beings perceive the whole before the details, which is usually described as the whole is greater than the sum of its parts. The laws are quite simple and well-known. The first law is *Similarity*. As seen in **figure 1.0** human beings tend to group the similar shapes, therefor more are likely to say the shapes are organized horizontally than vertically. Often one notices the dissimilar solely because it does not fit in any group, which is method to create focus. This is named anomaly. The second law is *Continuation*. One tends to continue the natural flow of a line. In **figure 1.1**, instead of breaking it down to 4 segments, one tends to see 2 continuities crossing. There is no use in breaking the segments into 4 separate lines, when the continuity creates meaning. The next law is the law of *Closure*. If what is perceived contains enough information, one tends to fill in the missing information and closure occurs. In **figure 1.2** one perceives a circle and a triangle, albeit the missing information, because of the

familiar shapes. One the most interesting laws is the law of *Prägnanz*, which is also known as *Simplicity*. One tends to see the simple shape rather than the segmented parts. In **figure 1.3** one perceives 5 circles rather than the solitary colored segments. Another law is the law of *Proximity*, which is when shapes are organized closer than surrounding shapes, they are perceived as groups. Or, as in **figure 1.4**, iterations of two lines are perceived rather than multiple individual lines. Finally the law of *Figure/Ground*, which is when either a shape is perceived because of the background or the background, is perceived because of the shape. This is a typical case of ambiguity in 2D, exemplified by the Rubin Vase in **figure 1.5**. Either there is two faces looking into each other, or there is a vase (Interaction Design, n.d.). These were the general Gestalt laws, but Gestalt contains more laws than mentioned, though the mentioned will be used later to make a point in the research which is why one must be aware of these.

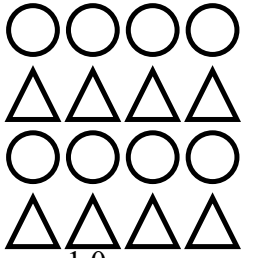


Figure 1.0

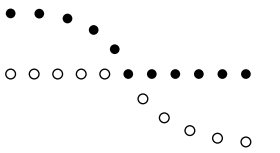


Figure 1.1

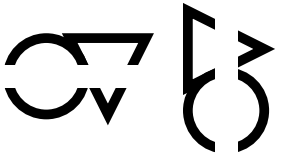


Figure 1.2

Figure 1.3

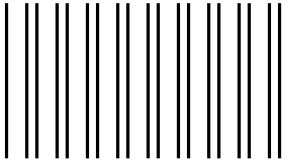


Figure 1.4

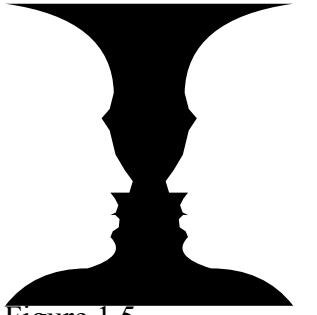


Figure 1.5

1.2 HOMEOSTASIS

1.2.0 - ESTABLISHMENT

In order to understand the very first separation of the inside and the outside, one is forced to go as far back as when the very first bacterial cells owned the world. It is here the arguments for creating a conscious mind has a starting point, which is related to the dichotomy of interior and exterior. Damasio (2012) has investigated how the very first conscious mind was constructed and how the nonconscious single cell survived and did undergo decisions, which is required when adapting to environment, without a conscious mind. In fact, the conscious and nonconscious process does not have to coexist to maintain life, as the process of the nonconscious mind can maintain life without a conscious companion (Damasio 2012, p. 31). As aforementioned, to understand the construction of the conscious mind, one must grasp how the nonconscious mind survived and adapted to the environment. The first single cell was superior to the bacteria because the entire DNA was collected in the nucleus; the nucleus being the command center. The single cell also had cytoplasm which is where the transformation from fuel into energy took place by control of organelles as mitochondria. The exciting part of this single cell in architectural retrospect is that the cells have a skin. The boundary, which is called the cell membrane, separates the survival process of the cell from the exterior, the environment. The knowledge on single cells is paramount to understand the human body, as the human body is nothing more than billions of cells put together in the same strategy. The billions of cells would constitute tissues to form organs and connecting different organs to form systems, and finally as a result of the cooperation of the cells, the neuron was created. There is a difference between the multicellular organisms and the single cells. The single cells do not cooperate in a complex society, which is why the tasks must be performed alone. Now, the multicellular organisms have structured complex societies where each cell is specialized to perform at a particular field, although the single cell organism has the same components as the multicellular organism, such as membrane, cytoplasm and nucleus, the multicellular organism share the fact that the nucleus commands the components to stay alive for

as long as the genes allows with the single cell organisms. In other words, the nucleus has power of willing to live for as long as the genes allow it. The willing precedes the knowledge and deliberation of life conditions. The nucleus and the cytoplasm interact and rearrange the inside of the cell in moment-to-moment changes in the environment with an extraordinary precision, which is prescribed genetically. The will, as Damasio (Damasio 2012) refers to the determination of survival, is paramount to the construction of the conscious mind because the determination of survival, which allows the cell to rearrange instantly and adapt to changes in the environment, are decided by nonconscious cells. Considering the adaption, one might question how a nonconscious cell has the ability to make a decision. The decision is quite simple for the cell, as the nucleus reacts through prescribed genetic information, though there is a profound explanation which will be presented. Another question is how can the cells pass the nonconscious will to the conscious mind? This is where the neuron is presented.

1.2.1 - NEURONS

There are approximately 100 billion of neurons sandwiched among a larger number of glial cells. The neurons contain a nucleus, cytoplasm, and membrane and so on, just as any body cell; furthermore it also consists of axons and dendrites. The neuron operates through the axons by sending an electrical charge, created through the passage of ions, namely by potassium and sodium, and receives messages from other neurons through the dendrites (Mallgrave 2011, p. 126; Damasio 2012, p. 38). The dendrites and axons are tube-like prolongations that, when considering the primitive cells, was only used temporarily, but later became permanent, hence evolution, and these tube-like parts of neurons can be between only a few centimeters to a couple of feet long. The difference of the neuron and body cells is their function to produce electrochemical signals, which is capable of change the state of other cells in the body. As the neurons influence other neurons, endocrine cells and muscle fibers, when changing the state of other cells it regulates the behavior and that, in the end, contributes to creating the mind. In short, the transmission from the axon through the brain stem or spinal cord to the tip of a limb is exactly what causes the muscle to act. But the neuron

is not critical for survival, as one might observe the plants, which does not have neurons. The neurons existence is for the benefit of other cells in the body. The purpose of the brain the neurons constitute is to assist the management of life, which they do by receiving signals from body cells to assist them by either releasing chemical molecules resulting in changes in body cells, or by exciting muscle fibers by producing current, which results in movements. In the end the neurons will be representing the body state of the part they belong to, while always being connected to the body. When reflecting the structure of collaboration between the cells in the body and how the mind works, one can start to see the relation of creating a mind and the particular cell system; when the body interacts with the environment, the brain stores the changes and reacts by creating a representation within the brain. A major breakthrough in grasping the neurons was made by Donald O. Hebb, whom created a principle that when two neurons fire together, the synapse is modified through growth and ultimately end up wired together. This result in great efficiency as the brain tends to group neurons into loops or maps that oscillate in synchronized rhythms. The neuronal circuits in the brain cause the representation. As Mallgrave (2011, p. 128) quotes Buszáki: "Representation of external reality is [therefore] a continual adjustment of the brain's self-generated patterns by outside influences, a process called 'experience' by psychologists". In a way, one can argue that humans are nothing more than an organism determined to survive by constructing virtual models of the world, while continuously adapting by changing the inside. Here, the first task of architecture is beginning to make sense, namely the division of inside and outside.

1.2.2 - MAINTAINING LIFE THROUGH HOMEOSTASIS

Any changes that needs to be made, e.g. if exposed to cold the body will firstly shiver and try to maintain the normal body heat, and if that is not sufficient, secondly it will decrease heat loss by decreasing blood flow to minimize cooling, and in the end, the body will minimize the metabolism to decrease the need for fresh blood flow and oxygen supply, is therefore dependent of the ability of the cells to procure nutrition, consuming and digesting it to ensure the power to the body (Damasio 2012, p. 41; Cold Weather Health Risk 2015). The energy

referred to here is better known as ATP in modern biology. When the body makes changes the ATP is paramount. Countless parameters needs to be changed to maintain life, parameters as amount of oxygen and CO2, which can vary only in a narrow range, the acidity of the bath in molecules of travel from cell to cell and also the temperature of the body. This is just to name a few parameters. When these parameters exceed the narrow acceptable range, one feels discomfort. The mental state the nonconscious process put the conscious mind in when disobeying the fundamental rules of life regulations, is a request to find a reasonable solution for a situation the nonconscious device cannot handle anymore. By all means, the range the parameters need to be in must be held. The process of keeping a balanced state is called homeostasis. One might question, how did was this process of homeostasis ever implanted in these cells. To grasp the answer, one must beware of the properties of molecules, as they have the ability to either attract, or reject, another molecule. Reviewing the genes in the DNA, where these molecules interact, they can combine constructively and destructively as a result when either attracted or rejected. Here, the issue of value is reached. As stated by Damasio: "Gene instructions led to the construction of devices capable of executing what, in complex organisms like us, came to flourish as emotions, in the broad sense of the term" (Damasio 2012, p. 44). What one needs to notice is that all these parameters the body needs to keep in a certain range, are all controlled and organized without a conscious mind, meaning that the nonconscious process is in control. This raises the question of, if the nonconscious process is in control of the body parameters keeping them in a certain range, what exactly does the conscious mind have to be in charge of, and do they ever interact? Also, correcting the balance after they begin is not a reasonable solution. There has to be some kind of anticipation. Damasio suggests that to grasp how the nonconscious process interacts with the conscious brain, one must grasp how human beings value, and why.

1.2.3 - APPRECIATION AND USEFULNESS

When presenting the topic of value, one must not mistake it for economic value directly, though it is related to it in a broad sense. Why we value objects, and why we calculate loss and gains, is in fact related to homeostasis, our survival.

There is an uneven distribution of items and to maintain life, one must acknowledge the distribution to do so. Considering how the cells started to create a system of value, the rewarding system is introduced. Molecules as dopamine, norepinephrine, serotonin, cortisol and oxytocin are produced to pleasure the organism, which is a perfect procedure to value the environment through the inside. But what exactly prompts the nuclei, which in this case is the neurons situated below the cerebral cortex in the brain stem, to release the molecules? Damasio (Damasio 2012, p. 47) suggests that the valuation is tied to the need to survive, which is how one establishes the values in social and cultural life. This connection explains why the brain circuitry is so dedicated to prediction and detection, namely so maintain life. Natural selection must have perfected the process of homeostasis, since the modern human body can maintain these narrow ranges quite well. As Damasio concludes: "It is reasonable to conclude that the primitive of organism value is inscribed in the configurations of physiological parameters". Hereafter Damasio establishes two conditions of how one attributes values to object and activities.

First, maintaining living tissue within the ranges of homeostasis suitable to context. Second, the regulations required for the process to operate within the range, associated with well-being in the current context. Whenever the chemicals representing the correction from homeostasis traverse through the brain, it allows the nonconscious brain to detect and measure and therefor act as a sensor. At the same time, the measured departures allow other devices to command corrections and to promote a paramount feature, namely the incentive and disincentive, which are the basis of prediction (Damasio 2012, p. 49). In the developed mind, which is qualified to map internal states, the parameters to maintain homeostasis corresponds to the conscious process of experiencing pleasure and pain. These experiences are essentials for survival, as pleasure means continuing the process with no change whatsoever, but pain means a change in various processes. Even certain organisms without a brain have developed an important ability when experiencing pain above a certain level, namely movement. Being able to sense the interior and the surroundings, a policy was developed, which is called response policy, a set of simple rules to make the decision to move. Now, many senses are in play when sensing the exteroception, which is the surroundings, senses as smell, taste, touch, hearing, vibrations and seeing are all included in making the decision. But

to use these senses most effectively, guidelines must be employed. Of course, the guideline until this point is quite simple; if this is present, then do that (Damasio 2012, p. 51). It is not yet an effective guideline, which is why an incentive is developed, for, in certain circumstances, to favor some responses over others. The mechanism measuring the degree of need is paramount for the experiences of pain and pleasure, in fact, Damasio suggests that the incentive mechanism is necessary to achieve guidance of behavior, which is made through the rewarding system of pain and pleasure. Rewarding with pleasure is a measurement of need, which is where the mechanism of incentive becomes exceptional. Before being able to measure the needs, the incentive mechanism needs three information, given through the senses, name (I) the current state, (II) the desired state and (III) a comparison, to either confirm or invalidate the changes. To speed up the process certain molecules were involved; incentive molecules, which is why incentive molecules process configurations that are associated with pleasure. In brief, the incentive mechanism rewards the body if physically improving survival situation, which in architectural terms means that if the climate inside is preferable for the homeostasis process, the body will be rewarded. As evolving from being a cell, other drives to inform the conscious mind about the homeostasis range, was formed, such as motivations and emotions. Being able to predict certain situations, to value differently in relation to homeostasis and adapt to surroundings through information from senses are basic processes of humans. One might question, how is these processes connected to consciousness and further to architecture? So far, the relation to architecture seems a bit far yet, but relating consciousness with e.g. rewarding system, ability to value and react on surroundings is to come.

1.2.4 - CONSCIOUS MIND

It is how the survival translates the rewarding system through the conscious mind that is interesting for an architect; how the autonomous systems are expressed through emotions and feelings. The body state is expressed through emotions, which explains why feelings may serve as a scale of how well one manages life. But what is quite surprising, is that there is no need of conscious mind and conscious feelings to change the behavior, as the configuration of chemical

parameters already influenced non-minded organisms (Damasio 2012, p. 56), which means that a change in behavior can occur without a conscious feeling or emotions. This is an important note, as it will have an influence on an argument in latter process. Damasio gives an example of a nematode, the C. elegans. It has 302 neurons placed as a chain of ganglia. If there is food, it will feast alone, but if there is a threat in its surroundings, they will come in groups. They do not know exactly why or what they are doing, but as simple a brain as theirs, it merely use signals from the environment and change behavior. Damasio suggests that the behavior is quite complex, if one was not aware of the C. elegans is a worm, and not a complex creature one would suggest evidence of interindividual cooperation.

The implications of ideal homeostatic states are that the advantage of consciousness derives from improving life in even more complex surroundings. This makes the human-being, the only known conscious creature, superior to any other creature. Damasio (Damasio 2012, p. 57) argues that brains that produced images had more detailed conditions of inside and outside, leading the organism to generate more effective and differentiated responses. Here Damasio is implying the ability of seeing and memorizing. At a certain point, when humans developed the conscious mind, the simple regulations to survive were not a challenge. But as the mind grew to progressively more deliberated regulations, effected by personhood, the mind seek certain ranges of well-being. "If brains prevailed in evolution because they offered a larger compass of life regulation, the brain systems that led to conscious minds prevailed because they offered the widest possibilities of adaption and survival with the sort of regulations capable of maintaining and expanding well-being" (Damasio 2012, p. 59). The regulations to be made with the conscious mind are even broader than the non-conscious mind, leading to ever expanding the well-being of the homeostasis.

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Whatever the conditions of maintaining life was, in prehistoric era, the cells managed through by means of homeostatic balance. Keeping the acceptable ranges through autonomic systems, not requiring a conscious mind, leads to the acknowledgement of the non-conscious mind being the root for the conscious mind. The cells were developed to manage ever complex inner systems and ever complex surroundings with even more elaborate brains. The mere differentiation of what is inside and outside, of the elaborate bodies, is a paramount ability to both survive and creating the mind one appreciate today, meaning the ability to both grasp the conditions of outside the body and inside the body while still making decisions. Damasio argued that the unconscious mind rewards the conscious mind be releasing pleasure through the rewarding system, which means there is a clear connection between emotions and feelings.

Being able to value in relation to maintenance of living tissue suitable for the current context, raises an interesting question about the relation of inside and outside in climatic terms. This implies that the mind is an active measurement tool, keeping up with the dynamic changes of climate in order to regulate the processes to operate within the homeostatic range, associated with well-being. As human beings are known to be conscious, it makes the human highly superior in maintaining life, resulting in extending the well-being to various extents, and if so, one might suggest art as being partly the extension of well-being. Architecture as a visual perception and how the perception is perceived in the mind might be a main issue of experiencing architecture, as it might demonstrate how the mind unravels possible issues caused by e.g. equally plausible interpretation or memory in relation to rewarding system.

1.2.5 - SURVIVAL MECHANISMS

Understanding the importance of differentiating between inside and outside, makes on question how the different species accomplish to reestablish any imbalance in the homeostatic equilibrium, considering solely the thermal environment, as the statement of problem limits the research paper so. The ocean, for instance, has a more stable thermal environment than the land. Species living in the ocean do not experience big fluctuations in thermal conditions, compared to the species living on land; there is a change in thermal climate when it is night or day, when it is winter or any other season, when the wind blows, when it rains and so on. In order for the species to move out of the ocean and on to land, the "migrating" organisms were to develop thermal strategies to en-

sure survival regardless of bigger fluctuation of climatic extremes (Heschong 1979, p. 1). The living organisms have different strategies in order to maintain the balance of homeostasis. The plants, for instance, drop off their leaves to ensure a reduced exposure to temperature extremes, whereas some animals choose to hibernate. Considering human beings, who has developed a system to regulate the internal body temperature through metabolism, has a heating technique involving vibration of muscles, while by controlling how much blood flowing to the skin from the inner body heat, the heat can easily escape and cause cooling (Heschong 1979, p. 4). There are many strategies, but interesting strategy in this context must be the ability to migrate within buildings.

It is not all animals that have the ability to build a nest, though those who have this ability are considered to choose the best microclimate in order to survive. When building a nest, there is complete transformation of the environment. As pointed out by Heschong (1979, p. 8), there is at least created 6 new microclimates when building a squared house. Assuming one is building on northern hemisphere; the north side will be in shade most of the time, while the south side will be bathing in sun. The east side will have morning sun with possibly little to no wind, while the west side may have more wind and evening sun. On the roof it is more cool and exposed to sun when possible, and finally there is the inside, which is sheltered from rain, sun, wind and so on. When considering architecture, for instance in Tunisia, the two-story house with a central courtyard with colonnades along the side, operates in a fashion allowing the users in the day time to have a cool interior caused by the thermal mass, while in the night they move out to the open sky.

An important aspect of this subject is how the nervous system is attuned to notice, and when. Heschong suggests that when the difference of temperature is not too great, the body uses metabolic strategy in order to adapt to the new environment, and thus the thermal stimulus is no longer noticeable. Heschong gives an example of a subject walking into a warm room and noticing at once the warm air, though within few minutes, the metabolic strategy strikes and the subject feels normal in the room; not being able to feel the thermal stimulus any longer that is. This substantiates the suggestion that the nervous system is attuned to notice changes and not steady states in the environment (Heschong 1979, p. 19).

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Being exposed to the natural context, there are ever changing environments the human beings have to adapt to, which is accomplished through several strategies. The ability to use senses for information about the space and the thermal conditions seems rather blurry, as the senses used to experience thermal conditions is mainly the sense of touch, which is related to tactility, and yet, the senses are not experienced in isolation, but rather as a bag of information delivered to the conscious mind.

- Adaptive behavior occurs when the homeostatic range is threat ened, and in order to reestablish balance, different strategies are accomplished depending on whether cooling or heating.

- Senses and the nervous system are interested in changes in the environment to ensure a healthy balance of homeostasis.

Before suggesting a solution for the relation between consciousness, art and senses, questions about perception are to be answered, e.g. does all senses have a certain effect on the well-being? Assuming that architecture is felt through all senses, then how do all these apply to our emotions? How does the conscious mind operate in relation to memory? What happens when experiencing the extremes of the thermal conditions occurring on land? Questions like these, will be answered in later chapter, as before being able to give a proper answer, one must grasp how subjectivity relates itself to the world through visual percepts.

1.3 INTRODUCTION TO BRAIN ANATOMY AND MICRO-CONSCIOUSNESS

Grasping that ambiguity is paramount to dynamic architectural forms, one is lead to further ask how to create ambiguity in mind, and how does what one perceives make sense. In other words, how does one make meaning of the perception, and how is that related to architecture? Architecture is not experienced through only visual perception, but to take on this subject, it seems rather logical to start by grasping the processes of visual perception and making meaning, before further investigating the emotions experienced by all senses, and finally how all this is related to thermal comfort. Another classical issue is the issue of actuality and reality; is what the mind represents of the world, the real world, or merely ideas of information received through sense? In order to understand that multistability is paramount for creating meaning and making sense of the world and that the senses may affect the thermal comfort, a quite short introduction to the anatomy of the brain is presented, as the information advocate the understanding.

1.3.0 - VISUAL CORTEX

The concept of nodes and essential nodes created by Zeki and Bartels (1999) explains the system which the visual perception undergoes in order to make meaning. The retina receives light and stimulates the retinal nerves and further passes through the lateral geniculate nucleus (**figure 1.6**), or LGN, which is a part of the thalamus. The LGN is made of six layers of two types of cells that have the task to sort the bits of the stimuli. The cells focusing on processing fast-moving stimuli are called M cells, while the other type of cells, focusing on slower-moving stimuli are called P cells. The LGN enhances and suppresses the character of the retinal input, meaning that not only the eye is selective in assimilation and processing data, but also the LGN is involved. This means the pathway of the retinal nerves is firstly abstracted by both the retina and the LGN before arriving to the occipital lobe where the nerve translates the input to signals to the primary visual cortex named V1 (Mallgrave 2011, p. 140). Here signals belonging to different attributes within V1 will be distributed to compartments with each its specialty. In other words, V1 receives the data and

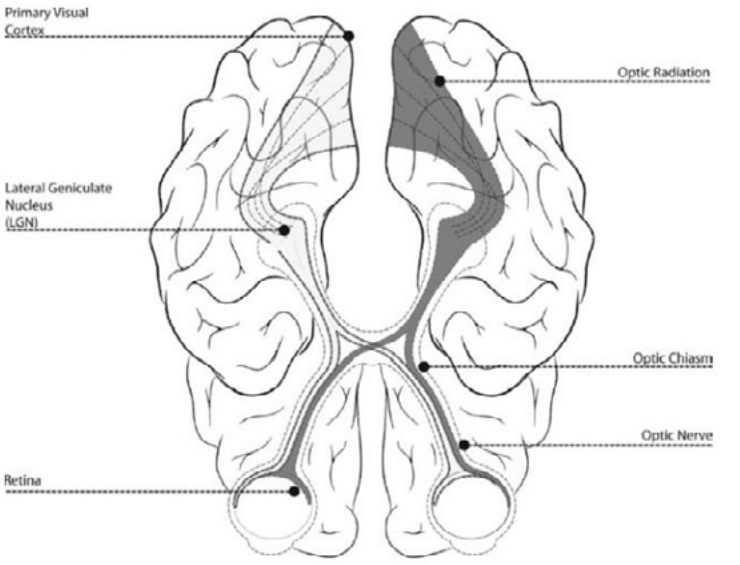

Figure 1.6 - Horizontal section of the brain

sorts the impulses by type and then sends the complex vital information further to the next visual area (Zeki 2006, p.246; Mallgrave 2011, p. 141-142).The next visual area surrounding V1, named V2, is where the input coming from the specialized compartments in V1, is adjoined, and yet another visual area is surrounding V2. The reciprocal connection continues among V3, V3A, V4 and V5 where all of these are specialized visual areas that receive input from the previous visual areas, namely V1 and V2. Although, as shall be argued in this paper, all connections are reciprocal, providing a feedforward signal. Where the bits of information will be sent to depend on the selective cells, as each visual area is sensitive to certain percepts, e.g. the neurons in V3 processes shapes, orientation of lines in motion, while some neurons only respond to certain type of lines, e.g. horizontal lines. In V4 the neurons respond to colors, while some neurons only respond to certain colors, e.g. red., the V4 furthermore also responds to angled lines. The area V4 is anatomically located in the fusiform gyrus. The area V5, which is anatomically placed outside the occipital lobe, processes stimuli related to motion.

This is briefly the setup in the visual cortex. One must notice that even with this many visual areas they are all reciprocally connected to V1 and V2. The pathway of the visual perception includes memory and other areas of the

brain, such as temporal lobes (form, color, recognition of object), parietal lobes (space, motion, depth) and frontal cortices and more, and so does other senses. Zeki introduces the word node (Zeki 2006, p. 246), by which he means a stage in the path, e.g. area V4 or area V5, or even the specialized compartments that feed V4 and V5. Another word Zeki introduces is an essential node (Zeki 2006, p. 247), by which he means an activity becomes perceptually explicit, resulting in no further processing. Any node can become an essential node by one condition; there is no further processing because the activity has become a perceptual site. A conscious correlate also makes a node an essential node. Zeki introduces the term micro-consciousness, by which he means a conscious correlate which is the activity in an essential node. In summarizing, the visual consciousness involves many micro-consciousnesses that are both distributed in time and space. Micro-consciousness is distributed in space because the locations of conscious correlate are spatially distinct, as well as it is distributed in time, because different areas take different time to complete. For instance, location is perceived before color, which is perceived before form and motion. It may take up to 80 milliseconds before reaching a micro-consciousness, meaning that the world visually perceived is about 80ms late.

To further grasp the meaning of an essential node, Zeki suggest using area V4 as an example. This is the area where color is processed, and also perceived, generating a micro-consciousness as a correlate of activity. It is implicit that the nodes from the areas V1 and V2 are not essential nodes, as the bits of information are further processed in V4, but they can become essential nodes in two conditions.

(i) When activity in V1 and V2 leads one to become consciously aware of the fact that the dominant wavelength has changed, as when a scene is viewed in two different illuminants. This is a consequence, as Zeki puts it: *"[...] of the fact that most of their chromatic cells are concerned with wavelength composition and seem to lack the machinery for long—range interactions that generate colors"* (Zeki 2006, p.248).

(ii) When area V4 is damaged, it leads to a perceptual state by activity in as early as V1 and V2. This is characterized by not being able to construct the constancy of colors. In other words, being cortically blind means being

achromatopsic. One can only detect the strength of light, resulting in shadows, but no color can be ascribed to the scenery.

Furthermore, studies in area V2 and V3 show they are involved in object recognition, and V2 possibly being responsible for conversion of short-term object memory to long-term object memory. The conversions seem to happen in layer 6 of V2 (Lopez-Aranda et al. 2009). The number of layer ascribed reveal the depth of the brain, meaning layer 6 is deeper in the brain than layer 1. This information becomes vital in order to grasp how one can ascribe meaning to objects. It is widely accepted that when experiencing architecture it involves emotions and therefore the limbic system. A short introduction to the system seems to be inevitable.

1.3.1 - LIMBIC SYSTEM - HYPOTHALAMUS

Within this paper, the main focus will be pointed at the regulation of temperature, regulation of emotional responses and storing of memory. There is no absolute agreement on the structures occurring in the limbic system yet, therefor there will only be introduced structures, which have been known for a certain amount of time and are widely accepted. One the most important parts of the limbic system involved with mediation of endocrine, autonomic and behavioral functions is the hypothalamus. (i) It regulates and controls the release of 8 major hormones by the hypophysis. It is furthermore involved in (ii) regulating temperature, (iii) control of water and food intake, (iv) sexual behavior, (v) controlling the daily cycles in physiological state and behavior and finally (vi) the regulation of emotional responses. The hypothalamus is situated at the center of the limbic system and functions as a cross of pathways, which can be seen on **figure 1.7**. It is mainly subdivided into four parts; (i) supraoptic zone, (ii) tuberal zone, (iii) mammillary zone and preoptic zone (**figure 1.8**). The preoptic zone will be introduced for itself. Within the supraoptic region, there are a number of nuclei; the paraventricular and supraoptic being the most prominent (Neuroanatomy 2015). It is within the cells of these nuclei that the release of certain hormones becomes paramount for emotions. The cells secrete vasopressin (ADH), oxytocin and corticotropin releasing hormone (CRH). The ADH and oxytocin will be lead

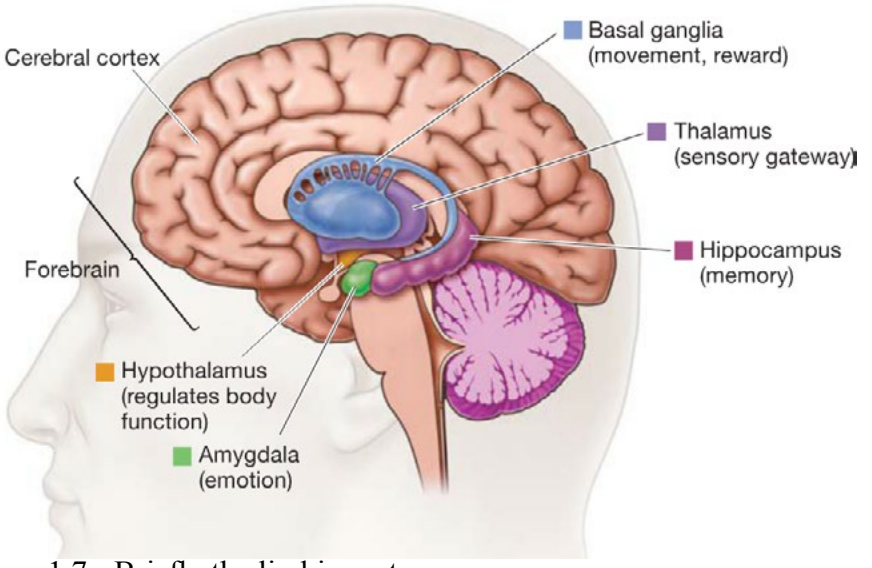

Figure 1.7 - Briefly the limbic system

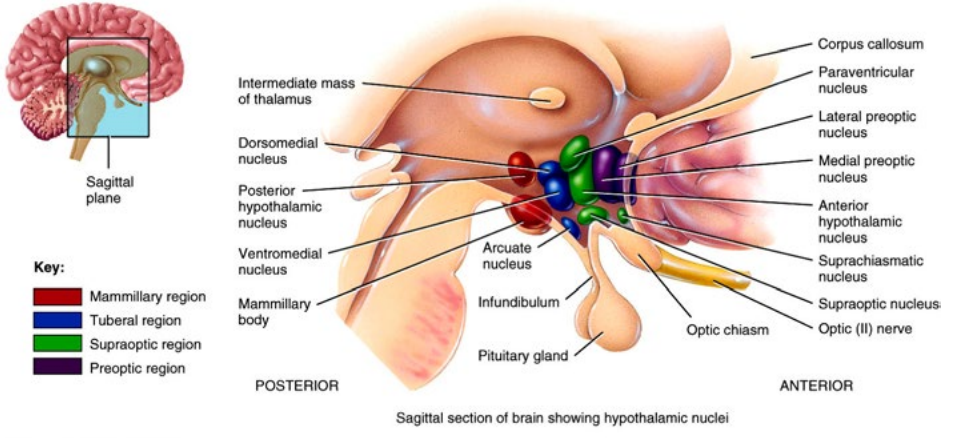

Figure 1.8 - The three zones of hypothalamus

through the supraopticohypophysial tract and released into the blood circulation. The CRH will be lead through the portal system and take action on the anterior lobe of the pituitary. The pituitary gland is also known as the hypophysis (Neuroanatomy 2015). The portal system is one of two connections between the hypothalamus and hypophysis. When the hypothalamus releases hormones, they are either carried through the axons of the cells, this being the first type of two connections, or they are transported through the blood vessels and released into the hypophysis, or pituitary gland, and this being the second type. The tuberal region is involved with eating and appetite, which for now will be overlooked. The third region, the mammillary region, may play a sovereign role in thermoregulation. Only anatomically is the mammillary region correlated the hypothalamus, because they do not appear to be closely related to the endocrine and autonomic functions. The mammillary nuclei are believed to play a role in memory (Neuroanatomy 2015). The four bilateral fiber tracts in hypothalamus consist of two large tracts that are bilateral pathways connecting to the mammillary nuclei; the fornix carries fibers from the hippocampal formation and the mammillothalamic tract (MTT) contains bilaterally running fibers with the anterior group of the thalamus. It is important to notice the connection between the mammillary region and hippocampal formation and anterior nucleus of thalamus. Another important pathway is the stria terminalis, which is an afferent pathway (receiving pathway) from the amygdala to the hypothalamus (Mohandas and Rajmohan 2007).

The many functions of the hypothalamus are mainly of homeostatic nature, for instance, when the body reaches a high temperature, the anterior part of hypothalamus activates mechanisms resulting in sweating and blood vessel expanding in the skin. If the temperature is too low, the posterior part of the hypothalamus is responsible for shivering and regaining heat. The hypothalamus, besides being involved with endocrine and autonomic functions, is also involved with emotions which explain the pathway stria terminalis.

1.3.2 - HIPPOCAMPUS

The hippocampus, meaning “searhorse” in greek, has three zones as well; (i) the dentate gyrus, (ii) hippocampus proper and (iii) and the subiculum. Within

the hippocampus proper, there are different connectivity and therefore the hippocampus has further been subdivided into four fields: CA1, CA2, CA3 and CA4 (CA: Cornu Ammonis). The circuits of the hippocampal region are differentiated between the afferent and the efferent pathways. Considering the afferent pathways, there is a reciprocal connection to amygdala through the fornix (Mohandas and Rajmohan 2007; Yvonne et al. 2009), which in particular is interesting as the hippocampal formation mainly deals with the episodic memory (Arbib 2015), while amygdala deals with emotions. The pathways between the organs is interesting because of how they affect each other, and how the overall experience of a certain object, space, thermal condition is felt is a consequence of the pathways within the brain. Therefore in understanding the pathways, it is suggested that an overall understanding of how one is affected becomes clear. One of the most important pathways regarding memory and emotions is the fornix. The fornix is C-shaped tract, beginning as the bundle of fibers called alveus. Alveus is white matter made of afferents and efferents (receiving and giving pathways). The fibers from the alveus further become the fimbria, which is the fringe, or periphery if one will, of the hippocampus (**figure 1.9**). When going posteriorly, the fimbria of each hippocampus splits and form legs, or crus, of each hippocampus. The two crua comes together and becomes the hippocampal commissure which provides two major pathways ensuring a communication between the two hippocampi. After the hippocampal commissure the fibers are referred to as the fornix, which continues in an arc to the anterior commissure. Here the fornix splits into three parts, making the fornix in particular an interesting organ considering memory and emotions:

(i) The split before the anterior commissure is called precommissural fornix, which branches out to septal nuclei, ventral striatum and the cingulate cortex.

(ii) A few fibers from the fornix continue through the anterior commissure to the contralateral hippocampus, being a major path of communication between the hippocampi.

(iii) The split after the anterior commissure, which is an important

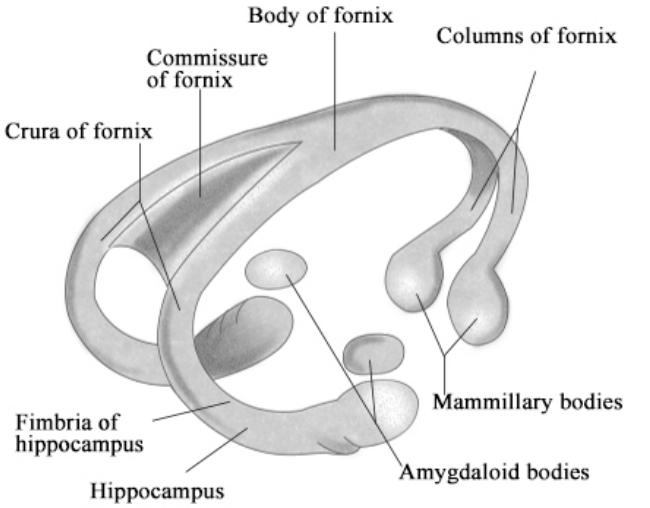

Figure 1.9 - Structure of fornix

split, is called the postcommissural fornix, and branches out to the mammillary region of the hypothalamus and the anterior nuclei of the thalamus.

The precommissural fornix connects to a number of regions, including septal area, preoptic nuclei, ventral striatum, orbital cortex and anterior cingulate cortex, but there will be only a short introduction of the preoptic area as it is possibly responsible for thermoregulations. The postcommissural fornix connects to the anterior nuclei of the thalamus, which in turn connects to the cingulate cortex, which is responsible of regulating heart rate, blood pressure and cognitive, attentional and emotional processing. Both the fornix, which has been introduced, and the entorhinal cortex, which is connected via the cingulate cortex, are two major paths of the hippocampus (Limbic System 2015).

The subiculum, being the third zone of the hippocampus, functions as a direct path to the entorhinal cortex, which is the organ that projects further to the cingulate cortex. It is here that the loop of James Papez is presented (**figure 1.10**). The Papez loop was originally the blue boxes, while recent findings are presented in green boxes (Limbic System 2015). There is a reciprocal connection between the hippocampal formation and the association cortex, and through possibly the

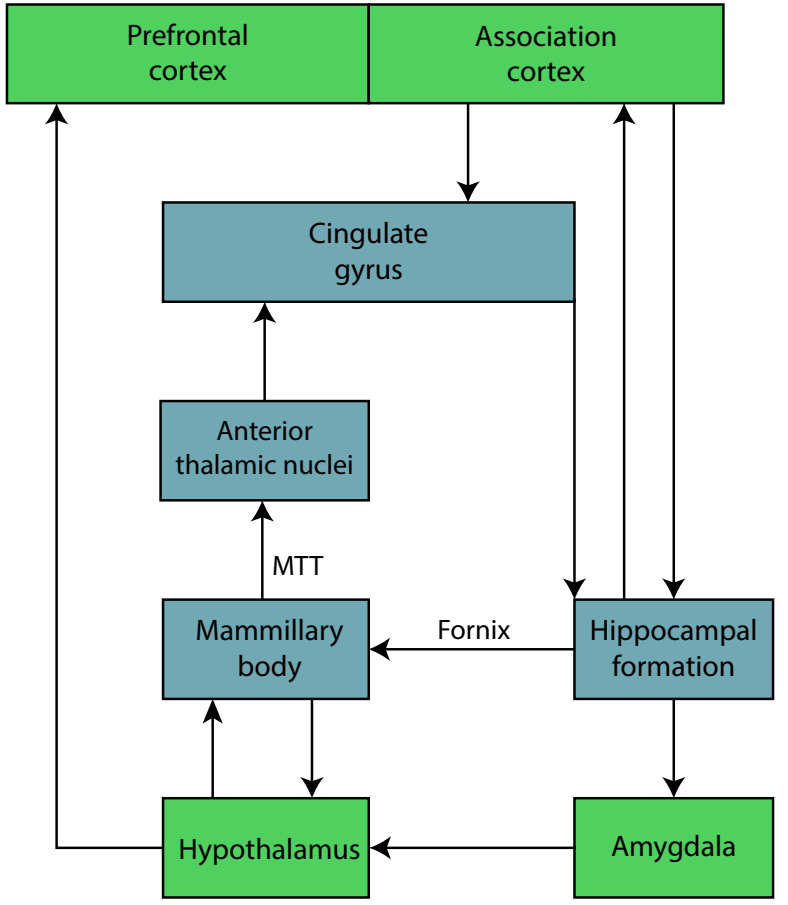

Figure 1.10 - Papez Loop *(Green boxes represent recent findings - Blue boxes represent original loop)*

subiculum there is a connection to amygdala, which is further, connected with hypothalamus, or more specifically the mammillary body. The connection continues through MTT to the anterior nuclei of thalamus. Moreover there is a connection through the fornix from the hippocampal formation to the mammillary body. From the anterior thalamic nuclei there is connection to cingulate cortex, where there is finally a connection to the association cortex. It is here there is a relation to the visual perception as described earlier. The association cortex is a part of the prefrontal cortex, which allows the sensors to be related with the limbic system and finally creates an "accumulation" in the hippocampus according to the Papez loop.

1.3.3 - AMYGDALA

The amygdala, meaning "almond" in Greek, is the epicenter for emotions, emotion behavior and motivation. There is an amygdala in each hemisphere. It is situated adjacent to the hippocampus, and similarly has major pathways which contain both afferent and efferent fibers. The amygdala receives inputs from all senses and visceral inputs as well. It is mainly involved with emotions as fear and rage, though it is also used as a memory of stimuli, which is why the amygdala is often referred to as emotional learning. There are five major pathways, paramount for grasping the world and creating a reaction (Limbic System 2015).

(i) The ventral amygdalofugal pathway

(ii) Stria terminalis

(iii) A direct pathway to hippocampus

(iv) A direct pathway to entorhinal cortex

(v) A direct pathway to dorsomedial nucleus of thalamus

The ventral amygdalofugal pathway is connected with the anterior olfactory nucleus, anterior perforated substance, piriform cortex, orbitofrontal cortex, anteri-

or cingulate cortex, and ventral striatum. More importantly, the ventral striatum includes part of the caudate, putamen and the nucleus accumbens. It is the projections from the ventral striatum that are important in a basal ganglia circuit, which is important for a stimulus-response associative learning. The basal ganglia circuit is also associated with functions as eye movement, cognition and emotions (Gallman and Weyhenmeyer 2007, p. 102). The ventral amygdalofugal pathway is furthermore also connected to hypothalamus and septal nucleus, though the major pathway to the mentioned organs is through the stria terminalis. The stria terminalis resembles the fornix not only in form and function but also the stria terminalis has precommissural and postcommissural branches, where the precommissural branches to the septal area, as the fornix, and the postcommissural branches to the hypothalamus, as the fornix. Although, the fornix branches to the mammillary region of the hypothalamus, the stria terminalis branches to the lateral nucleus and ventral-medial nucleus of hypothalamus. Furthermore the stria terminalis only connects to subcortical structures, as any cortical structure happens through the ventral amygdalofugal pathway (Limbic System 2015).

The central nucleus of amygdala produces conscious emotions through the ventral amygdalofugal pathway to the anterior cingulate cortex, prefrontal cortex and orbitofrontal cortex. Furthermore the central nucleus produces autonomic components of emotions, such as change of heart rate, blood pressure, respiration and so on, through efferent pathways to the brainstem and lateral hypothalamus (Limbic System 2015).

1.3.4 - PREOPTIC AREA

The preoptic region, situated adjacent to hypothalamus, contains neurons that are able to sense subtle changes in hypothalamic and core temperature. These are thermosensitive neurons, which also receives an infinite amount of somatosensory input from the skin and spinal thermoreceptors (Boulant 2000). There is no single area that acts as center of thermoregulation, but the regulation is regarded a structure forming a loop, including the hypothalamus, the brain stem and spinal cord (Boulant 2000; Parkinson and de Dear 2015). The lower brain stem and spinal structure are capable of sensing body temperature

and capable of initiate thermoregulatory responses. As the nervous system is involved it can select the behavioral and physiological responses most appropriate. Various studies (Magoun et al. 1938; Hemingway et al. 1940; Freeman et al. 1959; Hammel et al. 1960) have shown that the preoptic area is responsible of thermoregulations and thus also vasodilation and vasoconstriction, which are body temperature regulating mechanisms. Regarding pathways, the median forebrain present a bidirectional path passing through the lateral hypothalamus, which is an important path as efferent signals pass through from the preoptic area in order to control skin blood flow and shivering (Boulant 2000). An obvious afferent input to the preoptic area from the thermoreceptors of the skin through the somatosensory system is paramount for regulating the body temperature.

The research within the field of thermoreceptors relation to the limbic system (in terms of memory and emotions) is quite narrow. This specific field is interesting in many aspects of architecture, as it may provide information and knowledge of how the architect should involve the thermal comfort, in order to expand the pathways. It has been documented for instance that people with an artistic mindset tend to have a greater volume of amygdala than non-artistic mindsets, suggested to be of creativity reasons (Asari et al. 2010).

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Regarding the autonomic and endocrine responses to emotions, it is the limbic system that causes change in heart rate and blood pressure, more specifically a circuit in the cingulate gyrus, amygdala and hypothalamus. Preoptic area is responsible of thermoregulation, which will be further investigated in relation to the ambiguous state of being inside and outside, as well in relation to the conflict of visually perceiving being inside or outside but being thermally in the state of the opposite. The brain, as a whole, is infinite in neural connections. The mentioned connections are known connections and widely acceptable, but many other connections may be possible, e.g. any bidirectional neural circuit through multiple sensory systems. This fact should be stressed.

AREA	FUNCTION
Cingulate gyrus	Autonomic functions regulating heart rate and blood pressure as well as cognitive, attentional and emotional processing.
Hippocampus	Long-term memory
Amygdala	Anxiety, aggression, fear conditioning; emotional memory and social cognition.
Hypothalamus	Regulates the autonomic nervous system via hormone production and release. Secondarily affects and regulates blood pressure, heart rate, hunger, thirst, sexual arousal and the circadian rhythm sleep/wake cycle.
Mammillary body	Memory
Nucleus accumbens septi	Reward, addiction.
Preoptic area	Responsible for thermoregulation by stimuli from thermoreceptors, mucous membrane and hypothalamus.

Table 1. Functions, connections and structures of limbic system (The Limbic System 2015).

- V4 area, which is situated in the fusiform gyrus, is responsible of generating colors, while both area V2 and V3 are involved in object recognition, meaning that one becomes first conscious of an object before ascribing color.

- The micro-consciousness which is both the perceptual site and the processing site is distributed in time and space, and in order to perceive the objects of the space, the process needs to be completed. This makes one question whether the visual perception, in terms of geometry, is also "bending" in time and space, if so, then Euclidean geometry is not how one perceives the world 'out there', but rather in non-Euclidean geometry.

- The association cortex allows the sensory mechanisms to be involved with the limbic system, indicating a memory storage including all senses, as area V2 does suggested by Lopez-Aranda (2009). This becomes in particular interesting as visually perceiving a certain material should be able to evoke the tactile sense, the olfactory area and so on, and as the association cortex is involved further with the mammillary region and the preoptic area there is an indication that the thermoregulation is influenced by senses, and possibly stored as memory.

- The hippocampus has direct connections to the entorhinal cortex (via the subiculum) and the amygdala. The entorhinal cortex projects to the cingulate cortex, resulting in the hippocampus can affect the cingulate cortex through the anterior thalamic nucleus or the entorhinal cortex. The cingulate cortex further projects to the temporal lobe cortex, orbital cortex, and olfactory bulb. Therefore all of these areas can be influenced by the hippocampus (Limbic System 2015). The limbic region, the amygdala in particular, plays a pivotal role in behavior.

Regarding ambiguity in architecture, with a certain focus on the dichotomy of inside and outside, neurologically there seem to be a coherent possible explanation of visually interfere with the thermal experience of inside and outside. The question of how one makes meaning of the visually perceived becomes a vital knowledge in order to grasp how, and when, the ambiguity of visually being outside or inside is ascribed. A natural issue seems to be evoked regarding the visual perception, memory storage, tactile and preoptic area stimuli. The issue of reality and mental representation is a question that has been asked since Plato, and yet no answer seems to be sufficed.

1.4 ISSUE OF REALITY AND ACTUALITY

One must differentiate between two kinds of categories. As suggested by Dalenoort and de Vries (Dalenoort and de Vries 1994, p. 112), to avoid controversies and causal relation between two categories, one must differentiate between mental processes and physiological events. *"[...] one must indicate the process underlying the cognitive event, from which the cognitive event emerges, and show how these physiological processes cause the other physiological processes [...]."* (Dalenoort and de Vries 1994, p. 112). It is suggested that to increase the understanding of the correspondence of mind and body, one must apply the kind of thinking of bottom-up (BU) and top-down (TD) processes, as these may be paramount to construct the correspondence between the cognitive representation and the physiological representation (Dalenoort and de Vries 1994, p. 114).

The main issue is of epistemological order, as Realism suggests that objects that are detected through senses and manifest in memory, have a correspondence in the physical realm. But is the physical realm not a hypothesis established by the brain through sensory information? This is the classical issue of body-mind, which is a problem that has been stated at least as far back as Plato (429-347 BCE). This is a relevant issue to consider, as the relation between the two is paramount for grasping the actuality and reality. The issue addresses what the mind claims to see and what is in the physical realm, and it is here that ambiguity becomes an interesting aspect, as multistability is positioned between the physical realm and the hypothesis created by the mind through senses. Through time different aspects have been presented, including Plato, Aristotle, Descartes and Kant. A brief presentation of the historical evolution of the issue will be presented, but not in depth, as this field aspect is not within the scope of this paper.

When Plato stated that the body is of the material world, the main argument was that the soul is of the world of Forms and therefor immortal. Plato also argued that Forms, or ideas, do not exist within space and time, as the objects do, and that Forms are true reality experience by the soul (Silverman 2012). The best known example to grasp Plato's idea of body-mind problem is in his work *'Phaedo'*, which is a dialogue between Socrates, students and himself. Plato argues that

the true substances (the term substance is referring to being), are not physical within the body, but rather eternal Forms (Robinson 2012), which are immortal. The Forms make the world possible and intelligible, and the connection with intelligibility is what the intellect must grasp to in the process of understanding. One of the most important arguments of the immortality of the soul is that the intellect is immaterial as a consequence of Form being immaterial and the intellect must have an affinity with the Forms apprehended (Robinson 2012). In conclusion what Plato argues is that objects are not real, but merely mimics of the real Forms. The argument by Plato is missing the binding between the body and mind. In other words, what keep the mind in the body and how do they connect?

However, Aristotle did not believe in the Forms, as presented by Plato. In reading on Aristotelian forms (Robinson 2012), which in brief allows natures and properties of things to coexist embodied in those things, resulting in explaining that the soul is the form of body, the Aristotelian form is usually interpreted as materialistic as he argues that the soul of a person is no more than his nature as a human being, meaning that when the body perishes, the soul does too. Though he agreed upon the suggestion that intellect is immaterial, he argued still that the soul and the body coexist. If the intellect was material it would not receive all forms, e.g. the eye only apprehend reflections of light, not sound, whereas the ear apprehend sound, not light. Therefore, he argues, if intellect was a physical organ it could only be sensitive, or apprehend, a limited range of physical things, which is not the case, as the intellect can think about any kind of material object (Aristotle, De Anima III, part 4). Aristotle's aspect, in the end, is that the problem is elementary.

The whole issue is then again discussed by Descartes, who presents a new aspect of the phenomenon. Descartes presents two types of beings; *res cogitans* and *res extensa*. The former is a thinking substance and the latter is extended substance. Descartes introduced the Cartesian dualism by suggesting the world being divided into spiritual/mental and physical/bodily worlds (Robinson 2012), and hereby stating that the mind cannot exist without a body, and the body cannot think itself. Descartes also stated that he could doubt if he had a body, but he could not doubt if he had a mind. In Meditation VI, Descartes states: *"I have a clear and distinct idea of myself as a thinking, non-extended thing, and a clear and distinct idea of body as an extended and non-thinking thing. Whatever I can*

conceive clearly and distinctly, God can so create." (Descartes 1984). Here again Descartes refers to the fact that the mind is a substance distinct from the body, as he cannot doubt the mind, and therefore the essence of the mind is thought. In other words, Descartes believes that the immaterial mind and the material body causally interact, while having an ontological distinct substance relation.

Kant also joins in on the discussion and writes in 1781 Kritik der reinen Vernunft (Critique of Pure Reason): "*Space is a necessary a priori intuition that lies at the root of every awareness. One cannot imagine its negation, although one can imagine it to be empty. It is the necessary condition for the possibility of perception, and not a consequence of perception, it is an intuition a priori, the necessary basis for external perceptions*" (Kant 1999, p. 38). Here Jan Koenderink coins the fact that the mind must be a geometric engine, solving geometric issues as they do not adhere to the Euclidean rules of geometry (Koenderink 1990).

As there seem to be no solution to the body-mind problem, Dalenoort and de Vries suggests that one should interpret the incompatible worlds, of mental and physical, as different representations of one and the same world, and knowing that the two worlds interact, why then deny the possibility to consider both as one system? (Dalenoort and de Vries 1994, p. 115). In general, one is accustomed to divide between the body and mind, as separate systems, which may be an illusion. For instance, when having a conversation with a person, the illusion is not active; not meaning that people interact with conversation, but the aspect of one system is the product of material processes; mind and brain, conversation and people speaking (Dalenoort and de Vries 1994, p. 115). Therefore in this paper, it has been decided to borrow the meaning to consider the mind as a process of brain, and that there is an external world that can be observed. In other words, the world 'out there' is one and same world for everyone, merely with different individual interpretations and thus different mental representations. This alludes to other questions, when relating to architecture; if the mind process the interpretation of the world within the brain, how does the organization of objects operate? Does the mind at all interact with the world 'out there'? A.C. Zimmer, suggests a relation of the mental representation and physical representation through a neurological aspect, caused by the phenomenon of multistability, or ambiguity.

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- It has been decided to accept the suggestion by Dalenoort and de Vries (1994), namely that there is one and same world for every conscious mind, but each consciousness interpret the world differently, thus different individual mental representations.

- Hitherto, if the perception is multistable, then so is the conceived physical realm. This implies that the conceived physical realm is dependent of the sensory information, and further raises an interesting question: is it possible to create an imbalance of perception in architecture, allowing the user to stabilize more than one percept? And what are the neuronal consequences of such imbalance?

1.5 GEOMETRIC ASPECT THROUGH MULTISTABILITY

When observing the Kanizsa Cube, the duck/rabbit illustration or Rubin's vase, one is able to stabilize more than one meaning to the illustrations. This phenomenon, of giving the exact same percept more than one meaning, is portraying how perception operates through geometries and gathering information about the objects meaning and relationships between these objects and oneself. Koenderink (1990) concludes in his article that the brain can organize the percepts and becomes a veritable geometry engine. How one decodes the geometry perceived becomes a vital knowledge, as this influence the experience. Starting off by investigating the 2D objects, such as patterns and paintings, one notices, e.g. by looking at the Kanizsa Cube through 8 holes (**figure 1.11**), that the brain has a tendency towards simple forms, which is confirmed by Gestalt theory. A.C. Zimmer (1995) suggests a complimentary relationship between the singularity, which is the unique point of view, and the stability, which is the mechanism of making sense by simple forms: *"The second aspect of the complementarity, namely the interaction between local vs. global optimization, can best be exemplified in the field of spatial perception where the forked effect of local optimization [...] and the uniqueness of the point of view give rise to a stable image of the surrounding world despite the fact that any given projection can originate from a multitude of spatial arrangements"*. LaGournerie in the last century (**figure 1.12**) and Ames since about 1935 have shown this and how local orthogonalizations or symmetrizations together with the singularity of the viewing point result in the unique spatial impressions even if they contradict 'known facts' as e.g. the relative height of people in the Ames-room (**figure 1.13**) (A.C. Zimmer 1995, p. 103). Zimmer also suggests that the impression should be the strongest when the tendency to global stability and the sensitivity to local disturbances are about equal. Furthermore, A.C. Zimmer experiments with the perception of depth through a wire cube, suggesting that aperiodicity, convexity and symmetry breaking are the decisive points to create the effect of depth in drawings

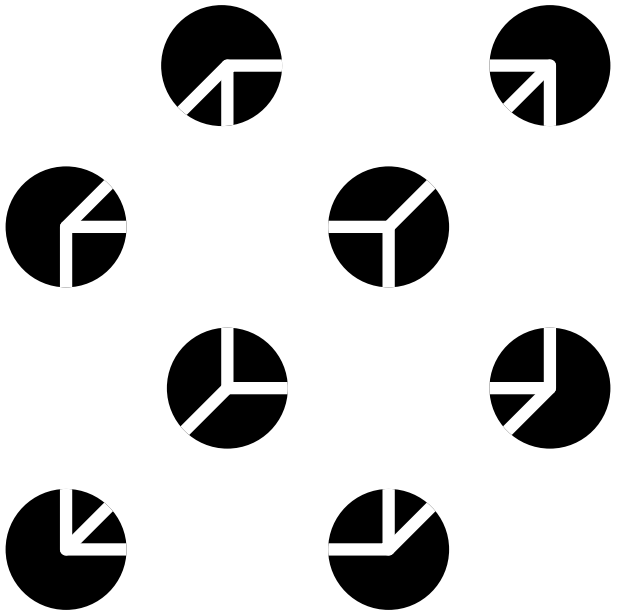

Figure 1.11 - Kanizsa Cube through 8 holes

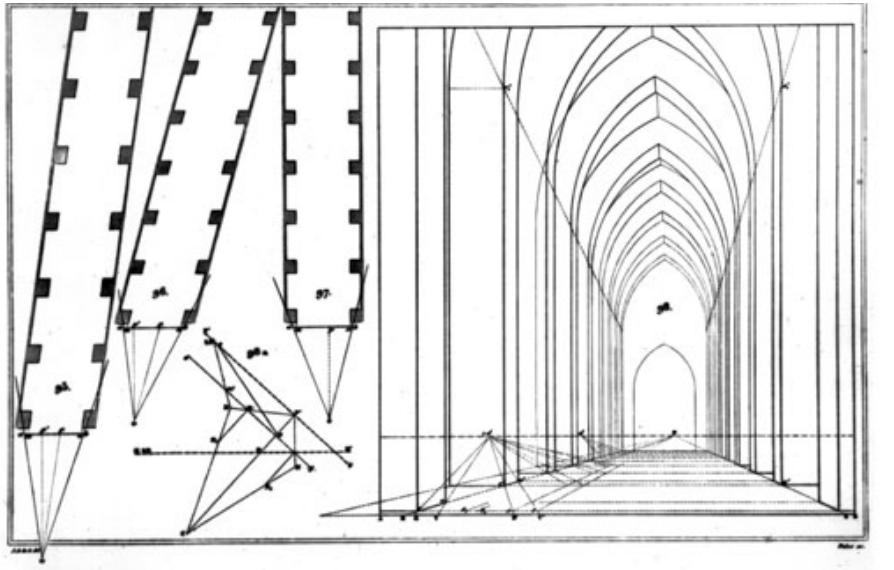

Figure 1.12 - Three possibilities of the plan by LaGournerie

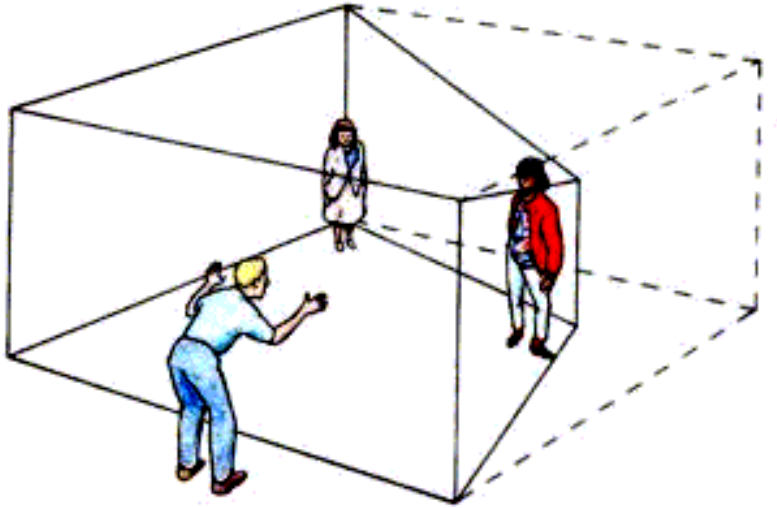

Figure 1.13 - Illusion by perspective by Ames

(A.C. Zimmer 1995, p. 116), implying that how the mind decodes the geometries of the world 'out there' is not merely Euclidean geometry, but rather non-Euclidean geometry. The non-Euclidean geometry excludes the fifth axiom by Euclid and allows bending. This has also been suggested by Manfred Euler (1994, p. 325). Euler (1994) argues that the visual system reconstruct and recognize shapes and objects regardless of affine transformations, which is related to time and motion. He substantiate by further arguing that the mechanism grasping the invariance must be acquired actively (Euler 1994, p. 325). The visual system is additionally flexible enough to disambiguate shapes and objects. Euler uses an illusion (**figure 1.14**) to emphasize the illusion transferring, by analogy, the concept of curved-space time to perception, and that hereby the mind inhabits a non-Euclidean universe. The rays imitate the action of gravitational field and the parallel lines correspond to light rays, *"the "straightest" lines (geodesic) in space-time"* (Euler 1994, p. 326). He furthermore also suggests that the experiment demonstrates the insufficiency of the projection and the necessity of activeness. Euler concludes that space-time and matter is interwoven, which is quite interesting considering the problem of the mental representation of the world. If the percept introduces no disambiguating action, the suggested com-

plimentary of singularity and stability enters into force. But to imitate a non-Euclidean world is quite a task, which even masters of perspective seem to fail.

LaGournerie (A.C. Zimmer 1995, p. 122) notices a problem in the famous painting School of Athens by Raphael (**figure 1.15**), here the two spheres held up by Euclid and a colleague in the right corner of the painting, are represented as circular spheres, whereas they should have been eclipses. On account of natural perspective, the sphere should look shortened to Raphael, and therefore be represented by spheres. But as Raphael's knowledge includes the basis of the shape and considering the position of the spheres in the painting, Raphael choses to recognize them as circles, which indicates automatic and not analytic processes. This implies hereby two theoretical results, namely (i) that perception includes both TD and BU processes, and (ii) the components of complex percepts are processed glance for glance, in its

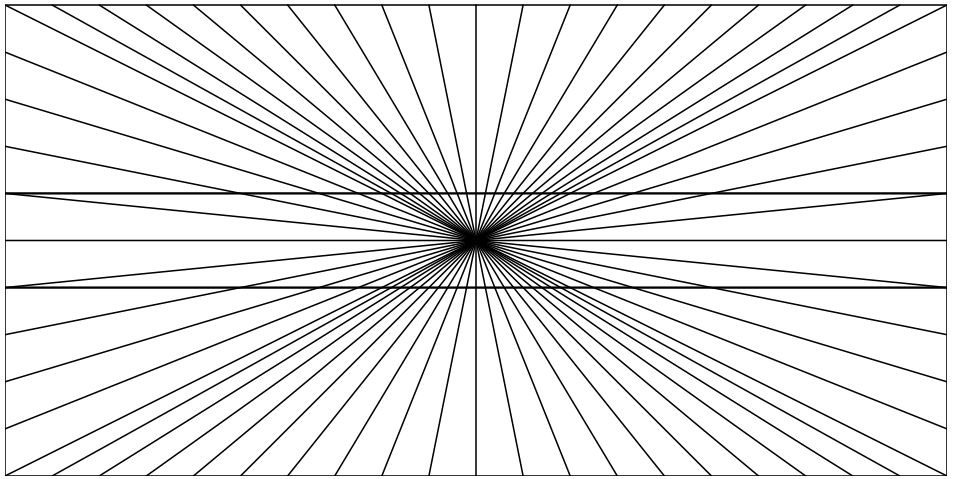

Figure 1.14 - Two parallel lines appear bended

own frame (A.C. Zimmer 1994, p. 122-124). Grasping a scene through processes of glance by glance is also substantiated by Euler (1994, p. 314-315).

In a brief historical retrospect, one shall observe that ancient view of active perception seems close to modern knowledge. The eyes scan the scene and focuses on the most important regions, meaning that the sensory interface has an active exploring component, which relates very well the endo-exo worlds. Euler (1994, p. 315) suggests that it is more than mere transfer of information, but rather a transformation of information in the sense of meaning. The endo-system interprets the incoming signals. The ancient view included the essence that perceived objects were imprinted on the perceiving system, corresponding to the process of solid objects imprinting their shapes on the sensing hand. This has also been suggested by Ivins (2011, p. 5). Analyzing art and geometry, Ivins suggests that space is not merely observed by vision, but in fact explored tactually, because the vision can only see things, as when there are no things in space, even though empty, it continues to exist, by reason of the exploring hand as it knows it is in

Figure 1.15 - School of Athens by Raphael (1509-1511)

space, even without contact. Using an example inspired by Euler, a blind man using a stick to grasp the scene, epitomize the issue of information transfer from the exo- to endo-world. If the man holds the stick tightly, the representation is more certain than if the stick was held loosely. Similarly, in visual perception one can experiment through illusions as distortions can be made sensible, and one can investigate the internal percept with the external reference (Euler 1994, p. 326).

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- As suggested by Zeki's micro-consciousness, which is the activity in a node becoming an essential node is distributed in time and space, creating a percept that is non-Euclidean, seems to be plausible as substantiated by Euler (1994). For an architect this becomes interesting as space is experienced over time, allowing various geometries to be interpreted differently depending on singularity and stability, as suggested by A.C. Zimmer (1995). In other words; space is perceived in movement, which should be noted by the architect.

- Euler suggests that when creating distortions, or ambiguities, in the visual perception, and afterwards disambiguating the percept, can possibly, "hold the stick tight", and enhance the meaning of the perceived. In other words, if the visual perception is ambiguous or in any way create uncertainty, which can happen when one of the dimensions, for instance the dimension of time, is uncertain, then presumably another sensory perception will support, and hereby disambiguating the perception.

Furthermore, when a conscious mind is situated in an ambiguous situation, there seems to be some kind of attractors within the mind, competing to ascribe meaning to the perceived. The attractors may have a paramount responsibility of what one perceives. In order to further grasp how one makes meaning and the affect solely by visual perception, the processes, as suggested by A.C. Zimmer namely, TD and BU needs to be presented.

1.6 BOTTOM-UP AND TOP-DOWN PROCESSES

These processes have been used to describe the direction of the transformed information before reaching the point of recognizing. The process of top-down (TD) and bottom-up (BU) can be explained with an example. If one is looking into a crowd, searching for a friend, it involves higher cognitive attention. One must have a representation of the friend in the mind while searching; filtering out the background, meaning that sensory information is not a main method of perceiving the friend. One searches with a plan in mind. This is considered a TD process. But if one is looking into a crowd and perceives a face that is salient, it has come to one by BU process. The main difference is that BU process includes and dominates through sensory, whereas the TD process involves goal directed processes. The processes interact infinitely; it is therefore a big challenge to understand each process as insolating them is a hard task (Beck and Kastner 2008).

What is selected when multiple stimuli occurs and how we select and represent visual information becomes a crucial mechanism, as the laws of Gestalt, which are laws of visual organization, may be directly grasped as principles of disambiguating by vision through either TD or BU process. As suggested by Beck and Kastner (2008) there is a competition between TD and BU processes where one process suppress the other, and reaches the representation of visual information. As an architect, the processes are important to understand, as how the represented visual information will be reached, play an important role in how one is experiencing the specific visual representation. Both processes are important to include, as higher cognitive processes and sensory processes might be proven to be a delight for the brain.

Inevitably, how one reaches the specific visual representation through neural competition, needs to be outlined. As presented by Beck and Kastner (2008), there are three principles of selective attention:

(i) The many systems in the brain, such as sensory and motor, cortical and subcortical, that represents the visual information are competitive, meaning that the system that 'wins' will be at the expense of others. These competitions occur automatically across the brain systems.

(ii) Looking for the friend in the crowd will pre-activate units that help match with the internal representation and therefore have the advantage of increased processing weight. *"Thus, such top-down mechanisms introduce bias signals that help resolve the ongoing competition. The competition among multiple objects can also be biased by bottom-up mechanisms that separate figures from their background, or constitute objects by principles of perceptual organization."* (Beck and Kastner 2008).

(iii) If a visual object gains dominance in the visual cortex, it tends to gain the dominance throughout the other systems, e.g. higher order frontal and parietal areas.

Through various experiments, inter alia Beck and Kastner (2008), it can be suggested that, the strength of competitive interactions within multiple stimuli are directly related to the spatial dimension in the visual area. This can be further explained; exposing the subject to multiple stimuli within a small display will induce the competitive interactions in early visual cortex that encompass the display, as in V1 and V2. Changing to a bigger display, and therefore expanding the receptor field (RF), the strongest competition took place in V4, where the RF is sufficiently large enough to encompass the display. It can, furthermore, also be suggested that, the bigger the spatial separation of the competing stimuli, the smaller degree of competitive interaction. *"[...] the magnitude of the suppressive interactions should be inversely related to the degree of spatial separation among the stimuli."* (Beck and Kastner 2008).

So far, one can conclude that visual stimuli compete, in multiple areas of the visual cortex, for neural representation, and that TD process is generated through cognitive demands and not by competing stimuli. The TD process, being directly related to frontoparietal cortex, is spatially directed attention to a location of a stimulus; e.g. being able to filter unwanted information in visual representation and therefore easily finding the friend in the crowd (Beck and Kastner 2008). However, TD processes can also be introduced through memory process, emotional process or motivational process. Whereas the BU processes are directly stimulus-driven. Having the source in the visual stimulus itself, it can

be explained as a visual salient item that is perceivable because it contrasts with its background. The meaning is in the stimulus. BU process is not necessarily generated through visual cortex, as processing may be activated in favor of an emotion through the amygdala. Considering the psychology of Gestalt laws of organizing perception, it becomes interesting to grasp how organizing can take part in BU processes. When considering the law of similarity, Bundesen and Pedersen (1983) made an experiment taking the time for the subject to detect a target letter, which had a certain color, amongst distraction letters, which had other colors (**figure 1.16**). They concluded that when organizing the background into groups of colors, the time to detect the target letter was improved, as this would also improve the BU process in contrasting the background with the target. An interesting TD process involving partly laws of gestalt was discovered by Bichot, Rossi and Desimone (2005) when recording from V4 neurons while a monkey searching for a color object amongst other colored objects. *"The response to a preferred stimulus (e.g. a red item) in a neuron's RF was enhance when it matched the cue*

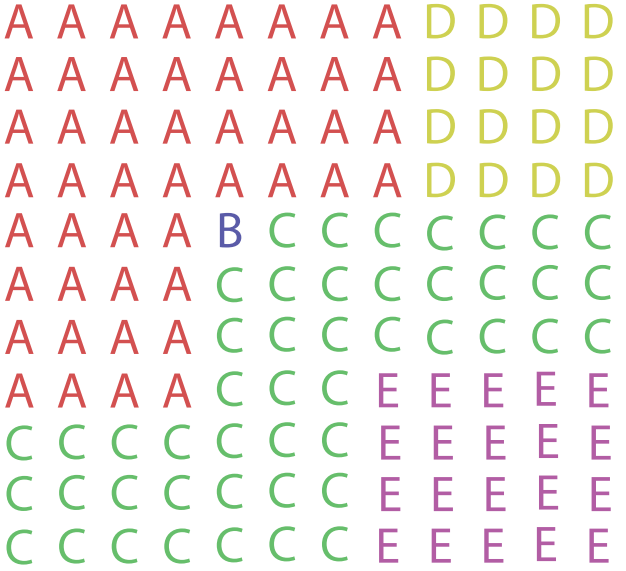

Figure 1.16 - The letter *B* is easier found when organized by colors

(e.g. indicating a red target), even when the monkey had not yet found it (i.e. it was not the target of a subsequent saccade)". (Beck and Kastner, 2008). This demonstrates how organizing, maybe in general, is involved in visual cortex processes.

It has been suggest that TD process is outside the visual cortex, which rests on the argument that attentional process is part of a sought-after object held in working memory used as a basis to select certain object. The working memory includes, as mentioned in earlier chapter, hippocampus.

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It can be concluded that both TD and BU process can influence the competition for visual representation, and that through various of experiments (Beck and Kastner 2008), it is suggested that the important site deciding what process will 'win' on the expense of the other is V4. It can furthermore also be concluded that when exposed to multiple stimuli in the visual field, competition for representation in visual cortex happen by suppressing neural response. It has also been documented that the competition is the greatest at the level of the RF, which may be involved with the fact that stimulus similarity (Gestalt psychology) affects the competition. As the two different processes compete to reach the visual representation, it becomes interesting to think of visual stimuli that are ambiguous, affecting both processes. In other words, in which direction does the brain resolve ambiguity when exposed to equally plausible interpretations? Here Zeki have a suggestion, explained through micro-consciousness, for how the brain solves the processes and reach the visual representation. So far, there has only been documented and argued within the visual exposition of objects, and how these interact with the brain. The systems of resolving the visual representation suggests many catalytic design ideas, concepts and principles for an architect. These will all be summarized in later chapter.

- Possibly the important site, deciding what process will 'win' on the expense of the other is V4, which is the same visual area generating color.

- The TD process is influenced by conscious expectation. Within this pa-

per the expectation will occasionally be termed memory-of-the-future. TD process influences lower areas, such as senses and emotions.

- The BU process is influenced by unconscious conditioned stimulus. The BU process influences the top, such as cognitive processes.

1.7 CREATING MEANING BY PERCEPTION

According to Zeki (2006), in order to grasp how one creates meaning of circumstances through memory and sensory percepts, one must grasp how the mind disambiguates. The explanation uses the theory of micro-consciousness. Neuropsychological studies are confirming that the mind use multiple spatial reference frames to perceive and act in the world 'out there', and physiological studies are expanding their knowledge of parietal and frontal cortex in order to grasp how the percepts are constructed (Colby 1998, p. 15-24). Zeki, on the other hand, argues that activity in an essential node is not necessarily dependent of an input from higher cognitive systems, meaning that TD processes, are not necessaire to create meaning of perception (Zeki 2006, p. 255).

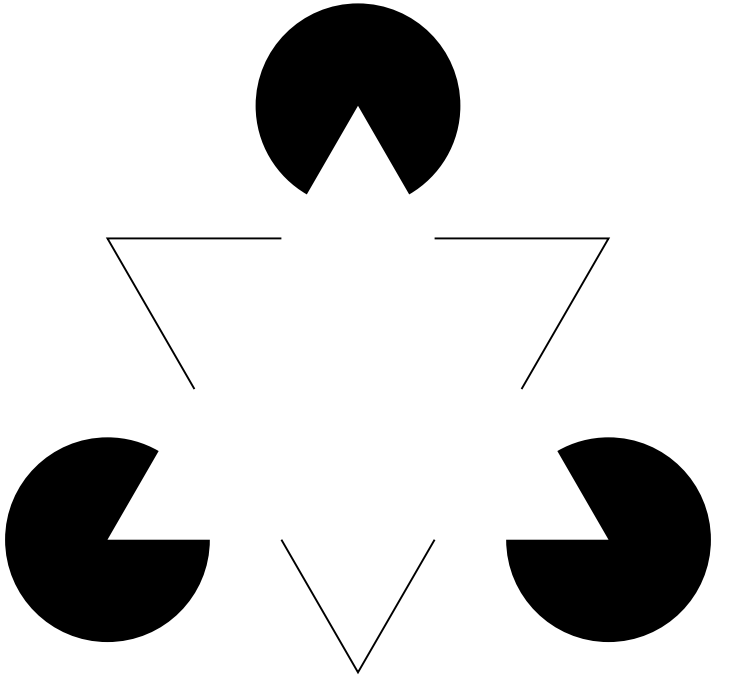

Figure 1.17 - The Kanizsa Triangle

An important statement by Zeki is that the brain is an active participant in constructing the world, in which it instills meaning to the many signals receiving. It is this signal that is used to instill meaning. The law of constancy is rooted in the fact that the brain is only interested in the constant properties of objects, situations and so on. Using the Kanizsa triangle as an exploring point (**figure 1.17**), Zeki indicates that the interpretation involves semantic element which is shaped through experience. As explained earlier, the TD process involves the frontal lobes, as they process higher cognitive thoughts, which one does as indicated in this case by Zeki (Zeki 2006, p. 254). A sharp discovery by Zeki questions the fact if TD process is necessary to interpret ambiguity in a certain way. Zeki argues that, if a TD process was implicit it indicates that the processing site and the perceptual site are different. Or in other words: *"[...] that an interpretation has to be brought to bear upon the result of processing in an area, the interpretation emanating from a*

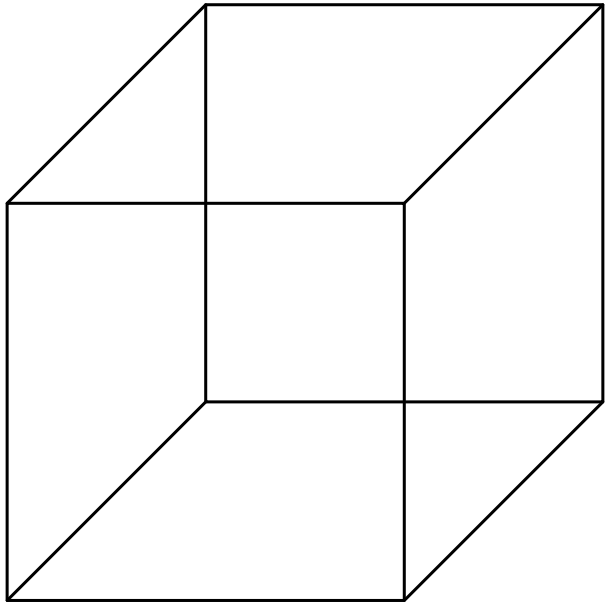

Figure 1.18- The Kanizsa Cube

different source than the processing site" (Zeki 2006, p.254). The mechanism of interpretation by visual perception includes the ability to interpret reflectance of different frequencies of light, resulting in color. Being able to interpret color, and disambiguate the reflectance, should in the same sense as interpreting the Kanizsa triangle, involve higher cognitive areas in the frontal lobes such as cortical area. Experiments by Zeki and colleagues (2000) shows that the construction of color involves the V4 complex and not the frontal areas or other areas implicated by memory (Zeki et al. 2000). The V4 complex constructs an essential node for color and the processing ends there, in the same sense as Beck and Kastner (2008) argued that processing is only required as long as no meaning has been established.

Further on, other experiments has been completed in order to study if TD process is involved when viewing figures as the Kanizsa triangle, and yet imaging experiments confirm that the frontal areas are not involved in interpreting the figure. If, as argued by Zeki, the processing site is the identical to the perceptual site, it indicates that perceiving and grasping takes place in the same site. While the Kanizsa triangle does not offer ambiguous state in the same manner, but rather deals with organization and understanding of shape, another figure will be used as an example to ensure there is no TD process involved. Another type of ambiguous figure has been introduced, namely the Kanizsa cube (**figure 1.18**). The cube allows more than one equally plausible interpretations, but only one interpretation is possible at a time. If accepting still that there is no TD process, which there may very well be, it means that the processing site is the perceptual site. This implies that a micro-consciousness, caused by an essential node, can be in several mutually exclusive states (Zeki 2006, p. 256). Knowing that the Kanizsa cube is ambiguous because of the lack of information on the planes, and hereby involving the topographic representation, and given that the cells in V3 complex are selective and mainly used to grasp the topographic representation, it implies that the cells in V3 cause the meta-stability, as the activity of some cells dominates perceptually and other times the other cells dominates, of course only one representation at a time (Zeki 2006, p. 257). The incoming signals are interpreted at an early visual area, without any involving of memory or higher areas. Now, if the micro-consciousness can have more than one state and occupy the conscious mind one at a time, then

Figure 1.19 - The wife/mother-in-law illusion

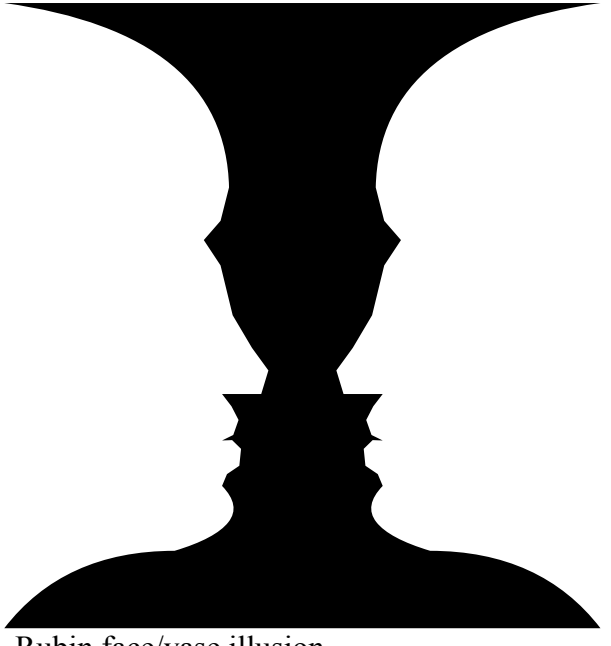

Figure 1.20 - Rubin face/vase illusion

what regulates the change from one state to the other due to activity in one essential node? And is it the same regulating mechanism that is involved when changing from one micro-conscious state to another due to two essential nodes?

So far Zeki has argued that during meta-stability, where both states involve the same object or attribute, the same cortical areas are involved. This supposition, as Zeki states, may be wrong but only further experiments will clarify the picture. For now, the arguments leads to the statement that the differences in processing in the same area results in different interpretations. Though when introducing bi-stable scenes, such as wife/mother-in-law figure (**figure 1.19**) and Rubin vase figure (**figure 1.20**), one state engages another processing site than the other state. The wife/mother-in-law figure involves age and perspective, and maybe even facial recognition. The Rubin vase involves shape-recognition and facial-recognition. An experiment with Zeki and colleagues (Kleinschmidt et al. 1998) shows that when the stimuli remain but the percept changes, there is indeed a shift in activated area. The fusiform gyrus is activated during facial recognition and object recognition, but there is observed a change in activity area within the fusiform gyrus when changing the percept. Furthermore there is activity in the fronto-parietal cortex when changing the percept. When a third “higher” area is involved, meaning a TD process is involved, it distinguishes this kind of ambiguity from the former discussed. If one is to say that one only becomes aware of the interpretation through a TD process, meaning that the fronto-parietal cortex dictates the percept, it would mean that fusiform gyrus are not sovereign in dictating what is perceived and therefore the perceptual site is not the processed site. This statement becomes a contradiction to earlier conclusions by Zeki and colleagues (2000). Another experiment also completed by Zeki (Zeki and Moutoussis, 2002) where two conditions prevail.

(i) The stimulus remains but percept changes.

(ii) The percept remains but stimulus changes.

Briefly in this experiment, one of the subjects eye was exposed to a house in certain colors, and the other eye was exposed to the exact same house, al-

though in opposite colors, resulting in opposite stimuli. This was also done with a face in same procedure. The subjects never consciously perceived the house or the face, but activity in the fusiform gyrus was detected in both cases. Here Zeki concludes that; firstly, TD process is not necessary to construct activity at an essential node. Secondly, Zeki concludes that one is not necessarily conscious of the change in activity in the brain. Thirdly, it was also concluded that, as discussed earlier, the perceptual site is the processing site. On the basis of these experiments, Zeki suggests that the activity in the fronto-parietal cortex is critical for one to become conscious of a change, without necessarily knowing what has changed. But to become conscious of what has changed, higher activity in an essential node is necessary (Zeki 2006, p. 260).

To summarize, it has been argued that activity in the same area can result in different micro-consciousness for the same stimuli, while two different micro-consciousnesses for the same stimuli can cause activity in different areas. Inevitably there is a shift in strength of activity. The shift happens either from one group of cells to another within a single area, or from cells in one area to another area, depending on where the activity takes place. There is an interesting problem, as pointed out by Zeki (2006, p. 261), the mechanism changing between the areas, balancing the strength of activity of the cells, can work on more than one area and allow one micro-consciousness to dominate another, despite the fact that the two micro-consciousness may be correlated. This mechanism changes between giving primacy to activity in a group of cells over another group and primacy to an area over another.

At the simplest level of ambiguity, which may be due to activity in a single area where the micro-consciousness has more than one state, there is no TD process, though when introducing a higher level of ambiguity, Zeki suggests that the ambiguous state may involve more than two distinct areas to bring their influence. When the ambiguity introduces memory, experience, learning and so on, it involves inevitably TD process from diverse sources influencing the perception. Being able to introduce more activity in more areas within the brain, it opens up the capacity of the brain and the perception as it allows the mind to be influenced by multiple areas. As Zeki argues, it is not that one is aesthetically pleased by

ambiguity itself; it is the fact that one can experience multiple experiences, still only perceiving one at a time, only by one and the same remaining stimulus.

SUBSET

Considering the fact that one experiences architecture both consciously and subconsciously, it becomes interesting to know that a space, which is a stimuli, can cause more than one perception, which is different micro-consciousness, while also two different spaces can cause activity in one area in the brain and hereby correlate each other.

- When stimuli remain and percept changes, higher "third" areas will get involved, if one state is processed in a different site than the other state. For architecture this means that one scene, or space, can evoke more than one meaning, which one can interpret differently.

- The mechanism altering the balance of strength of activity between cells or areas is the mechanism changing the perception, and hereby changing meaning of the stimuli. In architecture this becomes interesting, because of the mere fact mentioned above. Now, being able to change the perception by changing the primacy between the strengths of cells or areas becomes interesting. How does the mind and body react to such change?

- Allowing a "higher" ambiguity involves a TD process and hereby including possibly the hippocampus, meaning that being able to experience more than one percept may have an influence in well-being, as the hippocampus has afferent pathways from both amygdala and hypothalamus. Knowing that being able to change between perception can influence the mind and body through TD process, makes this field of neuroscience a goldmine in architecture, as theories may become confirmed and even lead to further developed theories and suggestions.

1.8 RATE OF APPARENT CHANGE

As Zeki argues, it is not the mere fact that a visual percept is ambiguous that is pleasing, it is the capacity of multiple experiences, even when experiencing one at a time (Zeki 2006, p. 264). When the rate of the experiences reaches a certain rate of apparent change it may result in, as documented by Stadler and colleagues (1995), activity in the dopaminergic system, implying a reward.

As mentioned in earlier chapter, there are different kinds of ambiguity. Some kinds of ambiguity, e.g. the bunny/rabbit-figure, are not a matter of time before changing perception and grasping the alternative figure. In fact, the perception may be the same forever if the subject has not learned to perceive the other interpretation. Spontaneous reversion is not the case in all ambiguities, thus this is a case of evolutionary ambiguity (Stadler and Kruse 1995, p. 6).

Spontaneous reversion: $Order_1 \longrightarrow Instability \longrightarrow Order_2$
Evolution: $Order \longrightarrow Instability \longrightarrow Higher\ order$

(Stadler and Kruse 1995, p. 6)

Generally speaking, the ability to change interpretation can be termed, with inspiration from Stadler and Kruse (1995), *cognitive flexibility*. The term includes being able to think and to imagine. Gestalt laws of visual perception and organization is, as mentioned in earlier chapter, a tool the brain use to organize and create competition between different interpretations. It is the organization that limits the amount of possible interpretations as some interpretations are non-salient and thus are suppressed. The interpretations that are organized differ in perception as there is a switching of alternatives as a function of varying strength of neural attractors. **Figure 1.21** explains how one and same stimulus may cause more than two interpretations, but only two possible organizations seem organized by the brain. Here the organization is met by a neural attractor, giving a figural organization and thus a meaning. Other interpretations may be learned and are therefore evolutionary ambiguous (Stadler and Kruse 1995, p. 9). Regarding the neural attractors, there exist fix-point attractors, periodic, quasi-periodic and

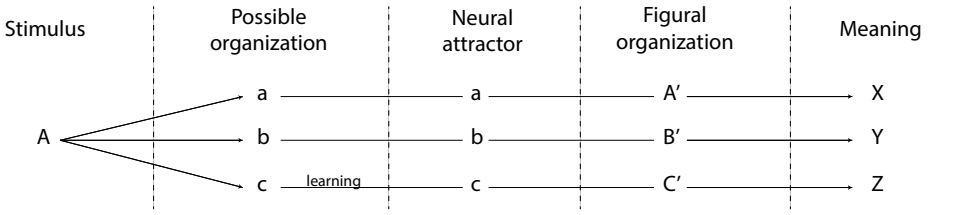

Figure 1.21 - One stimulus perceived differently after a newly learned organization, giving the stimulus a new meaning

chaotic attractors. When dealing with perception it is the fix-point attractors that are dealt with. Attractors in general are identified by serial reproduction, meaning the repeated reproduction of pattern lead to a simple results and do not change hereafter. The attractors show hysteresis, which explains why they tend to be stable and resisting changing (Stadler and Kruse 1995, p. 11). Certainly if the perception has to change, the stable state of the attractors need to be instable, therefore there must be a counteractive process against the stability. It has been suggested by Skarda and Freeman (1987), that a chaos generation is established, which is a process that precede the formation of new attractors. Another process is the self-satiation of figural processes in the brain as claimed by Köhler. Köhler claimed that a child, for instance, has weak permanent fixations (self-satiation) and thus give rise to a more widely spread area of weak satiation (Piaget 2007, p. 188). It is worth noticing that a child thus has a broader possibility of perception. In general, multistability becomes a question of switching between attractors.

One issue is how and what happens when switching between attractors, another issue is how attractors and meaning come together. One aspect has been presented by Amit (Stadler and Kruse 1995, p. 13). Amit states that an input in an attractor neural network (ANN) can lead to a network attractor. If it does lead to a network attractor, it leads toward a mechanism endowing it with meaning. The stimulus is classified as cognitively meaningful if the entering of the ANN lead quickly to an attractor. If failing to do so, the input is classified meaningless. Amit suggests that the meaning is within the particular attractor and the meaning depends on the level of cognitive process of the situated ANN. If an unknown stimulus is persistently imposed, it may cause learning, which is the formation of new attractors. This kind of learning is related to associative learning within the associative neural networks (Stadler and Kruse 1995, p. 13;

Stadler et al. 1995, p. 74). In other words, the learning increases the creativity because it expands the associative neural networks. Meaning is not only attributed to attractors, they can also be detached, for instance when repeating a word, the meaning of the words becomes detached. This is named lapse of meaning.

"We experience that our attention is pulled towards the interesting aspect in the perceptual field and that our actions are pulled towards the goals. This is exactly what the attractors of the neural network seem to do" (Stadler and Kruse 1995, p. 18). The perceived formation is a self-organization by complex neural network and not picked up by external information. With this aspect of giving meaning it will be the departure of grasping what happen when switching between the attractors at a certain rate.

Various experiments by Kruse, Stadler and Strüber (1995) evidenced that, by using multistable apparent motion (AM), that stability in perception is determined by inner dynamics of visual system, and that the stimulus is merely constraint of the self-organizing formation. The experiments also states that the rate of apparent change (RAC) increases over time (**figure 1.22**). Furthermore the experiments also stated that when teaching the subject another interpretation of the stimulus, the interpretation appeared spontaneously and the cumulated residence time was significantly enhanced with the newly learned interpretation. The mentioned experiments were all mainly BU processes; therefore two other experiments were completed, in order to argue the possibility TD influence on perception of objects. The first experiment involved the face/vase figure of Rubin. The shapes of the contours were changed and either the interpretation of the faces or the vases will be supported. When the subjects were presented with the figure-ground pattern, the subjects stated a stronger preference for the face-parts, when the contours were shaped like a normal human face in profile, which is illustrated in **figure 1.20** (Stadler et al. 1995). The figure-ground perception is purely a TD process as it filters the background (mentioned in *Bottom-up and Top-down process* chapter).

The main point to be made in this chapter is that the RAC is different in people, and can be interpreted as the amount of fluctuations of innersystematic fluctuations. The higher fluctuations of innersystematic fluctuations, the easier the system state can pass from one attractor to another, thus the RAC can be used a measurement tool of how close an individual cognitive system works to instability points, which may vary depending on personal characteristic. As suggested by Stadler and colleagues (1995), the differences in innersystematic instability and adaptive mental functions may have a relationship. Thus, if the readiness to change in multistable perception, e.g. using RAC as a quantitative measurement, is a measurement of innersystematic instability, then a variety of correlations between multistable perception and cognitive phenomena may be assumed. For instance, the innersystematic instability becomes a determinant of self-organized order formation, or in other words the Gestalt laws, and therefore the readiness to change should be correlated to cognitive flexibility, imagination and creativity. Furthermore schizophrenic persons show a tendency to have a higher RAC, and thus a higher readiness to change in perceptual multistability (Calvert et al. 1988). An interesting neurophysiological parameter is the over-activity in dopaminergic system of schizophrenia. When blocking the dopamine receptors in healthy persons, it lowers the RAC and the ability to perceive the less preferred alternative in multistable figures, although blocking dopaminergic receptors has an antipsychotic effect on schizophrenic. In general, blocking the dopaminergic receptors impairs cognitive flexibility (Stadler et al. 1995, p. 81). Furthermore the EEG tool was used on schizophrenic persons and demonstrated a higher dimensional complexity, meaning that the EEG may be used as a psychological measure of innersystematic instability (Stadler et al. 1995; Elbert et al. 1992).

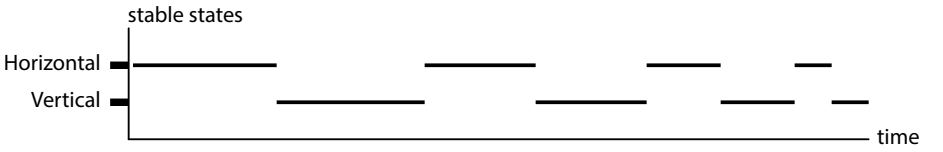

Figure 1.22 - Rate of change increase

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Reflecting this knowledge towards architecture and the ambiguous relationship between inside and outside, the experiments and studies mentioned so far are ideal for creating ambiguity by visual perception and increase the RAC, but the intentions are not necessarily directly related to ambiguity by vision, but rather ambiguity in sensory suggestibility related with and through thermoreceptors. At this point, it has been concluded that ambiguity by perception (by all senses) becomes an interesting subject as the RAC may involve dopaminergic activity and thereby pleasure, or in other words; a reward. In order to know how exactly the thermoreceptors gets included, requires the understanding of how tactility and visual perception may have a relation through neural network in the brain. In the same sense that the eyes are receptor field for the visual cortex, the thermoreceptors within the tactile sense also provide information about the world 'out there', and hereby gets involved in the homeostasis adjustments as presented by Damasio (2012).

- The other percept, $order_2$, may never be perceived if not learned to perceive it. The process of learning is implied to be vital for establishing a multi-percept.

- Increasing the RAC can influence imagination, creativity and dopamine activity. The higher fluctuations of innersystematic fluctuations, the easier the system state can pass from one attractor to another. RAC becomes measurement tool of how close an individual cognitive system works to instability points.

- Allowing the observer to teach himself, could theoretically improve the RAC, as the switching between attractors increases, and hereby cognitive flexibility. In order to allow the observer to teach himself, through BU influence, it may be suggested to use other perception than the visual. The senses sends inputs interwoven to the brain, thus the brain receives multisensory perception, and introducing another sense may overrule a sense and teach the observer new neural connections and hereby expand the ANN. The possibility of overruling a percept will be discussed in next section.

1.9 NEURONAL CONNECTION AND MEMORY

Firstly, it is important to stress that fact that architecture is not merely perceived through visual perception, but rather includes all sensory systems, thus architecture has the ability to engage many different areas of the brain. Secondly, V.S. Ramachandran, a neurologist, states that as pointed out in chapter Homeostasis, there are more than 100 billion neurons each able to form 10,000 synapses allowing the number of possibility for permutations and combinations excessively high (Mallgrave 2011, p. 160). A synapse is a structure where a region allows nerve impulses, electrical or chemical, to be transmitted and received. The synapse structure was a paramount key for the suggestion by Eric R. Kandel, who claimed that memory, was not a single area in the brain nor neurons themselves, but rather neural circuits. He discovered that short-term memory uses protein, specifically glutamate, to strengthen the synapses. Furthermore he discovered that long-term memory not only releases protein but also creates new synapses to enhance neural bond (Mallgrave 2011, p. 161). In general, Kandel discovered that memory is scattered throughout the whole brain, and not accumulated in a certain area. This is substantiated by the experience of when one recalls experiences of, for instance, last summer. The memories of visual, tactile, olfactory, temperature and so on, are all processed in different parts of the brain, meaning that the memory recalled are circuits residing in the firing patterns. An interesting conclusion by J. M. Fuster (1995) is that the memory is associative and that viewing a new event in light of the previous perception is interrelated, which means that there is a dynamic process between the previous experienced memory and new experiences. This particular dynamic process is explained by hippocampus and entorhinal cortex, both situated in the limbic system. As mentioned in chapter Hippocampus the hippocampus is critical in order to form episodic memory, which is the memory of new episodes occurring in life, but one can still use working memory which is a memory for ongoing activity (Arbib 2015). The hippocampus also plays a critical role in spatial navigation, which will be discussed in next chapter. Furthermore as the plasticity of the brain allows changes in the synaptic structure, the hippocampus allows the re-firing of certain circuits, when aspects of a stimulus reoccur (Mallgrave 2011, p. 165; Fuster 1995, p. 35;

LeDoux 2002, p. 107), i.e. a visit to the Grimm Center in Berlin (**figure 1.23**) may have evoked mental reinforcement resulting in a strong and complex neural pattern involving many sensory stimuli. If any aspects of these sensory stimuli should reoccur, the brain will give an impression of the previous experience of the stimuli. In this case, the plasticity and memory relates different percepts with other percepts, thus the visual, tactile, olfactory, temperature sensory and so on, of a certain material, spatial characteristic or composition can evoke a re-simulation of previous experience. In other word; Neurons that fire together, wire together.

An interesting observation through EEG and fMRI scans by Kounios and colleagues (2006) is that, when the subject is asked to solve a semantic problem in order to reach the "Eureka!"-moment, one of the first areas to be involved was the anterior cingulate cortex (ACC) and afterwards Wernicke's area, which is located in the left temporal lobe and is involved in language-processing. When the brain reaches an impasse, and breaks through, the subjects had the option to announce a "Eureka!" moment, or "insight" as termed in their article. The interesting obser-

Figure 1.23 - Grimm Center in Berlin by Max Dudler

vation is that the brain uses the anterior superior temporal gyrus, which is located in the right hemisphere, to solve the semantic issue, meaning the ACC transmits the issue to the other side of the brain to solve it. Kounios and colleagues suggest that when the ACC is aware of the failure in the language area, it shifts the matter to the right hemisphere where a coarser semantic coding allows more creativity.

"This hypothesis is also consistent with a recently proposed model of the neural basis of insight in verbal problem solving [...] according to which solvers initially focus on prepotent associations, possibly reaching an impasse if this does not lead to a solution. However, solvers may maintain weak activation for the solution [...] due to coarser semantic coding in the right hemisphere. Solvers may overcome impasse by switching attention to this weakly activated representation, suddenly increasing its strength. This shift of attention to a nonprepotent solution (or solving process) involves cognitive control mechanisms such as those associated with the ACC. This shift of attention may be less likely to occur when people use a less controlled mode of processing based on passive accrual of evidence" (Kounios et al. 2006, p. 888).

The ability to perform crossovers within the mind is dependent of neural circuits formed through experiences. The ability to associate is also expressed when experiencing, or grasping, a metaphor, i.e. when different domains share few attributes, the neural network raises the possibility to use knowledge from one domain in order to help organize another different domain. As suggested by Heilman and colleagues (2003): *"The manipulation of concepts in a network of a completely different architecture would allow the asking of particularly novel "what if" questions"*, and thus escape the constraints of existing internal models used for that particular domain.

The purpose of metaphor, as stated by Ramachandran in his books (Ramachandran 2011; Ramachandran 2004), is to forward a meaning, a thought or an experience. Ramachandran uses the term synesthesia, to explain the sensory crossover experienced when relating a color to e.g. a day in the week (Ramachandran 2004, p. 69; Mallgrave 2011, p. 174). Ramachandran furthermore suggests that the source of the ability to create a metaphor through sen-

sory crossovers is neuro-anatomically located in the angular gyrus, specifically fusiform gyrus, of the temporal parietal and occipital lobe (Ramachandran 2004, p. 74). This gives an interesting aspect of the neural network considering that a metaphor involves more than one area, as substantiated by Kounios and colleagues (2006). As discussed in the Introduction it is not unfamiliar to relate architecture to semantics and hereby create metaphoric architecture, but as Mallgrave (Mallgrave 2011, p. 182) points out, it is not that architects may and should not operate in highly abstract planes when designing a building, but the architects have to realize that most people do not perceive the world that way. Most brain scans show that the conceptualization is driven from below, BU process that is. The perception of architecture is formed by senses which are often subliminal; therefore the vitality of learning becomes increased.

Regarding navigation through space, the classical study by O'Keefe and Dostrovsky (1971) discovered certain cells in the hippocampus of rats. They placed electrodes in their hippocampus and found that some cells would only respond to where they are in the lab, thus the name place cells. The study discovered that no single neuron had any knowledge per se, but the population of neurons encodes knowledge in their circuit, i.e. one cells describing the height, another balance of right and left and so on, resulting in knowing the location. Within the hippocampus, which is also critical in constructing episodic memory, the place cells play an important role in navigation through time and space (Arbib 2015, p. 83).

SUBSET

Ambiguity and metaphors are much alike, but the difference occurs in, as mentioned earlier, if the alternative perception is an evolution of the order or merely an equally plausible alternative. The purpose of using a metaphor is to create a higher order, and hereby using creativity to forward another meaning, experience or thought. The spontaneous reversion of a percept is not to be confused with metaphor, as it was merely used to substantiate how instability can be used as measurement for readiness to change in percept. Indeed a metaphor is still ambiguous considering architecture and semantics, as it allows more than one interpretation of the perceived. It furthermore allows the conjunction 'or' to occur in mind.

Spontaneous reversion:	$Order_1$	⟶	*Instability*	⟶	$Order_2$
Evolution:	*Order*	⟶	*Instability*	⟶	*Higher order*

(Stadler and Kruse 1995, p. 6)

The reason for shedding light over metaphor is that neuro-scientifically the ability to change perception between more than one alternative, the readiness to change between these and to possibly add, by learning, an even higher order is closely related to generating creative thoughts and to memory. Here, the concept of metaphor becomes a metaphor for the memory and associative neural network. Furthermore, a metaphor has the ability to include all senses and emotions, and thus becomes a key to abstract thoughts.

- The metaphor, or ambiguity, of making $order_1$ instable to forward the $order_2$, or vice versa, so far seems to be enhancing the neural network and thus creativity, while it may also improve the RAC and therefore activity in the dopaminergic system. Thermally, being outside when being inside is not functional, as one seeks shelter from the outside.

- The plasticity of the brain allows memory to interrelate previous experiences to new experiences. This becomes in particular interesting when dealing with, what has been termed memory- of-the-future. When perceiving a certain space, which has aspects of earlier experienced stimuli, activates the re-firing of neural circuit and thus a memory and therefore an expectation of this certain perception is perceived. In order to expand the creativity, or in other words the neural network, the expectation could be false, and a new experience is added to the network.

- With inspiration from Arbib (2015) and by place cells, if the building functions as a brain, a building would be able to trace the people, only enable floor heating in exactly their position and hereby turning places with no activity off and thus possibly becoming energy saving. Using this concept the building would be able to lead people from A to B, assisting hospital users for instance. This concept is, furthermore ideal for ambiguous space; being, according to visual percep-

tion, outside, but, according to thermosensory, thermally inside. The building can be grasped as a homeostatic organism, which is inhibited with humans interacting as place cells, and instead of understanding the building as an organism itself, the building is grasped as an organism constructively aiding its inhabitants to maintain homeostatic balance. The building would be able to trace the people and, for instance, be able to either lead them from A to B, or even enable thermal comfort.

1.10 CONCLUSION OF PART I

It can be concluded that the laws of Gestalt are self-organizing mechanisms, improving the visual perception in order to create meaning. Therefore the laws of Gestalt become vital laws for architectural finish, such as separating a space, creating a division, and also the opposite, namely merging spaces. In general the laws of Gestalt are perceptual self-organization which becomes a tool for creating the percept wished. It should be emphasized that these laws are not 'meaning' themselves, and thus cannot create metaphor, although more than one law can be perceived, but this results in an ambiguous figure. But if one uses two laws in one space, creating two different organizations entailing two meaning, only then a metaphor can be created. And even in such cases, the laws of Gestalt were merely tools for a higher unit. This makes the laws of Gestalt candidate for architectural principles, considering the establishment of metaphor. Part II will immerse this subject further.

There are an infinite number of connections and bidirectional pathways in the brain, and those mentioned in earlier chapter are merely to give an impression of endocrine systems and memory setup. There is no doubt that the limbic system is responsible for the emotions, feelings and partly memory, and the connections to the cognitive area are no doubt either. These connections allow the brain to create an impression of the world 'out there' as the sensory systems provide information, through BU processes. As the signals are being interpreted, as Damasio (2012) suggested, the body adapts to its environment. The regulation happens through endocrine and autonomic responses. Therefore the sensory signals are vital for survival, meaning that both BU and TD processes are important. That the reality is the actuality, or vice versa, is not confirmed, and is an endless discussion, which is the reason for accepting the concept of being individual minds in one and the same world. The brain uses the information from BU processes and creates a relation to the world through TD processes, as the mind is an active conscious substance. The brain furthermore decodes the visual information in time and space, both neurotically and visually, before ascribing the perceived a meaning. The meaning ascribed can occur in different locations dependent of what is visually perceived and if the areas of the brain function optimally. Thus it can be concluded that visual stimuli is vital for creating meaning and can be used

to imbalance the perception. This becomes important information, as the ability to change between the percepts of one and same stimuli, or in other words the RAC, seem to create an activity in the dopaminergic system, possibly rewarding the mind for cognitive flexibility. The flexibility is related to the expansion of neural network, which is furthermore related to being able to grasp a metaphor as certain creativity is necessary to grasp one stimulus in different percepts.

It can furthermore be concluded that there is an intermingling between sensory systems, or as Ramachandran terms it synesthesia, which accumulates at the ability to interpret metaphors and relate smells with visual exposure, auditory notes, tactile sense and even tasting (Ramachandran 2011; van Atteveldt et al. 2014). In order to be able to grasp what is perceived, the brain goes from being instable to stable, with the possibility to cognitively being able to switch between these. Being able to change between the percept of one and same stimulus activates, according to Stadler, Kruse and Strüber (1995). As this paper is concerned with ambiguity, the delight involved and the relation to thermal comfort, the next section will introduce thermoreceptors and the neurophysiological relation to ambiguity. The RAC in this sense should not be grasped as the change between thermally feeling cold and thermally feeling warm, but rather as the rate of change between actual thermal comfort and the memory-of-the-future thermal comfort, meaning the expected thermal comfort, hence the name "actuality versus reality".

1.9.1 - FORMING THE HYPOTHESIS

Having assembled the required knowledge of visual perception, geometric decoding and creating meaning of the visually perceived and furthermore the influence of memory, it can be hypothesized that; to resemble the outside, it is not necessarily resembled by all sensory system, but rather reintroduce aspects of sensory stimuli, of the outside, in order to reactivate circuits and thus memory. Furthermore, geometrical aspects have been introduced to geometrical uncertainty to architecture, ensuring visual ambiguity.

There are studies documenting the possibility of intermingling of sensory systems (Ramachandran 2011; Ramachandran 2004; Ramachandran and Hubbard 2005), leaving the question of how visual sensory system is related to thermal comfort very open. An interesting point of departure is the placebo effect, as this effect in particular might have an interesting role in both thermoregulation and memory-of-the-future. Considering the ability of prediction, which is important for survival and thus needs to be quickly and precisely updated, what happens when the expectation is nothing like the perception and which percept will bias?

With the knowledge of cross-activation by sensory systems, it is not impossible to imagine a cross-activation of visual perception and thermosensation, leaving the mind in an ambiguous and instable state. The hypothesis is that when the cross-activation of the mentioned senses occurs, and the two percepts are ascribed to be contradictory, it leaves the mind in an instable state, forcing one perception, interchangeably, to make a decision toward a stable state, which might be substantiated by synesthesia and hereby other senses. As argued in previous section, the action of enhancing the neural network, or creativity, may result in activation of dopaminergic system.

Part II

Beyond thermosensory

The established hypothesis will within Part II be substantiated, and further investigate the implementation of hypothesis in architecture with regard to thermal comfort.

2.1 PLACEBO EFFECT

Considering the hypothesis established in previous section, the thermal regulation being influenced by other sensory will here be investigated. It is important to grasp the biasing competition of perception, in order to further grasp if the perception can affect behavior. The placebo effect, and the cross-activation mechanism, being synesthesia, can possibly in combination reach the point of positive alliesthesia. Alliesthesia describes the pleasure of reestablishing the homoeothermic balance, which may, as presented later in the chapter, also be influence by other sensory, such as visual sensory. For instance, if one was to be situated in a space where a fireplace is within the visual perception and the space is made entirely of brown-darkish wood, one is presumably expecting a higher thermal comfort than if the space was made of raw concrete, no fireplace, metallic framework and very big windows. The expectation could be referred to as memory-of-the-future.

The Bayesian brain hypothesis uses Bayesian probability theory, which most placebo predictive models are based on, as the theory states that the brain has a model of the world that is optimized by using sensory inputs (Friston 2010). Being primarily grasped as medicinal treatment, placebo effect is a phenomenon forcing a hypothesis, or expectation, to be indefinitely correct. Placebo in this paper will be defined as *the effect of forcing an expectation on the endocrine and autonomic regulations*. As mentioned in the chapter *Bottom-up and Top-down processes* there is an ongoing competition of TD and BU processes involving somatosensory system, limbic system and prefrontal cortex. The ongoing competing is to inform the mind about the environment and is therefore crucial information for homeostatic regulations. Therefore one might question behavioral affect by perception, as the perception is in an ongoing competition. There are studies showing that placebo hypoalgesia, which is actual pain relief by expectation, influence both TD and BU process, suggesting that the expectation created by the cognitive conscious mind, through memory and other areas depending on the expectation, are in competition with sensory signals. In other words, *"that placebo hypoalgesia is the result of combining top-down prior expectations or predictions of pain (relief) with bottom-up sensory signals at multiple levels of the neural hierarchy"* (Büchel et al. 2014). Many studies uses pain and pain relief to grasp the effect of placebo, and even though this paper is concerned with the placebo effect in relation to thermosensation and visual perception, there are many identical properties as argued by Büchel and colleagues (2014). Therefore the results are important to extract and apply to this papers concern also.

Büchel and colleagues (2014) developed a predictive internal generative model, based on Bayesian system that is used to predict the outcome of a subject in testing the case of placebo. In brief, the model states that the posterior probability *p(pain|sensory input)* is proportionally connected to the product of the prior probability *p(pain)* and likelihood of *p(sensory input|pain)* (Büchel et al. 2014). See **equation 1**. In other words, the new incoming information is integrated with prior knowledge or expectations. The predictive model is a hierarchical model and suggests that feedback connections from higher area to a lower area carry predictions of expected activity. For instance, knowing that the connection between V1 and V2 in the visual cortex is reciprocal (see chapter *Visual cortex*), then the feedback connection carry predictions of expected activity, whereas the feedforward connection, from V1 to V2 transmit the residual activity in V1 to V2, which was not predicted by V2 (Rao and Ballard 1999). The model is generative as the predictions, which are TD processes, are generated through a model whose variables are optimized on different timescales, meaning that the brain uses a model to continuously optimize the impression of the world through sensory inputs (Friston 2010; Büchel et al. 2014). This suggested model is based on the mismatch between TD predictions and BU signals, meaning that if the sensory signal bias the prediction, then the mismatch becomes a prediction error report and is forwarded to higher areas, which are those concerned with the prediction. This process is crucial in order to minimize the predictions errors; fulfilling the free-energy principle, which in short is an active reference within the brain, minimizing the regulations by adapting to the environment. Regarding the BU signals

$$p(\text{pain}|\text{sensory input}) \propto p(\text{pain})p(\text{sensory input}|\text{pain})$$

Equation 1

in pain, the nociceptive system, which is situated in the body periphery, transmit afferent signals to the dorsal horn of the spinal cord and further to supraspinal structures. As mentioned there are many pathways in the brain, but those important to understand the predictive coding model are the diencephalic regions; the rostral ventromedial medulla (RVM), the periaqueductal gray (PAG), the amygdala (AMY), hypothalamus (HT) and thalamus (THA) (Büchel et al. 2014). The TD prediction is a cognitive action and thus originates in the cortical area, including the rostral anterior cingulate cortex (rACC) and anterior insula (AI) and which projects to the PAG, who in turn sends projections to RVM. The RVM modulates signal transmission at the dorsal horn. Here the predictive coding model suggests that the connections are not unidirectional but rather reciprocal connection, meaning that the rACC to PAG to RVM also goes backwards. This process can be seen in **figure 2.0**. The BU signals are met by TD predictions and it is within the mentioned pathway the mismatch-loop goes on, reporting the "surprising" if needed to. It is worth noticing that the biased competition between TD and BU processes is mentioned in previous section, in which it was concluded that the TD process influence lower areas and BU process influence higher areas. The predictive model is important in which it suggests a neurophysiological relation of the placebo effect, which will be introduced in Neurophysiological relations chapter.

The effect of placebo is based on both expectation and experience,

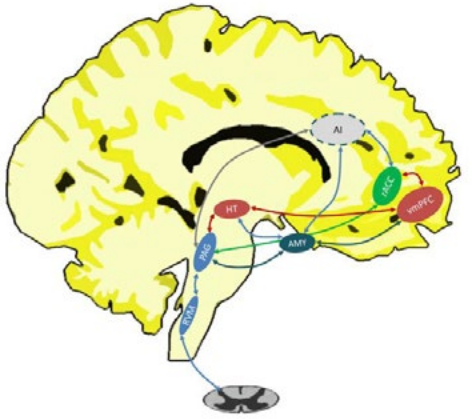

Figure 2.0 - The reciprocal connection of rACC to PAG to RVM

which are correlated through the process of learning. For instance, when pairing the pain relieving treatment with a sensory cue, an expectation of pain relief is formed (Meissner et al. 2011; Büchel et al. 2014; van Laarhoven et al. 2011). In other words, if the subject receives pain relieving treatment, and the subject sees and feels (visual and tactile sensory information) the injection in the skin, then the subject forms an expectation of pain relief. The mechanism detecting errors is the foundation of cognitive theories of learning and extinction (Crombez and Wiech 2011). As stated by Crombez and Wiech (2011) after reviewing the investigations by van Laarhoven and colleagues (2011); *"We tend to experience what we expect. More pain is experienced when participant were informed that most subjects experienced the stimuli as painful. More itch is experienced when participants were informed that most subjects experienced the stimuli as itch"*. But naturally, the world is not hallucinatory where the expectations are constructions of the reality. Furthermore, the expectation often undergoes a neural prediction error regulation in favor of the BU sensory signals to update the expectations (Crombez and Wiech 2011; Büchel et al. 2014). This means there are two mechanisms in competition; either the expectation bias perception, or the perception updates the expectation. Here Crombez and Wiech (2011) suggest that somatosensory experiences that are ambiguous are more malleable to expectations than experiences with clear perceptual characteristics. This suggestion substantiates the hypothesis within this paper so far, using ambiguity to create imbalance. Regarding the predictive model by Büchel and colleagues (2014), the placebo effect is caused by matching a predictive model with incoming data by explaining away the prediction error. But if the sensory data input is "too far away", as put in the article, a dramatic revisit of the model would occur in order to explain the sensory input. If the subject had an initial model of expectation stating that the treatment is "a real treatment reducing pain", it might be replaced with a model of "deception and no treatment" (Büchel et al. 2014). As seen in analogy of earlier mentioned visual multistability, in which competing percepts can each suffice two different models. The prediction error would be dramatically reduced as one model points in one direction, and the other in another direction, leaving the mind in either great prediction error or close to none. At this point, the predictive generative model explains the bias between TD and

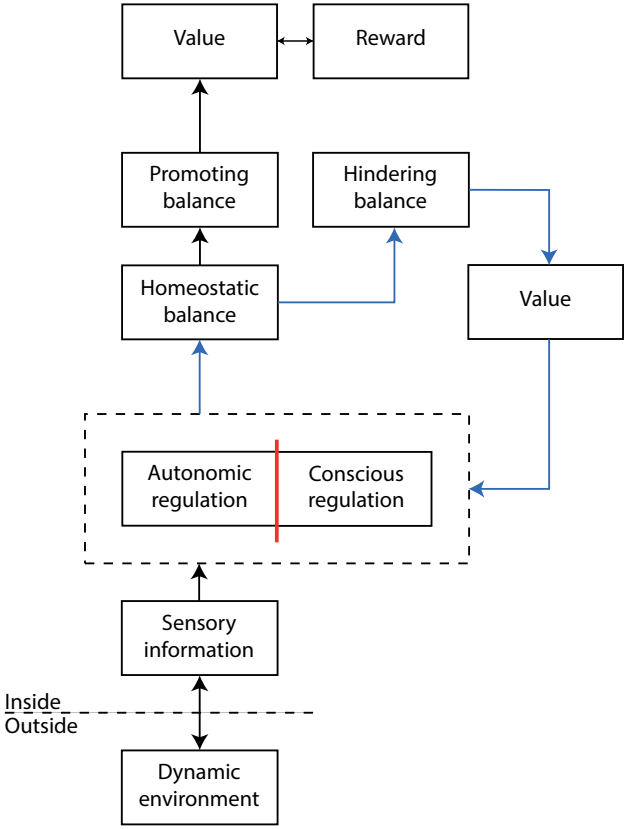

Figure 2.1 - *As argued by Damasio (2012), the sensory information affects the bodily regulations. If the regulation promotes the homeostatic balance, then a value will be ascribed and a reward will be released. If the regulation hinders the balance, a value will also be ascribed, but no reward will be released. In fact, pain will be released in such situations. The loop marked with blue lines is a loop of adaption to the specific environment.*

The red line between 'autonomic regulation' and 'conscious regulation' describes the complicated relation between these, as a cognitive top-down process might in certain situations overrule the bottom-up sensory information. Which regulation favors over the other will be discussed in later chapter, the important point to be made here, is that the autonomic regulation and the conscious regulation have a bidirectional relation.

BU signals, fulfilling the free-energy principle, and becomes essential to regulate homeostatic balance, and thus is valued as the precision of the prediction.

When revisiting the model of homeostatic regulation (**figure 2.1**), the value-system operate as the final step before either rewarding or punishing body, which can be felt consciously. There are studies substantiating the fact that the dopaminergic system (DA) is involved in the placebo effect (Scott et al. 2007). The DA is the main neurotransmitter in the mesolimbic system, ensuring dopamine release when rewarding the body. The release happens through the ventral tegmental area (VTA), the ventral striatum (VS) and the front areas e.g. as ventromedial prefrontal cortex (vmPFC) (Büchel et al. 2014). The suggested predictive model further states that DA can signal the precision of the predictions. Scott and colleagues (2007) made an important study on individual differences in reward-responding that explains the expectations and effects that are induced by placebo. Scott and colleagues (2007) focused in particular on the nucleus accumbens (NAC) and the DA, as these regions are known to be centrally involved in the encoding of reward expectations. In conclusion, the study substantiated the statement of NAC DA release elicited by administration of a placebo, meaning that, as the predictive model stated, VS dopaminergic responses represent a set-off that leads downstream responses. Thus the DA as neurotransmitter can be interpreted as the precision of predictions, and therefore the value.

Considering the main mechanism of placebo, which is to influence the perception by prediction, Damasio (2012) and Friston (2010) has stated that the ability of prediction is crucial for maintaining the homeostatic balance. Friston (2010) uses the free-energy principle to describe the homeostatic regulations. However, the free-energy principle becomes an extension of the suggested predictive model, as the principle ultimately describes how adaptive systems resist a natural tendency to disorder, which the suggested model includes. The biological agents must avoid any surprise by either minimizing the predictions error or optimize the prediction by perception, and therefore ensuring to be within the homeostatic acceptable range (**figure 2.2**). The free-energy principle is the upper bound on surprise, meaning that if the biological agents minimize free energy, implicitly they are also minimizing surprise. As seen on **figure 2.3** the free energy is a function of two important things regarding perception and action,

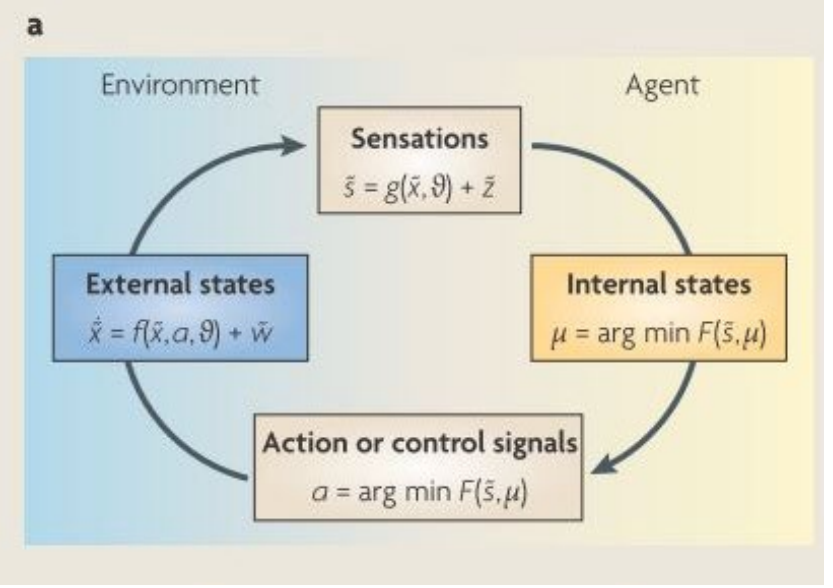

Figure 2.2 - The loop which ensures to minimize the free energy

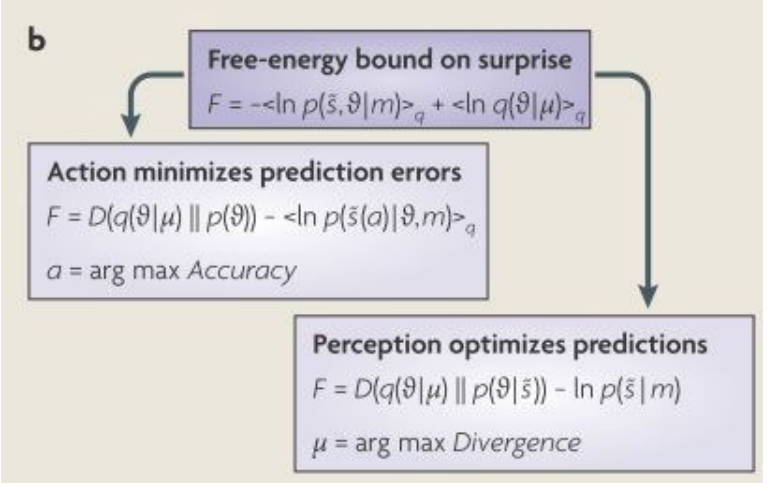

Figure 2.3 - The free energy is reduced by sensory states and recognition density

namely sensory states and recognition density (Friston 2010). The recognitions density is an approximate probability distribution of the causes from sensory data input. This means that the free energy can be suppressed by changing the sensory input by action, or change the recognition density by changing internal states. In brief, the free energy builds upon a model of generate sensory data and on recognition density. *"Free energy can be reduced only by changing the recognition density to change conditional expectations about what is sampled or by changing sensory samples (that is, sensory input) so that they conform to expectations"* (Friston 2010). The free-energy principle is ideal for the predictive model, as it supports the statements by the predictive model in a homeostatic manner. According to the free-energy principle in biased competition, the synaptic efficacy controls the deterministic evolution of states, and random fluctuations in these states are responsible for generating sensory data. The amplitude in the fluctuations indicates the precision, and thus the reliability of prediction errors. As mentioned, the predictive model is a hierarchal model, and it is the mentioned precision that controls the influence of BU prediction errors and TD predictions. As shown in **figure 2.4**, the precision modulates the amplitude of the errors, in order to allow those with highest precision a higher impact on units that encodes conditional expectation. In another aspect, this means that precision is similar to the synaptic gain of the prediction error unit. Here Friston (2010) states that the obvious candidate to control gain, and thus encoding precision, are neuromodulators as dopamine and acetylcholine, which is coherent with the suggested predictive model. A neurophysiological review of the suggested predictive model will be presented in the Neurophysiological relations chapter. A brief inspection of how the mind places the body in space is introduced.

SUBSET

The model suggested by Büchel and colleagues (2014) can be used to understand the neurophysiological relations when a TD signal bias BU signal and vice versa, as it furthermore coherent with the free energy principle suggested by Friston (2010). The suggestion by Crombez and Wiech (2011) substantiates the concept that creating an ambiguous state within the somatosensory experience, allows

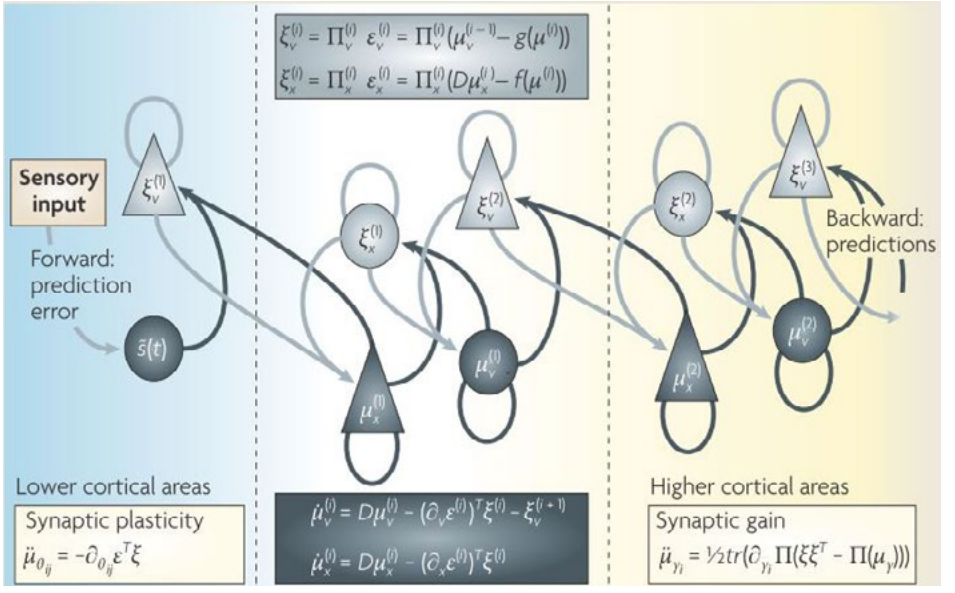

Figure 2.4 - The forward and backward prediction through synapses

expectations to bias perception; meaning that if the mind has a cold thermosensational expectation of a certain space that offers an actual warm thermosensation, the instable perception of the space itself functions as an ambiguous space as the thermosensations contradicts the expectation (see **figure 2.5**). This ambiguity will increase the innersystematic fluctuations, making it easier for the system state to pass from one attractor to another. Also as further substantiated by the framework developed by Büchel and colleagues (2014), if the incoming sensory data is "too far away", one would create another model that contradicts the initial model, and it would dramatically reduce the prediction error, as one do not know what to believe; resulting in an instable state. This paper creates the hypothesis that, as mentioned, if the rate of change between the expected percept and the sensory percept, reaches a certain changing frequency, then, as argued by Stadler and colleagues (1995) and concluded in the chapter Rate of apparent change, there is an increase of innersystematic fluctuations resulting in possible activation of dopaminergic system and an increase, or expansion, of neural network and hereby creativity. The increase in DA could be explained by the predictive model and free energy principle, as an attempt by the mind to understand the environment more precise. *"Environmental challenges threatening homeostasis and positive expectations*

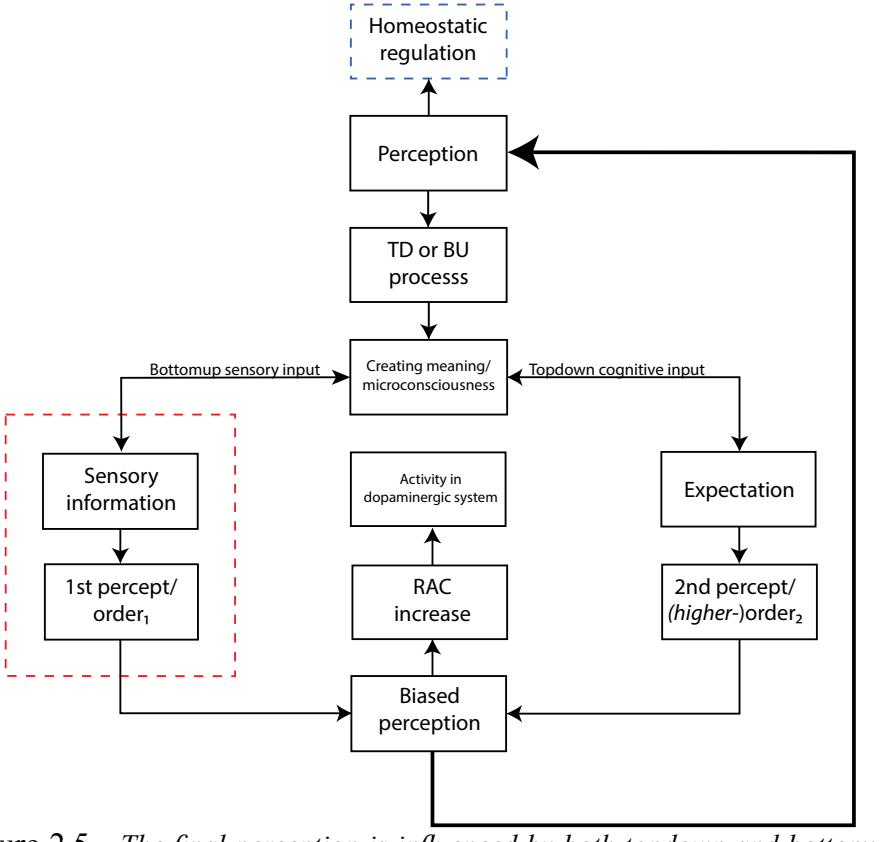

Figure 2.5 - *The final perception is influenced by both topdown and bottomup process, depending on the competition. The biased perception can be predicted using the predictive generative framework model suggested by Büchel and colleagues (2014) and the free-energy principle reviewed by Friston (2010). The switch in perception results in a higher RAC and activity in the dopaminergic system. The biased perception is the perception the homeostatic regulations takes notice of. The box marked in red dashed lines refers to the RAC and dopaminergic system diagram, while the box in blue dashed lines refers back to the Homeostatic regulation diagram.*

capable of reducing the bodily response are therefore interacting with each other conferring vulnerability and resiliency, respectively. These effects are thought to be the basis for the formation of placebo effects and point to individual expectancies as important modifiers of biological processes in both health and disease" (Scott et al. 2007). This statement by Scott and colleagues (2007) is substantiated by the predictive generative model and the free energy principle.

- When rewarding the expectation prediction, there are VS DA releases, allowing one to interpret two things; the VA DA release becomes a measurement tool for the prediction, and the release also implies a satisfaction. But to know what happens neurophysiological, there seems not be sufficient information, therefore in later chapter there will be reintroduced a more neurophysiological specific aspect of placebo.

- According to the free-energy principle, if the expected or signaled perception reestablishes homeostatic balance, then the perception is a catalyst for reward, because of minimizing free energy. Also, the free energy can be minimized by changing the recognition density to change conditional expectations about what is sampled or by changing sensory input, so it conforms to expectations.

Hitherto, the placebo effect, as explained by the predictive model and the free energy principle, is a reliable effect to understand the neurophysiological effect by architecture. But how does the body place itself in space, other than through place-cells as explained in chapter Neuronal connections and memory in hippocampus? Are there differences in how the body adapts to its environment, if so, then what are the boundaries?

2.2 BODY IN MIND

How does the body and mind reach consensus? The statement that senses are the source of information about the world 'out there' is a widely accepted notion, which leads to the birth of the concept body schema. In brief, body schema coins the relation of the perceptual space and the body, placing the body in space through sensory processes. This means that the body schema is plastic as the environment is not constant (Robinson, S., 2015, p. 138). This relation between the body and the environment substantiates the fact that the body and environment should not be grasped as independent entities, but rather as a whole. The body schema is mainly divided into two spheres, namely the peripersonal space, usually describing the space within the reach by hands (Berti 2000, p. 415). The second space, named extrapersonal space, is the space beyond the first space. What is important to grasp in this context is the fact that the mentioned spaces do not interact separately, but rather they are emergent attributes of interacting cortical and subcortical areas (Robinson, S., 2015, p.139). Referring back to the arguments by Damasio that one attributes value in correspondence to homeostasis regulations and context, this statement of the body grasping the surroundings through dynamic multisensory processes is merely substantiation. Sarah Robinson (2015) argues through different fields of cognitive science that the human body and its environment is one entity, which is a shift in modern awareness. Sarah Robinson suggests that a comprehensive understanding of the body must include the dynamic environment (Robinson, S., 2015, p. 140). Considering this paper, it is an interesting statement, as the knowledge acquired hitherto indicates that the body is in constant adaptive state to its dynamic environment. Regarding thermal sensory and both the peripersonal and extrapersonal space, they are emergent attributes of interacting cortical and subcortical areas, meaning they are the attributes created by the biased competition of TD and BU processes. Furthermore, when considering the thermal sensors, Lisa Heschong argues that thermal sensors are not sensors of distance, meaning the thermal sense do not inform the mind whether the space is warm or cool, before actually being in situation, or actively in contact. Therefore one must rely on other senses, for instance if an object looks soft, like wool, one might establish a hypothesis that the object is warm, like a sweater. What

becomes interesting, considering the relation of thermal experience of inside and outside, is that these clues from other senses may become so strongly associated with a certain thermal feeling, or experience, that it substitutes the actual thermal experience; e.g. the taste of mint seems refreshing and cooling regardless of the thermal experience (Heschong 1979, p. 24). There is no doubt that the mechanism operating, to ensure one can relate to earlier experiences, is the memory.

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- There is a better relation to the environment in the peripersonal space than in the extrapersonal space, suggesting that the peripersonal space is what is signal as BU, possibly biased by is expected in extrapersonal space.

- As thermal senses are not senses of distance, therefore if one is situated in a space not being able to first thermally sense the space, then another sensory may dominate and become the percept. This becomes interesting as synesthesia includes the issue of sensor crossover, which is clearly implicated.

Using different senses to establish an idea about the environment, as suggested here, is coherent with the placebo effect explanation. However, the more sensations are in agreement, the higher reliability; meaning that if both visual sensory and thermosensory are in agreement, the perception is biased according to the sensory agreement. But how does the sensory agreement occur? And what attributes influence such agreement?

2.3 SYNESTHESIA

In previous chapter is has been suggested that the expectation of one sensory might influence the perception of another, meaning an intermingling of sensory systems, or in other words, a crossover between different areas within the brain. Interesting information to be noted is that the placebo is triggered by the memory, prior experience and anticipation, meaning a higher cognitive process is involved. It becomes interesting to investigate whether a TD process is necessary to experience a cross-over between senses. In other words; is it possible to perceive a multisensory experience, before it is biased by a (or more) TD signal(s)? So far it has been argued by Zeki (2006) that a TD process is unnecessary to make meaning of a color, as a micro-consciousness is established in the essential node, without cognitive influence. The main perk if the TD signal is unnecessary, is that the cognitive process, which is the personal mind, become an indifferent factor, meaning that the experience can be universal, to some extent. Not all people have the same efficacy of sensations and not everybody has the same crossovers. But as Ramachandran (2004, p. 82) argues, to some extent the cross-over, as explained by the phenomenon synesthesia, is a universal ability in everybody. If the possibility of a TD influence occurs, the perk is that an expectation is in competition with a sensory input, allowing an apparent change in between. It will be investigated where the balance is, considering TD influence or BU domination.

Synesthesia was first discovered by Charles Darwin's cousin, Francis Galton. Galton discovered that certain people link numbers with colors, or specific tones with a certain color. The discovery was not investigated until recent years (Ramachandran 2004, p. 61; Ramachandran 2011; Baron-Cohen 1996), where it was confirmed that the condition is of genetic matter. Otherwise, the phenomenon was considered bogus, as Ramachandran states it (2004, p. 61; 2011; Ramachandran and Hubbard 2001a). Baron-Cohen and colleagues (1996) found that synesthesia is more common in females, with the ratio 6:1 and that synesthesia occurs in 1 in 2,000 people. However contemporary research suggests that there are no difference in occurrences of synesthesia between male and female, and that synesthesia occurs more often than earlier suggested. In fact, approximately 1.4% of the population is considered to be synesthetes according to the largest published

prevalence study on grapheme-color synesthesia (Simner and Carmichael 2015). More researchers seem to have even more different results than aforementioned, which implies that the experiments vary considerably and that synesthesia may be defined differently. Ramachandran (2004 p. 61-62; 2011; Ramachandran and Hubbard 2001a) lists 4 historical hypotheses about the phenomenon. It has been hypothesized that people who claim to experience a crossover are either;

(i) Crazy and they consider themselves unique and trying to draw attention.

(ii) Drug addicts and drug caused damaged areas in the brain.

(iii) Recalling childhood memories of, for instance, refrigerator magnets with certain colors of number.

(iv) Or they are being metaphorical, connecting one sensory with another in order to make meaning. For instance, the cheese is sharp, or a loud blue shirt, and so forth (Ramachandran 2004, p. 61-62; Ramachandran and Hubbard 2001a).

Ramachandran further provides argumentation for why neither of the above-mentioned hypotheses are possible. Firstly, Ramachandran (Ramachandran and Hubbard 2001a), whom has dealt with many synesthetes, report that most synesthetes thought that everybody experienced the world the same way, and that most the times, when scientists finds something not fitting the bigger picture, it gets brushed under the carpet, as stated by Ramachandran (2004, p. 61). Secondly, there is some truth that synesthesia is more common amongst users of LSD, although this make synesthesia even more interesting, as it predicts that chemicals can influence synesthesia. Furthermore synesthesia is only reported during the trip, and only few people have reported the experience. In fact, many drug users do not experience it in general (Ramachandran 2004, p. 61; Ramachandran and Hubbard 2001a). Thirdly, if memory was an explanation, then why do the condition run in the family, and that hypothesis also fails to address why only some stimuli evokes

a crossover in sensation (Ramachandran 2004, p. 61; Ramachandran and Hubbard 2001a). Forth, the case of metaphor is not a solution, as metaphor, which on neural basis is known very little about, remains a mystery, thus solving a mystery by mystery is nonsense; although inversely, synesthesia might be the explanation of metaphor (Ramachandran 2004, p. 62, Ramachandran and Hubbard 2001a).

In order to argue that synesthesia is not bogus, several experiments will be mentioned, designed so they cannot be faked by subjects. First experiment to be mentioned was completed by Ramachandran and Hubbard (2001b) where the subjects were exposed to a screen of 5's and 2's, where the 2's were forming a triangle. According to the synesthetes, a certain color was ascribed to a certain number, and another color to another number; meaning if exposed to **figure 2.6**, and asked to point out the 2's, the subjects will experience two colors differencing each other and rapidly point the 2's out. Also they would be experiencing the triangular shape. In other words, the synesthetes will find the 2's in BU manner, rather than filtering the background in TD manner. Results from Ramachandran and Hubbard (2001b), evidenced a great difference in timing (up to 20s by non-synesthetes and immediately by synesthetes), confirming synesthesia is not faked, and implying that the TD process is unnecessary. The next experiment, also completed by Ramachandran and Hubbard (2001b), also implied that the color ascribed to the number, is caused by visual sensation. A number was placed in the periphery of the visual focus, with the distance from focus point to periphery as a variable. The subjects stated that the number was not identified, *"but it must be an "O" because it looks blue"* (Ramachandran and Hubbard 2001a; Ramachandran and Hubbard 2001b). A final experiment will be mentioned to argue that the color ascribed is not caused by a TD signal. Ramachandran and Hubbard (2001b) further exposed the subjects to roman numerals, such as I, II, III, IV and so forth, and these evoked no colors, meaning that the visual grapheme of the number is the trigger to perception of color, and not the concept of a certain number.

A contemporary hypothesis (hyperconnectivity) formed by Ramachandran and Hubbard (2001a; 2001b; Ramachandran 2004, p. 68), suggests that as V4 area is situated in the fusiform gyrus, and the visual grapheme area is also in fusiform gyrus, being adjacent to V4, there could have occurred cross-wiring between these. It has been further suggested that a single gene mutation

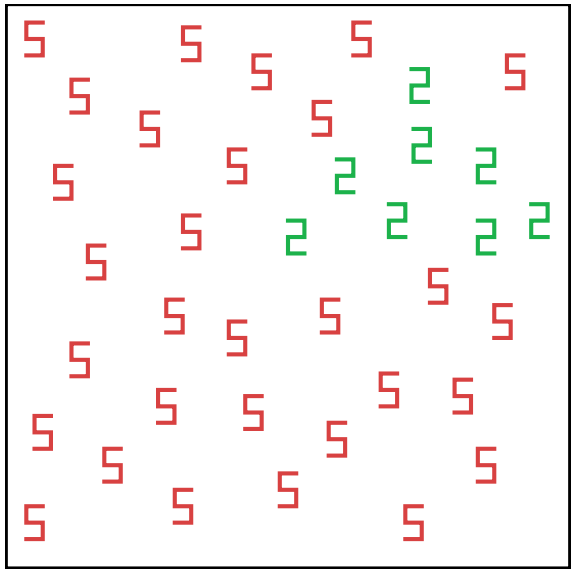

Figure 2.6 - A synesthete would fast, if not immediatly, point out the 2's. The diagram is illustrated as seen by a synesthete

causes an excess of crow-wiring or a defective pruning of connections, hence it runs in families. In regards of the pruning of connections, a well-developed mature brain has fewer connections across the brain than an immature brain. This has been discovered in the fetal macaque, where approximately 70-90% of the connections to V4 are from higher areas, whereas in the adult brain, approximately 20-30% of the connections to V4 are from higher areas (Kennedy et al. 1997). Therefore the defect mutation of pruning leads to continuously persists the internal connections within fusiform gyrus (Ramachandran 2004, p. 69; Ramachandran and Hubbard 2001a). It is important to note that the hypothesis of hyperconnectivity suggests that the cross-wiring allows the opportunity to connect a number with a color. In order to ascribe a certain number to a certain color, one needs the process of learning, as one is not born with number and graphemes hardwired in the brain, but it is possible that if a number has been ascribed a color once, there will be a tendency to strengthen that connection; *"A given number only evokes a single color"* (Ramachandran and Hubbard 2001a). So far, synesthesia has been argued to be of BU determination, but following experiments will evidence that TD signals can influence the perception as well. A quick reminder; ambiguous meaning was influenced by TD, while the visual

information received was of BU signals. First experiment to be mentioned was conducted by Ramachandran (2001a), exposing synesthetes to a number build by another number, see **figure 2.7**. The subjects reported a voluntary switch between colors, implying a modulation of TD influence. Another experiment conducted by Ramachandran (2001a) exposed the synesthetes to an ambiguous figure, namely THE CAT figure, see **figure 2.8**. The subjects report to see the ascribed color to the certain letter, interchangeably between H and A. In brief, the experiments suggest that the concept of a number also creates synesthesia, as several subjects furthermore have reported that the color of a certain number is stronger when imagined, than perceived (Ramachandran and Hubbard 2001a). In this case there are both synesthetes that see the specific color when the specific grapheme is perceived (BU signal), others when the number is imagined (TD signal). In contemporary neurology, the neuroanatomical loci of creating the concept of a number, is not known, although studies have shown when the angular gyrus in the left hemisphere is damaged, the brain cannot perform arithmetic (Grabner et al. 2013; Ramachandran and Hubbard 2001a). As the angular gyrus is placed higher up, adjacent to the temporal parietal occipital (TPO), it has been decided that synesthetes that intermingle sensory with concepts through the angular gyrus and TPO, are higher synesthetes. It is worth mentioning that higher synesthetes have been reported to see colors when imagining the concept of a day, month or year also (Ramachandran and Hubbard 2001a).

"If the faulty gene is selectively expressed in the fusiform gyrus, at an earlier stage in processing, the result is a lower synesthete driven by visual appearance. If the gene is expressed selectively higher up, in the vicinity of the angular gyrus, the result is a higher synesthete driven by numerical concept rather than visual appearance." (Ramachandran 2004, p. 70).

The difference is of conceptual or visual matter; the concept of an abstract thought, such as a number, a day, a month and so forth, can be linked with a sensory, in the same manner sensory information can evoke another as in lower synesthetes. Inspired by Domino's (1989) study by examining creativity in fine arts students, in which it was found that synesthetes are more creative, Ramachan-

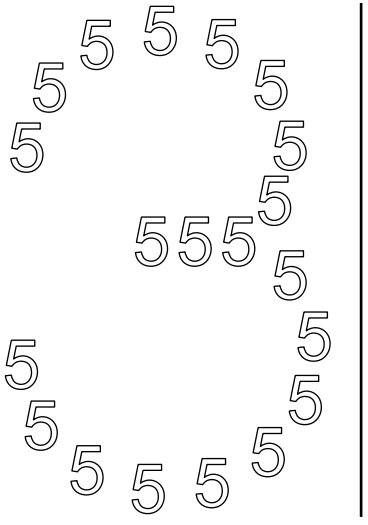

Figure 2.7 - Character ‘3’ made of characters of ‘5’

Figure 2.8 - The ‘H’ is the same character in both words

dran continues to extend the hypothesis of hyperconnectivity. Ramachandran and Hubbard (2001a) suggest that if the ability to cross unrelated concepts, and create metaphors, involves non-topographic conceptual maps, then the cross-activation of perceptual maps in synesthesia may occur in the same manner. In an experiment, attempting to argue that most people are synesthetes, Ramachandran and Hubbard (2001a), uses an example used first time by Köhler (1929), whom was introduced with the psychology of Gestalt. The experiment will entail the auditory and visual connection. Two Martian letters from the Martian alphabet are introduced, see **figure 2.9**. The subject, being the reader, would have to guess which letter is Bouba and which is Kiki. According to the experiment conducted, approximately 95-98% suggests that Bouba is the smoothed letter. In contrast to Kiki, the brain observes visually that Kiki has a sharp inflection, and when presented to the auditory cortex; *“Your brain performs a cross-model synesthetic abstraction, recognizing that common property of jaggedness, extracting it, and so reaching the conclusion that both [the visual and auditory inputs] are Kiki.”* (Ramachandran 2004, p. 72). Interestingly the angular gyrus is located at the crossroad between the parietal lobe (including the somatosensory cortex) and the occipital lobe (including visual cortex), explaining why lesions in the angular gyrus do not permit

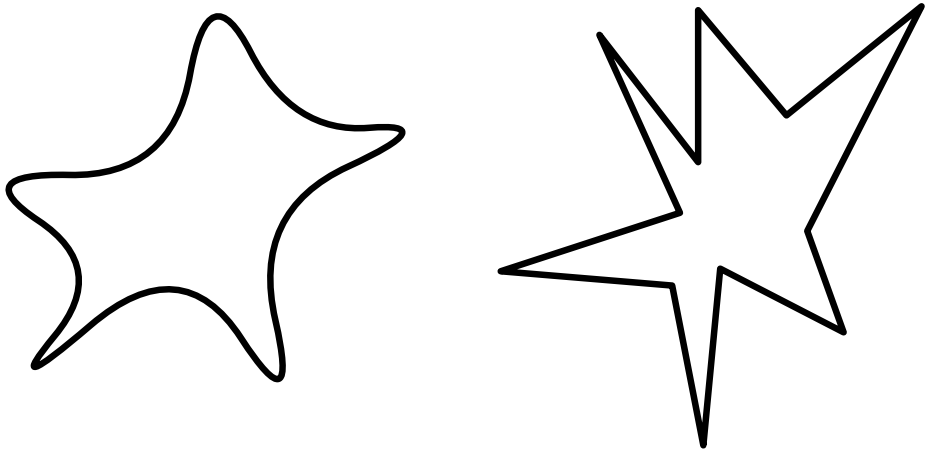

Figure 2.9 - The letters ‘Bouba’ and ‘Kiki’, respectively

cross-modalities. Ramachandran and Hubbard (2001a) continue to suggest that the property of abstraction is highly influenced by the angular gyrus, and that lesions in right or left angular gyrus limits the ability to grasp metaphors, which further might explain why schizophrenias understand metaphors quite literarily.

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So far it has been suggested that creativity and metaphor are related through neural hyperconnectivities in the parietal lobe and angular gyrus. Therefore, the hypothesis of this paper remains plausible, although an investigation of how tactility, in thermal manner, may be related to emotions becomes interesting for several reasons. If the tactility, including the thermosensation, can evoke emotions, then a cross-activation connects the somatosensory cortex and insular cortex to generate emotions. As it has been suggested, that TD signal can influence the perception voluntarily, allowing a change in perception of the visual information; e.g. the number 3 build of 5’s. Therefore the suggestion of placebo effect can bias the BU signal during cross-activation is plausible. Furthermore, the somatosensory cortex comprises four distinct regions; Brod-

mann's area 3a, 3b, 1 and 2. All four areas are involved in processing tactile information (The Somatic Sensory Cortex 2015). In other words; in the same sense that Ramachandran explains Bouba/Kiki-effect, this paper hypothesize that a space get ascribed certain thermosensations and thermoregulations, finding overlapping attributes in sensory and ascribe a certain emotion. The possibility of synesthesia connecting to the insula is yet to be investigated. If so, then as a cause of synesthesia, a sensory signal can influence another, and connect to the insular cortex, resulting in affecting emotions and thus the behavior.

- TD signals can influence the perception during cross-activation, changing the percept voluntarily. This implies that cognitive process can change the percept, meaning placebo effect may affect the final perception (TD signal).

- In the same sense that Ramachandran explains Bouba/Kiki-effect, this paper hypothesize that a space get ascribed certain thermosensations and thermoregulations, without any prior experience to be relied on (BU signal).

- The hypothesis developed by Ramachandran and Hubbard (2001a; 2001b; Ramachandran 2004), substantiates the hypothesis of this paper, namely that the visual signal may have a "hyperconnection" to thermal-decisive area of the brain, and further create a memory-of-the-future. If so, is it possible to regulate the thermal comfortability by visual regulations?

2.4 VISUAL AND TACTILE PERCEPTION

If the visual stimuli can affect the sensory perception, anticipation, thermoregulation and emotion (behavior), then what visual attributes exactly are affecting the brain; is it objects, geometries, lights, materials, compositions or a combination of all the mentioned? Such questions are not directly related to the hypothesis of the paper, but such questions become vital for an architect in order to ascribe the desired emotions, and behaviors, to the specific space. Starting by investigating the visual sense in combination with the tactile sense, in thermal matter, could be one starting point of many combinations, but as the hypothesis is of thermal concern, this combination is essential. It is known that sight as a sense, is vital for the understanding a space. Sight itself allows one to grasp the space in at least three dimensions and to approximate distance caused by binocular vision. Considering linguistics, in English "I see" also means "I understand". Cutaneous sensitivity includes the tactile sense, involving the skin. In general, all primary sensory are described as part of the somatosensory cortex. Sensory inputs from the skin, including tactile, thermal, pain and itch, are all providing information about the homeostatic range of the body (McGlone and Reilly 2010). The connection between the thermal sensation and visual stimuli has not yet been investigated, but an approximation has been made by Ramachandran and Brang (2008a), when investigating the two subjects, whom tactile sense is strongly connected to the emotions. The subjects were tested by observing the emotions when in contact with several textures. The test was redone 8 months later, without the subject knowing a retest would occur, to ensure the emotions were identical. It was reported the emotions were either identical or very close; see **table 1** for textures and emotions (Ramachandran and Brang 2008a). It is worth mentioning that some emotions were rather strong emotions, considering it is a concern of texture. For instance, one of the subjects experienced depression and disgust for denim; specifically blue denim intensified the emotion. The subjects reported that the temperature of the texture changed the emotion, implying the importance of temperature for emotive regulations.

Texture	*First test*	*Second test*
Bok Choy	Irritated	Uncomfortable and annoyed
Corduroy	Disappointed	Unpleasant, felt bad
Denim	Mostly neutral, no real emotion	Neutral, no emotion
Dry leaves	Distasteful, did not want to touch	Disgust, made her feel withered
Fleece	Disgust	Disgust
Lush leaf	Calm, peaceful	Curious, happy
Moist soil	A little uncomfortable	Made her feel damp and gritty
Paper	No emotion	Neutral, no emotion
Plastic paper clip	No emotion	No emotion
Rayon	Relaxed, comfort	Comforted
Ridged plastic	Cool, happy	Kind of fun, happy
Sand	Safe, happy	Fluttery, lighthearted, happy
Silk	Laughter	Laughter
Silk sleeping bag	Relaxing	Calm and neutral
Skin	No emotion	No emotion
Smooth metal	Sedated, calm	Relaxed
Soft leather	Extremely scared, makes her spine crawl	Afraid and repulsed
Tennis ball	Happy	Happy
Textured glove	Creepy, cool, weird	Excited, intriguing
Tylenol gel caps	Fun but weird	Happy
Water (room temp.)	Calm, felt like wet air	Calming, soothing
Water (warm)	Calm, but less so than room temperature	Mildly calm
Wax	Disgust	Disgust

Table 1 - The results from one subject

Furthermore, the experienced sensation was different when placing the texture on the foot, the face or the hand, implying that the emotion is not mediated by memory alone. If the subject established strong emotive association with a certain material, it should not differ according to the limb used to touch. Could the emotions be interpretations of the texture, in analogy of metaphor? If so, is the cross-activation not considerable enough, as arbitrary emotions are connected?

When reconsidering the relation between synesthesia and metaphors, one might question why the increase in cross-activation increases the propensity to non-arbitrary conceptual metaphors. This has been addressed by Ramachandran and Brang (2008a), suggesting that metaphoric sentences describing a meaning through arbitrary senses, such as; a loud shirt, green with envy and so forth, are in fact not arbitrary as such. But a word has penumbras of associative words. For instance, when saying ‘Juliet is the sun’, the brain can decode it

saying the word ‘Juliet’ is associated with: Italian, woman, warm, radiant, nurturing and so on. The brain further finds other words in the penumbra of the word ‘Sun’: warm, radiant, nurturing, solar system, sky, huge and so on. The brain finds the similar attributes and associations and connects the words: Juliet is warm, radiant and nurturing (Ramachandran and Bran 2008). It is here implied that most people are higher synesthetes as the connection is abstract and involve higher processes, whereas lower synesthetes are affected BU. Therefore, the impression of a space is built during the experience of the same architecture, as the brain relates them. If the architect desires to create a certain emotion in a specific space, the anticipation of the space is built in the spaces the user experience before it. The mind does not meet new spaces in a blank manner. In fact, prior experiences are ascribed to space, even easier if the spaces are presented in the same architecture, and thus every sensual perception experienced, until the specific space, contributes to the impression, anticipation and emotions of the space. In other words, the architect is designing a scientific experiment of both synesthesia and placebo, conditioning the users before the actual experiment. As pointed out by Suslick (2012), much of the modern technology relies on crossing sensory, such as visualization of sound, Braille’s alphabet, virtual reality gloves and so forth, which in general all are translations from one sense to another. As Ramachandran (2004, p. 73) used the example of Bouba/Kiki-effect, which is bidirectional translation of the visual and auditory, there are many sensations to be cross-activated and translated into. In fact, there is the possibility of crossing all senses, creating an immense amount of cross-activations. Senses such as tactile, thermal, visual, auditory, olfactory, gustatory and kinesthetic, may all form cross-activation (Suslick 2012). See **figure 2.10** for diagrammatic explanation.

In brief, the Bouba/Kiki-effect ascertains that prior experience is not necessary to relate sensory inputs and become consciously aware of the output. The hyperconnectivity hypothesis suggests that tactile sensation is directly connected with emotions; some have stronger connections than others. The hypothesis of the paper is further substantiated, as space get ascribed an impression, through cross-activation of sensory (such as thermosensation and visual stimuli), which further is related to prior experiences, creating an anticipation, and here the generative prediction model is in use, updating the perception. A neurophysiologi-

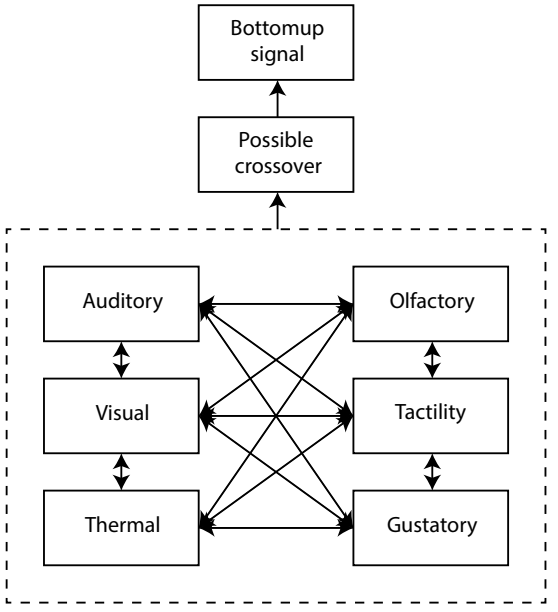

Figure 2.10 - Possible cross-activations

cal suggestion of the connection between tactility and emotions is provided by Ramachandran and Brang (2008a). It has been suggested that the tactile textures evoke highly selective activity in the somatosensory cortex, specifically in the SII. The area SII is known to provide an input to the insula (Kitada et al. 2005), which in turn projects to limbic brain areas, including anterior cingulate (Mishkin 1979). If the cross-activation is heightened between SII and the insula, and further to anterior cingulate, it may lead to synesthesia. The heightened activation could occur of two possible reasons. First, there could merely be an increase in axonal connections, such as in lower synesthetes. Second, there could have been a blocking of feedback modulation caused by transmitter imbalance (Ramachandran and Brang 2008a, 2008b). The second possibility is substantiated by another study by Ramachandran and Brang (2008b), where it has been suggested that 5HT2A receptors are the synesthesia receptors, based on the observations that synesthesia is temporarily lost with SSRI (Selective Serotonin Reuptake Inhibitor). The SSRI causes an increase of activation the serotonin S1, while reciprocally lowering activation of serotonin 2A, being 5HT2A, receptors. Furthermore,

the study suggests *"that the cross-activation in synesthesia is caused by a mutation of gene HTR2A on chromosome 13q"* (Ramachandran and Brang 2008b).

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Firstly, it is worth noticing that there are no readily relations between textures according to the emotions evoked by the subjects; meaning hitherto there is no 'universal' list of emotive relation to materials.

Secondly, given that most people are to some extent synesthetes, at least higher synesthetes, the possibility of crossing several senses is considerable, and should indeed be included in the design process, as it can influence emotions. The fact that visual stimuli can affect behavior has been documented in an interesting study made by Kim and colleagues (1998). The study describes the cloth color preference in the evening under the influence of different light intensities during the daytime. The study concluded that the subjects chose what the subjects themselves ascribed to be a 'warm color', to wear when feeling cold.

- In the same manner linguistic evokes penumbras of a word, it is hypothesized that attributes of a space do so as well. The meaning attributed is influenced by prior characteristic experiences.

- The prior experiences influence the ascribed impression, anticipation and emotions of a space, therefore every sensual perception experienced, until the specific space, have a vital influence. In other words, the architect is designing a scientific experiment of both synesthesia and placebo, conditioning the users.

- A space is constituted by many things, such as; light, spatial geometry, materials, thermosensation and so forth. But as suggested, if few of these characteristic attributes reoccur in later spaces, there is a considerable possibility of relating the spaces.

Hitherto it has been suggested that visual stimuli can affect emotions and thus behavior, implying that thermal comfort can be improved by visual regulations and ascribing, visual attributes, which has been 'learned' by the user in prior experiences.

2.5 NOTICEABILITY OF THERMAL COMFORT

The issue of comfortability in natural ventilated environments, as suggested by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and a hypothesis of using positive alliesthesia in buildings to improve the comfortability developed by de Dear (2010) will be reviewed to substantiate the hypothesis of this paper. The developed model by de Dear (2010) has been further developed to an updated model (Parkinson and de Dear 2015). The main argument by de Dear (de Dear 2010; Parkinson and de Dear 2015) is that the isothermal steady-state uniform environment only has the possibility to reach approximately 80% in satisfied occupants because uniform and steady-state environments leads to thermal neutrality and therefore still indoor air. The steady-state environment only reaches a comfortable level, and rarely a very comfortable level. A study by Arens and colleagues (2006) substantiates that uniform and symmetrical environments are limited to a comfortable level and never reaches higher levels of comfort, while on the other hand asymmetrical and transient environments can provide a higher level of thermal comfort (Arens et al. 2006). The acquired knowledge on perception, regulation and predictive model of expectation will here be used to suggest a solution to the issue of percentage of satisfied occupants. A quick review of the study is presented.

The study by Arens and colleagues (2006) included exposing the subjects to sequences of partial-body cooling and warming over three hours. The collected data included skin temperature, core temperature, thermal sensation and comfort responses for nineteen body parts, and the whole body. The body parts were as following; head, face, neck, breathing zone, chest, back, pelvis and both of; upper arms, lower arms, hands, thighs, lower legs and feet. The results of *"effects of individual body parts on overall sensation and comfort in warm ambient condition"* (Arens et al. 2006) show that when cooling body parts, the overall body thermal sensation is affected differently. For instance the pelvis, back and chest, which are rather big and central body parts, strongly influence the overall thermal sensation, while hand and feet do not affect as strongly. The overall comfort follows back-comfort closely and is not much affected by hand-comfort (Arens et al. 2006). When reviewing the results of *"effects of individual body parts on overall sensation and comfort in cool conditions"* (Arens et al. 2006) it showed that when heating the back, it only have half the effect on overall sensation than cooling the back. Comfort under local warming is similar to sensation, and hand comfort has a small effect on the thermal sensation. An overshoot in local comfort is observed, which is more pronounced than the observed overshoot in the overall comfort, meaning that the local comfort is more comfortable than the overall comfort. The observed overshoot during the tests are implying a tendency to anticipate. Furthermore Arens and colleagues (2006) also found that the overshoot for comfort is more noticeable in local body parts than the overall body. *"Overshoot in sensation and comfort is stronger when local body parts are cooled or warmed than when the whole body experiences a step-change"* (Arens et al. 2006), meaning that local changes are perceived as more comfortable than change in whole body temperature. The overshoot is visualized in **figure 2.11**. The fact that there is an anticipation influencing the comfortability is interesting as this phenomenon might be explained by the earlier suggested framework. The local change in thermal condition is highly valued, as the perceived stimuli tend toward restoring homeostasis, and therefore the predictive model activates the rewarding through the DA system, resulting in a more noticeable comfort (Arens et al. 2006; Büchel et al. 2014; Friston 2010). The perceived stimuli, as mentioned earlier, can either be a BU sensory signal or an expected perception processed by TD expectation. In concluding on the study by Arens and colleagues (2006), the highest levels of pleasantness are associated with transient conditions, and of short durations. *"The "very comfortable" votes happened only in asymmetrical environments, when the local cooling/heating helps remove some level of whole body thermal stress, and/or during transients, in which comfort perception anticipates and overshoots the coincident skin temperature"* (Arens et al. 2006). The notion of transient conditions are more favorable is well reviewed by Parkinson and de Dear (Parkinson and de Dear 2015; de Dear 2010).

'Alliesthesia', a term coined by Cabanac (1971), describes the fact that sensory stimuli can produce both pleasant and unpleasant sensations. There have been studies confirming the fact that positive alliesthesia plays a crucial role in pleasure and motivation, and therefore behavior. *"Such results suggest that alliesthesia is a general property of all sensations, and emphasizes the funda-*

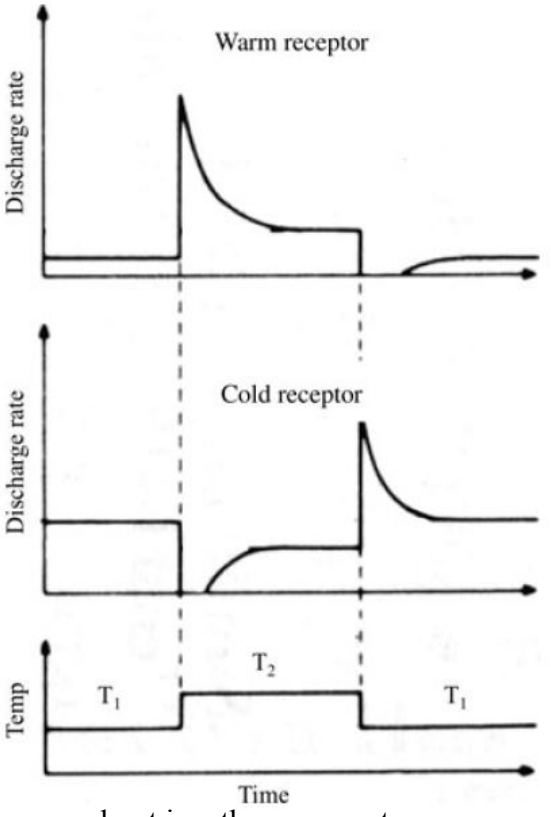

Figure 2.11 - The overshoot in a thermoreceptor

mental role of pleasure in motivation for all behaviors" (Brondel and Cabanac 2007). Positive alliesthesia describes the local change of temperature toward restoring homeostasis resulting in a very comfortable sensation. Parkinson and de Dear (2015) describe spatial thermal alliesthesia and its potential in influencing the overall acceptable thermal model applied in contemporary buildings. Thermal alliesthesia is thermal stimulus on the skin that counters a thermoregulatory load-error and thus will be perceived as pleasant (Parkinson and de Dear 2015). Also, in the article by Parkinson and de Dear (2015) a great deal of criticism on the steady-state heat balance equation is formed on the caption of uniform environment, indicating, as Arens and colleagues (2006), that a dynamic transitional and non-uniform environment to be more comfortable. The thermophysiology

of alliesthesia builds upon the thermoregulatory load-error signal and that the pleasure or displeasure is formed on the response of the environmental thermal stimuli; much in the same manner as free energy principle (Friston 2010). The load-error signal is any deviation from the set-point temperature derived from the body core. The set-point control theory is the depiction of having one single controller for thermoregulations. In brief, the controller would receive inputs from signals throughout the body; comparing the temperature with the set-point; produce load-error outputs in which thermoeffectors respond to (Parkinson and de Dear 2015). But the contemporary view on this subject is that the thermoregulatory system has multiple controllers proportionally controlling through separate thermoeffector loops (Parkinson and de Dear 2015). Positive alliesthesia has been defined as the thermal pleasure, but spatial alliesthesia is a perceptual process driven by cutaneous signals, and do not include the whole body model of alliesthesia driven from load-errors of central origin. The cutaneous sensory system will briefly be reviewed in order to grasp the spatial alliesthesia.

The skin is the ultimate boundary between the organism and its environment, dynamically updating about the microclimate environment surrounding the organism. As argued in previous chapter, sensory modalities function in cross-modal network ensuring a multisensory interaction with the environment (McGlone and Reilly 2010). The cutaneous sensation includes tactile, thermal, pain and itch sensing sub-modalities, but as this paper is concerned with thermal environment, the focus will be on the thermal sub-modality. However, the sub-modalities have been proven to be interconnected channels, albeit when operating in different areas of the brain (McGlone and Reilly 2010; Bentley 1900). The somatosensory system in the midbrain is the primary sensory modality, comprising all peripheral afferent nerve fibers, specialized receptors and cutaneous sensitivity. There exist two kinds of thermoreceptors; those sensitive to cold and those to warmth. Thermoreceptors include both nerve fibers that are myelinated and unmyelinated, meaning that the conduction velocity for instance, include both fast nerve fibers, such as Aδ, and slow nerve fibers, such as C-pain (the axonal diameter is bigger in fast nerve fibers)(McGlone and Reilly 2010). The neural firing rates by the thermoreceptors expose both static and dynamic com-

ponents, where the latter is highly sensitive to local skin temperature changes. Furthermore the cold receptors are more sensitive than their warm counter parts (Parkinson and de Dear 2015). The strongest thermal sensations are evidenced to be at the immediate onset of ambient temperature step-change stimuli, and also ambient temperature cycles suggest that the dynamic response is the cause of sudden change in thermal perception (Kingma et al. 2012). Here, there has been proposed a feed-forward control system, capable of anticipating effects of change and regulate pre-empt significant perturbation of the regulated variable, which is, logically, best placed in the skin for early detection of changing environmental conditions (Parkinson and de Dear 2015). The dynamic stimuli can be grasped as the rates of change at neural sensor sites. This notion is further substantiation of the overshoot phenomenon during temperature changes. Affective psychology theory, as described by Rozin (2003), further substantiate that the central nervous system has the possibility to use rate sensitivities from the thermoreceptors to anticipate the effect on body temperature, and further *"initiate effector actions in anticipatory manner"* (Parkinson and de Dear 2015).

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The phenomenon of overshoot indicates anticipation or at least a *guiding reaction*, which can be explained by the predictive generative model of placebo. Furthermore the study by Arens and colleagues (2006) suggests that local temperature change increases the comfortability, indicating a dynamic and asymmetrical environment is higher valued, than steady-state environment, by the body. The main argument for positive alliesthesia is the local change in skin temperature, within the non-uniform and dynamic thermal condition, into an opposite thermal condition, which, when related to the hypothesis of this paper, comforts the concept of developing an impression by prediction.

- The observation of higher overshoot in comfort than sensation indicates the anticipation by the body, highly rewarding the comfortability, is either a sensory signal or an expectation biasing the sensory signal. This also explains the taste of mint which is always refreshing and cooling regardless of the

thermal experience (Lisa Heschong 1979, p. 24). In retrospect of the hypothesis established in the paper, these sudden local temperature changes, tending toward reestablishing homeostatic balance, can be reached by TD process biasing the BU signal. In other words, allowing the expectation to bias the sensory signal.

- Local temperature changes and asymmetrical and dynamic environment is evidenced to be more comfortable and thus higher valued by the homeostatic regulation.

2.6 NEUROPHYSIOLOGICAL RELATION

The suggested predictive model by Büchel and colleagues (2014) suggest a hypothetical neurophysiological system, where a few areas has been omitted merely to simplify. The system is based on placebo analgesia, which is pain relief by placebo. But as the interactions in the prefrontal cortex (PFC) and the PAG-RVM-spinal cord axis also circuit opioid, DA, serotonin and oxytocin systems, which are neurochemical systems that are involved beyond pain behavior, then placebo-modulation of pain is merely an example of a broader pattern of regulation (Büchel et al. 2014; Wager and Atlas 2015). Using TD signal as a point of departure, it has been evidenced that the final segments of the TD modulatory system comprise PAG, RVM and the spinal dorsal horn. Within RVM and PAG there are distinctive cells that exhibit a pause of firing during analgesia. The pause of firing is named 'Off cells', while the firing of cells is named 'On cells'. In general the PAG-RVM-spinal cord is important for both pro- and anti-nociception. For instance, morphine –analgesia require opioid-DA communication in the VTA and NAC, which furthermore influence the 'Off cells' in RVM (Wager and Atlas 2015). An activation in the 'Off cells', as described, is termed descending pain modulatory systems, meaning a TD signal biasing BU signal resulting in pain relief. As one can see on **figure 2.12**, the PAG receives direct information from vmPFC, ventral lateral PFC (vlPFC), AMY, NAC and hypothalamus, which allows the PAG to control limbic and prefrontal cortical afferent and central pain circuitry. Furthermore the PAG have been evidenced to be activated during emotional responses (Buhle et al. 2012). Buhle and colleagues (2012) tested subjects by fMRI and found that subjects exposed to both physical pain and negative image viewing showed an increased activity in the PAG. Regarding pain, the most consistent place-related increase in response occur in the cortical regions, including dorsolateral PFC (dlPFC), vlPFC, vmPFC, medial orbitofrontal cortex (OFC), mid-lateral OFC (mlOFC). These areas show anticipatory increases in activity before pain, and responses in these areas can predict the strength of placebo analgesia (Wager and Atlas 2015). Knowing what areas increase in activity during placebo, allows future studies to interpret their results as possibly an effect of placebo, if activity in the mentioned areas arises.

Considering that the placebo effect is mainly a TD biasing a BU signal, it becomes interesting to see the impact of TD signals in other studies than placebo analgesia. Other studies, such as studies in stress and cortisol release, substantiate the hypothesis of biased competition of TD and BU. A study by Yvonne and colleagues (2014) suggests that the stress responses, which are mediated by the overlapping circuits in limbic forebrain, hypothalamus and the brainstem, contribute to the neuroendocrine and autonomic systems. The limbic regions, which regulates the stress responses further intersects with circuits responsible for memory and reward, providing a means to tailor stress response to experience and the anticipated outcomes (Yvonne et al. 2004). This indicates the stress response, which influences the regulation of neuroendocrine and autonomic system, is further influenced by the placebo effect.

What is interesting, as an architect, is the mapping of the psychological mechanisms onto the complex systems in the brain. It is known that the emotions are directly connected to behavior, so when relating placebo effect with emotions, the DA in particular, the neurophysiological explanation seems rather logic as presented by Wager and Atlas (2015). Wager and Atlas (2015) states that the principal approach to placebo paradigms include following elements:

(i) The presentation of sensory cues which will be associated with positive outcome, for instance pain relief, or negative outcome, for instance a shock through conditioning.

(ii) Verbal suggestion to induce expectation of improvement or exacerbation.

(iii) Rich contextual associative cues, a hospital for instance, and information about the interpersonal relationship, for instance knowing that the treatment is by an expert.

The distinction between pre-cognitive processes, that are independent of expectations, and conceptual processes, that are dependent of expectations, is useful, as conditioned clues, for instance, can evoke pre-cognitive associations, in the

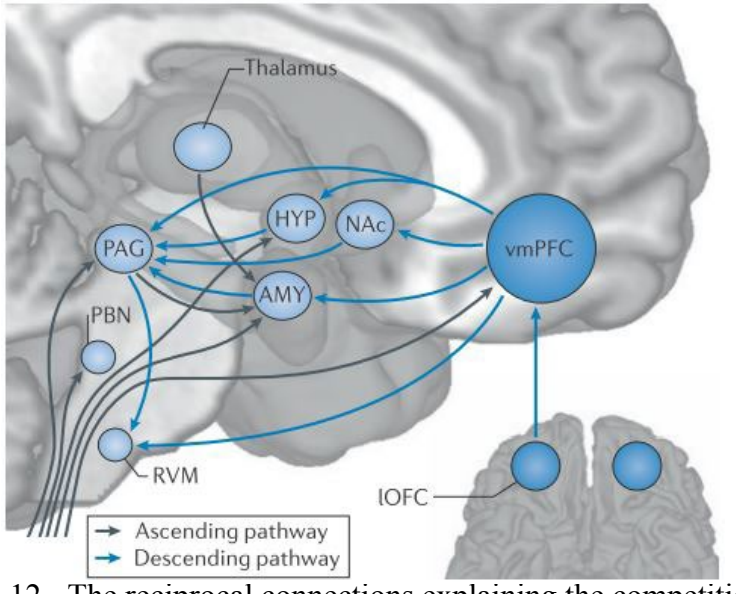

Figure 2.12 - The reciprocal connections explaining the competition

form of memory supported by the neuroplasticity changes in specific circuits. Depending on the circuits and the location, it can trigger neuroendocrine and autonomic responses, and thus influence emotions and behavior. *"Although placebo effects can encompass symptom reports, physiological signs and other behaviors, it is far from clear which brain pathways are essential for the effects on each type of outcome"* (Wager and Atlas 2015). There is not enough knowledge in this field in order to correctly map the outcome onto the brain, therefor future studies have the responsibility of doing such findings. Not only studies in neurophysiology and pathophysiology, but also in architecture, especially when, as argued by Wager and Atlas (2015), the context can influence the behavior.

The prefrontal areas create meaning for conceptual process, which makes the area a natural candidate for placebo outcomes. A study by Chib and colleagues (2009) evidenced that the vmPFC is the main influence of valuations, as the vmPFC ascribes a common currency that allows for a shared valuation for categories of goods (Chib et al. 2009). In understanding what mechanisms are influencing brain process and thus autonomic and endocrine regulations, Wager and Atlas (2015) suggests, that the studies that includes the three elements mentioned before, commonly results in an emotion-modulatory circuitry. These studies involve creating expectations by verbal suggestions and reinforcing the expectations through conditioning. Thus the placebo-induced modulations can be created by either; (i) belief in placebo, (ii) expectation of positive outcome or (iii) association learned through reinforcement. Although, studies have shown when combining these elements, a stronger placebo effect is obtained. The study by Carlino and colleagues (2015) concludes the article by *"In line with the cognitive theory of conditioning, our results indicate that just pairing a cue with different pain stimulus intensities is not sufficient, per se, to produce a learning process. What matters is the informational cognitive content of the cue, i.e. the meaning assigned to the cue itself"*.

The reinforcement, as used above, is the consciousness interacting with the prior experiences, using it to ascribe an attribution. In other words, the conceptual process is related to prior experiences by guiding attributions. These attributions can be defined as the process of ascribing an observed effect to a cause of mechanism (Wager and Atlas 2015). For instance, if one is to take a pill for relieving headache. After one hour, the headache is perished. One attributes the perishing to either the pill or the natural course of events. Studies show that both the attribution of efficacy and the reduced symptoms are required for conditioned analgesia, meaning that activation in the PFC after the placebo may guide the attributions of efficacy. If the attributions support the treatment, the learned placebo may be strengthened in other systems, such as AMY, NAC-VS and the brainstem (Wager and Atlas 2015; Morton et al. 2010). Furthermore, the study by Morton and colleagues (2010) concluded that when receiving a placebo treatment, the effect cause a lasting change in the cognitive, PFC, processing of pain. So there seems to be a possibility of self-reinforced placebo. If the placebo causes lasting changes in the PFC, up to 6 weeks (Morton et al. 2010), then the effect is reinforced over time, until reaching a point of neutrality. As suggested by Wager and Atlas (2015): *"First, if experienced benefits are attributed to a treatment when they match prior beliefs (for example, when pain experience is low) but not otherwise (for example, when pain is high), then disconfirmatory experiences will be discarded and belief in the placebo will persist. Second, if placebo treatments have deep effects on the sensory processes that give rise to symptoms (for example, spinal responses to painful events), belief in the placebo will not be disconfirmed*

because the ascending noxious input will be dampened" (Wager and Atlas 2015).

As mentioned, there are no specific studies that specify the psychological predecessors produce placebo effects on specific systems and outcomes (Wager and Atlas 2015). The suggested mapping of the psychological mechanisms is presented in **figure 2.13**. The figure explains how the signs, symptoms and behavior are influenced by the context, where the conceptual process influences the expectation, appraisal and memory, and the pre-cognitive associations influence the physiological process that are not within the reach of conscious control, such as the sensations, autonomic response and tendencies and hormones. These mentioned responses can influence the emotions, motivation and affective states, which ultimately influence behavior.

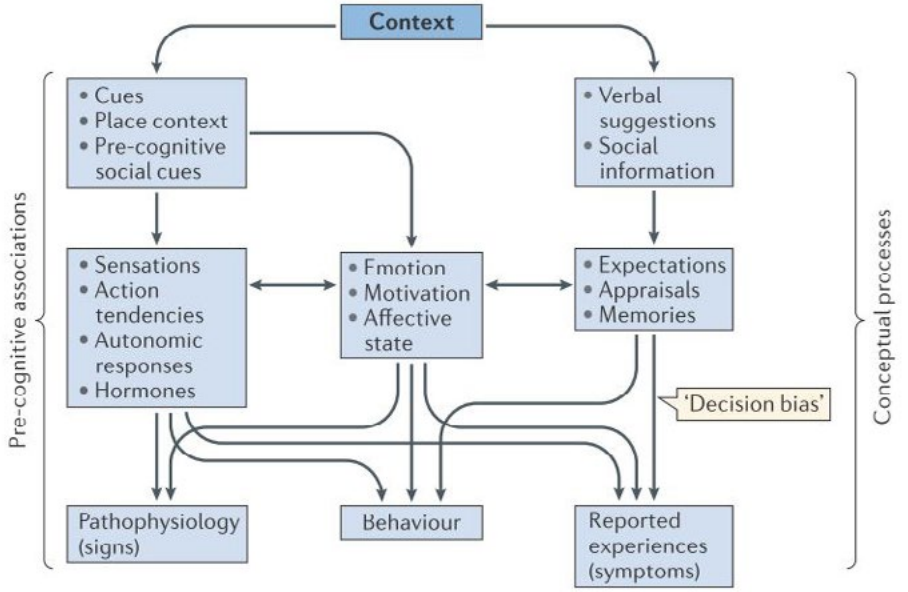

Figure 2.13 - The reciprocal connections explaining the competition

SUBSET

Activity in dlPFC, vlPFC, vmPFC, OFC and mlOFC, can describe the strength of placebo analgesia, and if the strength is strong enough the learned placebo can last for about 6 weeks after the experiment. It means there is a self-learning ongoing mechanism in the brain, slowly but surely readapting to the BU signals in the environment. The mechanism implies that the learned placebo is still intact during change of space, and therefore becomes a guiding mechanism for the body when considering architecture. According to the mapping by Wager and atlas (2015), the learned placebo is affecting the memory and place context. How memory and place context are related to autonomic responses, may explain what Lisa Heschong meant when writing: *"Simply being reminded of the cold winter storm outside can make us enjoy the warmth of the fireside more intensely [...]"* (Heschong 1979, p.22)

- In using the three elements traditionally used in placebo experiments, as presented by Wager and Atlas (2015), where the outcomes seem to correspond, it becomes interesting to see how these elements might be translated to architecture.

  - The presentation of sensory cues which will be associated with positive outcome, for instance positive alliesthesia, or negative outcome, for instance negative alliesthesia.

  - Visual suggestion to induce expectation of improvement or exacerbation.

  - Rich contextual associative cues, a geometric spatial characteristic for instance, and information about the interpersonal relationship, for instance knowing that the treatment is by an expert (architect).

2.7 CONCLUSION OF PART II

The hypothesis is re-presented:

With the knowledge of cross-activation by sensory systems, it is not impossible to imagine a cross-activation of visual perception and thermosensation, leaving the mind in an ambiguous and instable state. The hypothesis is that when the cross-activation of the mentioned senses occurs, and the two percepts are ascribed to be contradictory, it leaves the mind in an instable state, forcing one perception, interchangeably, to make a decision toward a stable state, which might be substantiated by synesthesia and hereby other senses.

It can be concluded that the placebo effect, as explained by the predictive model and free energy principle (Büchel et al. 2014; Friston 2010), is a plausible suggestion to understand how the body updates the perception either by TD or BU signals. The predictive model has been further substantiated by explanations of neurophysiological connections. It can also be concluded that the body regulates according to the peripersonal space, and might be influenced by the extrapersonal space. The hypothesis of hyperconnectivity as suggested by Ramachandran (Ramachandran 2004, p. 60-82; Ramachandran and Hubbard 2001a; 2001b; 2005; Ramachandran and Brang 2008a; 2008b) is plausible as an extension of the predictive model, which substantiate the hypothesis of the paper. It is important not to understand the hypothesis of the paper as a counterargument for the concept of integrating positive alliesthesia through personalized thermal control systems, but rather as confirmation. The hypothesis of the paper agrees on the local cutaneous changes in temperature are met with high comfortability, but the hypothesis suggests that if the expectation and sensory signal are "not too far away", the possibility, of TD expectation biasing a BU signal, is enhanced. The main goal of the hypothesis is that creating aspects of outside indoors can improve the thermal comfort partly by visual and thermal sensory signals and by cognitive expectation relying on experience. Otherwise, it can be concluded that alliesthesia in visual stimuli plays a crucial role for a pleasant or unpleasant experience. The study by Kim and colleagues (1998) confirmed

that the exposure to different light results in choosing a different, warmer, color.

How can this new knowledge be implemented in a design process? Knowing how mental representation is effected by either TD or BU process and further creating an expectation of certain spaces, allows the architect to choose wisely between aspects that share attributes with other sensory. A new aspect of architecture is introduced. For instance, if the architect list a number of parameters that change a space, e.g. material, height of space, fillet radius of edges, spatial continuum, singularity and stability, ascribing each of the extremes either an outdoor aspect or an indoor. In this way, the "outdoor" space presumably creating an expectation of hypothermia, in fact is actual hyperthermia, creating an ambiguous and instable percept both in thermoreceptors and visual perception. The presence of pleasure when expanding the neural network is substantiated by several studies (Zeki 2006; Stadler et al. 1995; Stadler and Kruse 1995; Mallgrave 2011; Ramachandran 2004, p. 76; Ramachandran 2011)

Of course, what has been reviewed here is a matter of many themes which each deserves full attention in order to fully grasp the function of for instance; associative plasticity, perceptual learning and memory, attention and biased competition and so on. These are all themes that need to be fully comprehended to form a solid base of the suggested solution to the problem formula. Hopefully when these thematic are investigated, questions such as; *"how can architecture affect the competition of reaching perception between the TD and BU processes - where does the specific impression/expectation of a space come from - where are they formed, and how can you disprove/contradict them?"* can be answered more specifically.

Part III

Evaluation

A short evaluation will be made in order to implent the acquired knowledge into a design-process.

3.1 RESEARCH SUMMARY

In the introduction few projects and statements from architectural theorists were presented. These statements all pointed toward the issue of perception and reality. It was investigated in Part I how the perception and reality converge and whether it is possible to disturb the perception and thus create imbalance in the perception or the world. It was further investigated how the mind withstand such imbalance, in which it was concluded that dopaminergic release was present. In Part I a hypothesis was formed in order to further investigate the driving forces of misbalancing the perception. It was suggested to use placebo effect as a point of departure, which later leads to synesthesia and ultimately alliesthesia. The main goal, as stated in beginning chapters, is to increase the percentage of 'very comfortable' users in spaces, and to create both a new perspective on thermal comfort, and to introduce a new perspective on architecture. Additionally, the field of metaphor was briefly explored and used as support for creating meaning by creativity. In fact, it is a major key to the hypothesis. These goals are believed to be accomplished.

3.1.0 - CONCLUSION

Throughout the hunt on either validating or invalidating the formed hypothesis, much more knowledge has been acquired, triggering other ideas and other hypotheses which include architecture. The field of interpreting the neuroscientific knowledge which is the artistic and architectural part is fascinating as the field is heavily expanding in this century. Architecture specifically is carefully balanced between science and art, thus making it possible to use neuroscience to further understand the art. In conclusion, the formed hypothesis is substantiated by multiple theories, including placebo effect, synesthesia and alliesthesia. Thus the hypothesis can be used to create both principles and analysis. This specific approach have introduced a new aspect of architecture, giving the possibility to view a project differently than before, namely the visual information of thermal comfort and thus the expectation. Furthermore, creating metaphors through visual and thermal attributes seems a possibility for increasing the thermal comfort.

3.1.1 - FURTHER RESEARCH

Regarding neuroscientific knowledge, further research should include the notion of Savant hypothesis which has been developed by the ingenious Allan Snyder, as the hypothesis deals explicitly with the creation of creativity. In general, the fields of neural network, predictive Bayesian coding, multistability and synesthesia in architecture, are all major fields, expanding the current notion of architecture. Regarding artistic movements, the basis of surrealism, as stated by Breton's manifest in 1924 (Breton 1924), is built upon the transition from the actuality to/from reality. Indeed surrealism needs to be further investigated and suggestively modernized.

Following research questions should also be answered: Where does the impression/expectation of a space come from? As a space includes more than merely visual perception and thermal sensation, it becomes vital to grasp, neurophysiological where the construction of the anticipation to a space, as a whole, is constructed; what are the variables, how are these variable constructed, why these variables in particular? There are many questions, and after this paper one must realize, that these questions do not contain straightforward answers.

3.1.2 - THEORY TO PRACTICE

In general, when crossing what seems as two different fields, the issue often appears to be going from theory of one field to practice in another. In this case, the paper has been dealing with many fields, although generally it can be summarized as neuroscience versus architecture.

There has been made many suggestions of how the acquired knowledge can influence the design, but the issue to be addressed when doing architectural research using neuroscience, is the translation of information. How can neuroscience influence the architect and architecture? The question states two issues, whom have different approaches. When informing the architect it is knowledge as, for instance that enlarging the neural network can improve creativity that inform the architect on how to expand creativity for himself. But when considering the architecture, the issue is on how to improve the architecture according to the

user; meaning that neuroscience in this case can have inputs on how architecture can influence behavior, which for instance has been attempted to do in this paper. It was first assured that architecture is a matter of senses, hereafter it was suggested how a dominating sense is involved with the world, which lead to neuroscientific explanations of how the brain and body are related to the world. How the brain and body are related to the world, has been the task for architecture in centuries to explore, and solely neuroscience is not necessarily the answer, as architecture is involved in many fields, such as; anthropology, statistics, engineering, philosophy and so forth. Therefore, the design parameters to be made of the paper have to be intelligently chosen, in order to allow the freedom of design for the architect. The proposals should nonetheless allow other solutions to be employed and still fulfill the proposal. For instance, a parametric solution should be acquirable in combination with the proposed principles. Therefore, the proposed principles should be grasped as guiding lines for an architect, rather than mandatory targets.

3.1.3 - THE FOUR PRINCIPLES

The following list has been established on the basis of the hypothesis and acquired knowledge hitherto. The principles will be broad, in the manner that they can be used in any architecture, as they merely advance the possibility of ambiguity, synesthesia and alliesthesia.

1. **Sequenced order.** The order of sensory perception of the user. According to the written theory, the spaces leave impressions through, inter alia, geometric character (visual), material (tactile), smell (olfactory), thermal comfort (thermoreceptors) and every sense in general, which will be reference points of the experience of the next space. Thus, this principle is vital to constitute the hypothesis. Translating this principle to architecture, it can be grasped as the usage of creating a sensorial metaphor in a space, independently of the next spaces. The word metaphor is used loosely, and deserves a definition; when crossing two, or more, independent sensory which imply a specific anticipation related to the initial sensory. This principle is the separation of spaces, and the linking of spaces, as it ensures the independency of spaces, while using their sensory perception to

imply an anticipation of next space.

2. **Ambiguous belief of navigation**. According to the developed hypothesis and place-cells, an ambiguous belief should be constituted to force more sensory, and possibly cross-activation of such, to be activated. The instability of navigation can stimulate more sensory cross-activation. Translating this principle to architecture, it can be grasped as the capability of bewildering the navigation of the user. Crossing mid-air walkways in an atrium, without the possibility to visually anticipate the navigation of getting there, can be considered an ambiguous belief of navigation. Leaving out the visual “how-to-get-there”-information is the essence.

3. **Thermal perception list.** Divide sensory perceptions into a thermal perception list. The characteristic features of the perceived are enlisted into a gradient temperature list. The list is used to ensure the ambiguous state. The characteristics of a space become the metaphor when re-experiencing them in another space. The characteristics can be introduced as materials, geometric/spatial character, a certain smell or even a piece of furniture, as long as the characteristic is related to the thermal sensation.

4. **Fictive motion.** A metaphorical potential of motion through space, evoking dynamic imagery. Space and time are interrelated through metaphors, creating a fictive motion. The architecture then reaches an animate state of being. As visual perception is the dominating sensory, this will create dynamic movements and can be constituted by deforming geometry in a specific reoccurring direction. This principle can be considered as obtained if the architecture indicates motion.

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5.1 ILLUSTRATION LIST

Process diagram: http://www.worldhealthdesign.com/Neuro-architecture.aspx

Figure A: http://www.3ders.org/images/sydney-opera-house-6.jpg

Figure B: http://globalfinance.zenfs.com/en_us/Finance/US_AFTP_SILICON ALLEY_H_LIVE/New_Yorks_JFK_Airport_is-dd725d9e 551b1a96ace3963350301711

Figure C: http://www.francethisway.com/images/places/ronchamp-chapel.jpg

Figure D: http://www.architecturetoursla.com/gallery/10a.jpg

Figure E: Own replica

Figure F: Own replica

Figure G: https://upload.wikimedia.org/wikipedia/en/1/1f/Ren%C3%A9_Magritte_ The_Human_Condition.jpg

Figure H: http://fumitaro.pixnet.net/album/photo/72975369

Figure I: http://www.fondationlecorbusier.fr/CorbuCache/410x480_2049_622.jpg?r=0

Figure J: http://www.architetturadipietra.it/wp/wp-content/uploads/2008/03/magia_superfici.jpg

PART I

Figure 1.0: Own ill.

Figure 1.1: Own ill.

Figure 1.2: Own ill.

Figure 1.3: Own ill.

Figure 1.4: Own ill.

Figure 1.5: Own ill.

Figure 1.6: (P. 140) - Mallgrave, H. F., 2011. The Architect's Brain: Neuroscience, Creativity, and Architecture. 1 Edition. Wiley-Blackwell.

Figure 1.7: http://3.bp.blogspot.com/-PkWWjCxRr20/VeLIJajRIoI/AAAAAAAAC3c/tASVtAYBW74/s1600/cerebro-ganglios%2Bbasales-cortex.png

Figure 1.8: https://bioluliaes.files.wordpress.com/2013/05/hypothalamus 1318026807983.png

Figure 1.9: http://www.buzzle.com/images/diagrams/nervous-system/fornix-structure.jpg

Figure 1.10: Own ill.

Figure 1.11: Own ill.

Figure 1.12: http://www.webexhibits.org/arrowintheeye/i/robustness1_large.jpg

Figure 1.13: http://www.quia.com/files/quia/users/aaronportengagh/PerceptInterpret/Ames-Room.gif

Figure 1.14: Own ill.

Figure 1.15: School Of Athens by Raphael (Raffaello Sanzio da Urbani). Made in 1509-1511. http://jackiewhiting.net/ArtHist/Images/SchoolAthens.jpg

Figure 1.16: Own replica

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Figure 1.18: Own ill.

Figure 1.19: http://3.bp.blogspot.com/-guwXHSsi-Dw/TkdLc4pnaKI/AAAAAAAAAIY/HpCqFoHJ5J0/s1600/wife+and+mother+in+law+optical+illusion.bmp

Figure 1.20: Own ill.

Figure 1.21: Own ill.

Figure 1.22: Own replica after: Stadler, M., Kruse, P. and Strüber, D., 1995. "The significance of perceptual multistability for research on cognitive self-organization". Ambiguity in Mind and Nature: Multistable Cognitive Phenomena (Springer Series in Synergetics). 1 Edition. Springer.

Figure 1.23: http://www.maxdudler.com/files/gbz_gl_21.jpg

PART II

Figure 2.0: Büchel, C., Geuter, S., Sprenger, C. and Eippert, F., 2014. "Placebo Analgesia: A Predictive Coding Perspective".Neuron 81, March 19: p. 1223-1239

Figure 2.1: Own ill.

Figure 2.2: Friston, K., 2010. "The free-energy principle: a unified brain theory?". Nature Reviews Neuroscience | Aop, published online 13 January 2010: p. 1-12

Figure 2.3: Friston, K., 2010. "The free-energy principle: a unified brain theory?". Nature Reviews Neuroscience | Aop, published online 13 January 2010: p. 1-12

Figure 2.4: Friston, K., 2010. “The free-energy principle: a unified brain theory?”. Nature Reviews Neuroscience | Aop, published online 13 January 2010: p. 1-12

Figure 2.5: Own ill.

Figure 2.6: Own replica after: Ramachandran, V.S. and Hubbard, E.M., 2001b. “Psychophysical Investigations into the Neural Basis of Synaesthesia “. Proceedings: Biological Sciences, Vol. 268, No. 1470: p. 979-983.

Figure 2.7: Own replica after: Ramachandran, V.S. and Hubbard, E.M., 2001a. “Synaesthesia - A window into perception, thought and language”. Journal of Consciousness Studies, 8, No. 12: p. 3–34.

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Figure 2.10: Own ill.

Figure 2.11: After: Kingma, B.R.M., Schellen, L., Frijns, A.J.H. and van Marken Lichtenbelt, W.D., 2012. “Thermal sensation: a mathematical model based on neurophysiology”. Indoor air, 22, no.3:: p. 253-262.

Figure 2.12: After: Wager, T.D. and Atlas, L.Y., 2015. “The neuroscience of placebo effects: Connecting context, learning and health”. Nature review, Neuroscience, 16: p. 403-418.

Figure 2.13: After: Wager, T.D. and Atlas, L.Y., 2015. “The neuroscience of placebo effects: Connecting context, learning and health”. Nature review, Neuroscience, 16: p. 403-418.

Equation 1: After: Büchel, C., Geuter, S., Sprenger, C. and Eippert, F., 2014. “Placebo Analgesia: A Predictive Coding Perspective”.Neuron 81, March 19: p. 1223-1239

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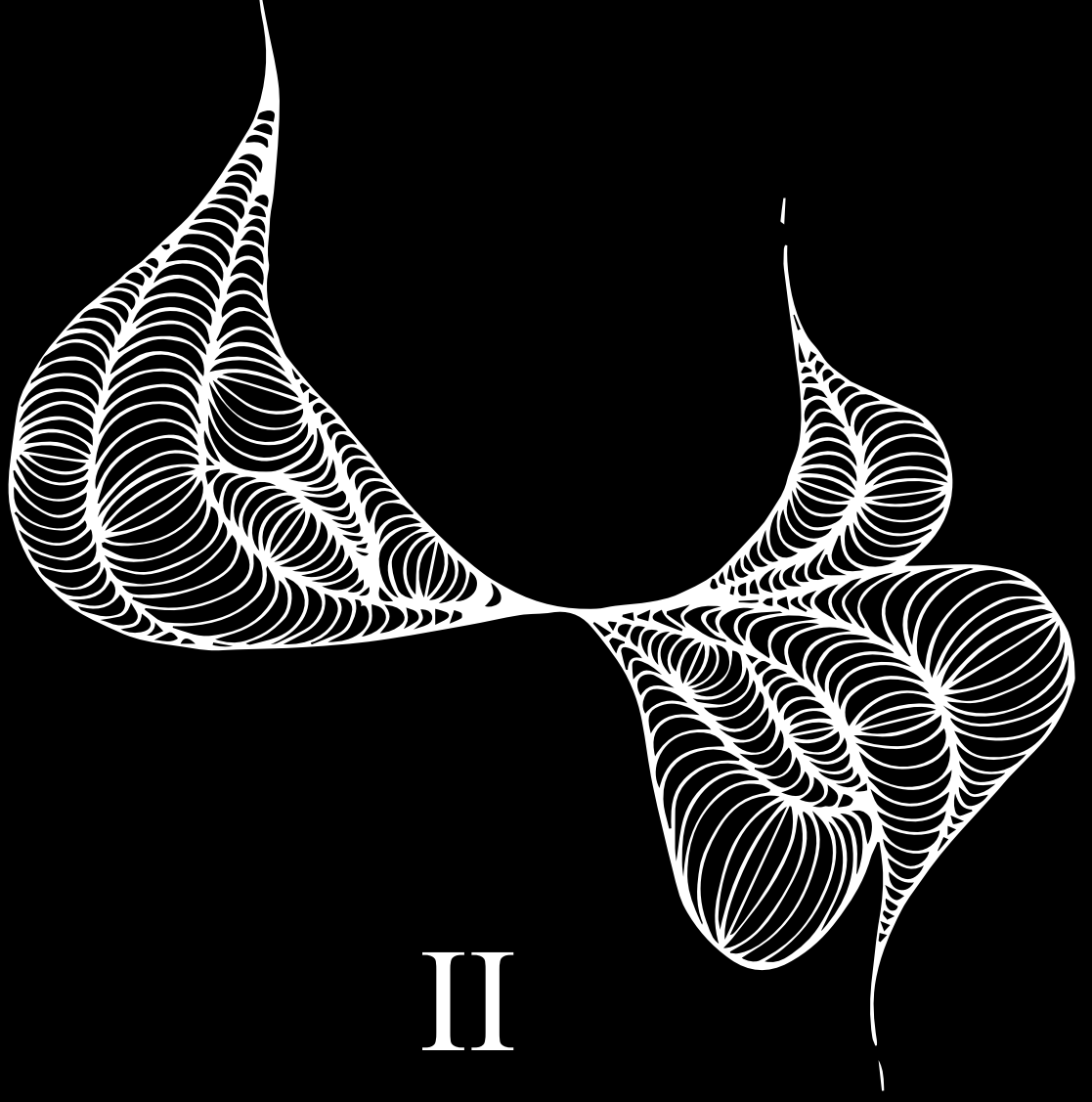

II

Beyond Thermal Comfort

A neurophysiological approach to architecture

MSc04 - master thesis by Zakaria Djebbara. Aalborg University 2015/2016

Title: Beyond Thermal Comfort

Part No: 2
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Author: Zakaria Djebbara

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Zakaria Djebbara

ABSTRACT

The following report is the second part of a Master Thesis based on a neurophysiological approach to architecture. As the first part has established a list of architectural principles, a project, appropriate to the theoretical framework, has been applied into an academic project. The project aims to build a thermal bath in Úlfarsfell, Reykjavik, Iceland, in agreement with the list of principles. Thermal conditions are in particular point of convergence, as the principles developed depend on interpretation of thermal sensory.

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I

Introduction

Introduction of Thesis

”Yesterday I was clever, so I wanted to change the world.

Today I am wise, so I am changing myself.”

Jalal ad-Din Rumi

Methodology

First statement
As the theory developed throughout Beyond Thermal Comfort has brought a new approach towards architecture, the principles developed will be used in the project to follow through. Instead of doing historical analysis and studies of other projects, basing the ultimate design on historical experience, the principles will here directly be applied to the architecture, following the theory of a neurophysiological approach to architecture. In other words, instead of basing the architecture on earlier projects, this approach allows a measurable entity using the developed principles of the theory. The project is thus developed on a scientific influence. Therefore mainly physical and technical analyses are introduced and only a brief analysis of the theme, as these thematic analyses advance insight of what a thermal bath in Iceland entails. This first statement of method is paramount to further grasp the argumentation occurring during the design process.
The theoretical principles developed should be grasped as guidelines advancing the possibility of ambiguity in architecture, and are reviewed in next chapter.

IDP
The method for design, is Integrated Design Process (IDP) as developed by Knudstrup (2004, p. 231-234). The intention of using IDP, which entails five phases, ensures technical, functional and aesthetic quality, by allowing the proposals developed to be looped and evaluated using specific analyses, which in this project entails the principles from the developed theory, and also both physical and technical analyses. As the approach is different than aforetime, each phase of IDP is thoroughly described according to this project.

1. Problem phase
A brief of the project is described and forms the problem seeking an architectural solution. The Statement of problem commences the design, as the brief is analyzed and the points of interest are extracted to grasp what the clients wish, and to compose an aspect of which analyses and functions are relevant. This phase becomes the framework of the project, and thus should be described very exact.

2. Analysis phase
Using the points of interest, analyses of the site, in terms of infrastructure, climate, geology, topology and demography, should only include physical measurable data. Furthermore, the functions of the design are also introduced in this phase, by using the principles from theoretical part according to the Statement of problem. This ensures an integration of theory in the project. Only physical and technical analyses are applicable, as the principles developed are the drive of the project. Contextual and geological analyses are included to ensure a correct perspective of the chosen site.

3. Sketching phase
Within this phase, the analyses are translated into physical sketches and models, including plans, sections, details, perspective. Also digital tools are used to shaping the proposals, such as size of room, windows etc. related to energy consumption and daylight factor. The creativity is driven by the principles, thus the proposals developed in this phase are according to the theory, ensuring integration of theory. Iterations pursuing validation from analyses are paramount and essential for this phase. Argumentation of quality of design is measured according to the principles and analyses from earlier phase.

4. Synthesis phase
By extending the solutions, acquired in the sketching phase, the project starts to form the detailed construction, the energy demand, architectural and functional qualities and supports the coherency of the iterations. Also this phase is evaluated according to analyses. As the principles are designed to ensure ambiguous experience, the principles are used thoroughly and the project can be measured using the level of appliance of the principles.

5. Presentation phase
This final phase constitutes presentation, and should represent the technical, function and aesthetic qualities. The spaces representing the principles the best should be visualized and presented. This phase also includes energy calculations, plans and sections. Physical models are also included. The project must be emphasized within this phase.

Summary
The method presented ensures an integration of wisely chosen analyses, including the principles developed in theoretical part, through iteration between analysis, sketching and synthesis phases. Leaving out analysis of theme and earlier projects, this thesis projects obtains a scientific approach. Finally a presentation, using digital tools and physical model, will emphasize the project. Figure 01 illustrates the method diagrammatically.

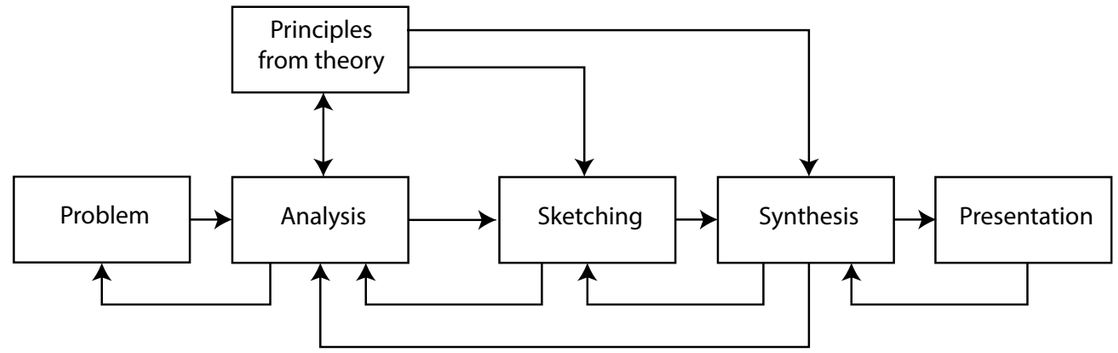


Fig. 01 - Method

Theory to practice

The theory developed and used in this project, concluded on four principles, and can be read in detail in the other separate report; Beyond thermal comfort.

The following list has been established on the basis of the hypothesis and acquired knowledge hitherto. The principles will be broad, in the manner that they can be used in any architecture, as they advance the possibility of ambiguity through placebo, synesthesia and alliesthesia.

1. Sequenced order. The order of sensory perception of the user. According to the written theory, the spaces leave impressions through, inter alia, geometric character (visual), material (tactile), smell (olfactory), thermal comfort (thermoreceptors) and every sense in general, which will be reference points of the experience of the next space. Thus, this principle is vital to constitute the hypothesis. Translating this principle to architecture, it can be grasped as the usage of creating a sensorial metaphor in a space, independently of the next spaces. The word metaphor is used loosely, and deserves a definition; when crossing two, or more, independent sensory which imply a specific anticipation related to the initial sensory. This principle is the separation of spaces, and the linking of spaces, as it ensures the independency of spaces, while using their sensory perception to imply an anticipation of next space.

2. Ambiguous belief of navigation. According to the developed hypothesis and place-cells, an ambiguous belief should be constituted to force more sensory, and possibly cross-activation of such, to be activated. The instability of navigation can stimulate more sensory cross-activation. Translating this principle to architecture, it can be grasped as the capability of bewildering the navigation of the user. Crossing mid-air walkways in an atrium, without the possibility to visually anticipate the navigation of getting there, can be considered an ambiguous belief of navigation. Leaving out the visual "how-to-get-there"-information is the essence.

3. Thermal perception list. Divide sensory perceptions into a thermal perception list. The characteristic features of the perceived are enlisted into a gradient temperature list. The list is used to ensure the ambiguous state. The characteristics of a space become the metaphor when re-experiencing them in another space. The characteristics can be introduced as materials, geometric/spatial character, a certain smell or even a piece of furniture, as long as the characteristic is related to the thermal sensation.

4. Fictive motion. A metaphorical potential of motion through space, evoking dynamic imagery. Space and time are interrelated through metaphors, creating a fictive motion. The architecture then reaches an animate state of being. As visual perception is the dominating sensory, this will create dynamic movements and can be constituted by deforming geometry in a specific reoccurring direction. This principle can be considered as obtained if the architecture indicates motion.

Statement of problem

Project description: A thermal bath in Úlfarsfell, Iceland.

The thermal bath should allow locals and tourists to enjoy the natural benefits of the fresh seaside air and thermal water, while providing high-quality spa and recreational services throughout the entire year. The proposal should trigger development in the area and propel Reykjavík as a tourist attraction. Úlfarsfell is a significant landmark on a prominent landscape, a place of great cultural heritage and historical significance with characteristics that must be fully preserved. When generating a vision for an intervention located within such a spectacular place, it is essential that the proposal can emphasize, respect and celebrate the site, while providing visitors with a unique experience.

The unique experience, acquired through sequences of baths and architectural appreciation, at the thermal bath must be able to; (1) endow the bathers with a renewed and improved perception of well-being according to thermal sensory, (2) (re)discover the abstraction of self-realization during ambiguous experience and (3) ultimately initiate a perception of pleasure caused by perceptual instability during the baths.
Furthermore, strategies for the energy efficiancy should be contemplated, and the building should be fully powered and heated through renewable resources.

Analyses, according to points of interest, will be introduced and reviewed.

Points of interest:

- Natural benefits
- High-quality spa and recreational services
- Emphasize, respect and celebrate the site
- Unique experience
- Tourism
- *Beyond thermal comfort*

II

Analysis

Site and theme analysis

”To let the brain work without sufficient material is like racing an engine. It racks itself to pieces.”

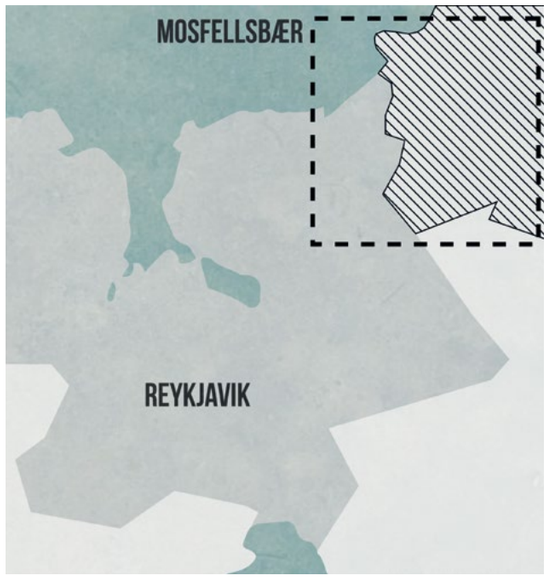
Arthur Conan Doyle

Iceland, Reykjavik

Geographically, Iceland is placed on the northern hemisphere, surrounded by the Atlantic Ocean, between Norway, Scotland and Greenland. The capital is Reykjavik situated in the south of Iceland. The total population is about 325,000, in which 120,000 lives in Reykjavik. Iceland offers both ice and fire, as the country still has active volcanos and mountains reaching 2,1 kilometres (VisitIceland.com). The country offers untouched nature around the whole island. Even from Reykjavik multiple mountains are visible to the naked eye. Reykjavik is situated in the south of Iceland at the corner of Faxa Bay. Reykjavik is the commercial, industrial and cultural center of Iceland (Britannica.com). Ever since the independence, the capital has grown, and smaller regions have been formed. One of these regions is Mosfellsbær, which is located east of Reykjavik.

Fig. 02 - Map of Iceland

Fig. 03 - Map of Reykjavik



Mosfellsbær - Úlfarsfell

Mosfellsbær is known as “the green city” as the city has been delivering naturally heated water for swimming-pools and domestic heating to Reykjavik. The city is situated 15 minutes from Reykjavik, and is reachable by bike and public transport. Mosfellsbær har rich opportunities of hiking and walking, as most of the nature remains untouched. Furthermore the city offers many recreative activities (PotterRager.com).
Úlfarsfell is a mountain located in Mosfellsbær, which is about 296 metres high. Being a very popular hiking route, the mountain offers a gravel route, clearly visible from the main route coming from Reykjavik to Mosfellsbær (TripCreator.com).

Fig. 04 - Map of site

Úlfarsfell

The picture is taken 600m above ground through Google Earth, and illustrates the specific site. It is situated on top of Úlfarsfell, with an extraordinary view over the harbour of Reykjavik. Also mountains are to be seen by the naked eye.

Fig. 05 - Perspective of site

Social analysis

Age distribution
There seems to be a fair distribution of age throughout Mosfellsbær, indicating a wide user group. It can be interpreted from the analysis that there is dominance of youngsters between 0 and 19. About 30% of Mosfellsbær is constituted by youngsters between 0 and 19. It is worth mentioning that the numbers only include Mosfellsbær, and not Reykjavik. There is a great possibility that some users come from Reykjavik also. The numbers are from 2014 (Reykjavik.is).
The graph exhibits population across ages.

It can be concluded that there is a rather large amount of youngsters, yet there is almost an equal amount of middle aged. Thus the age of users is fairly well distributed.

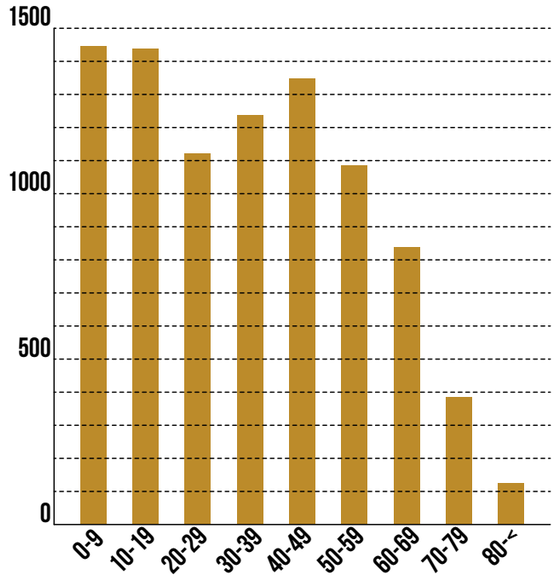
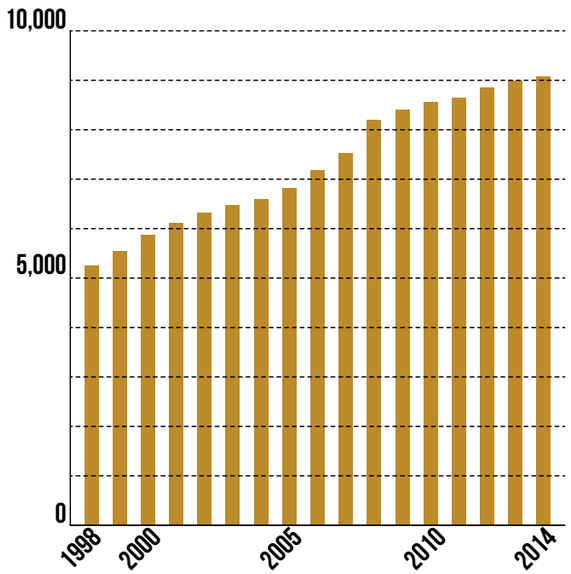


Fig. 06 - Age distribution

Population
The graph illustrates the total population of Mosfellsbær region. Since 1995 till 2014, being 16 years, the total population of Mosfellsbær has almost doubled, thus there has been a great increase of population in Mosfellsbær. The graph indicates a continuous growth. The numbers are the population as of 1st of January 2014 (Reykjavik.is).

It can be concluded that Mosfellsbær is generally a growing city.

Fig. 07 - Population



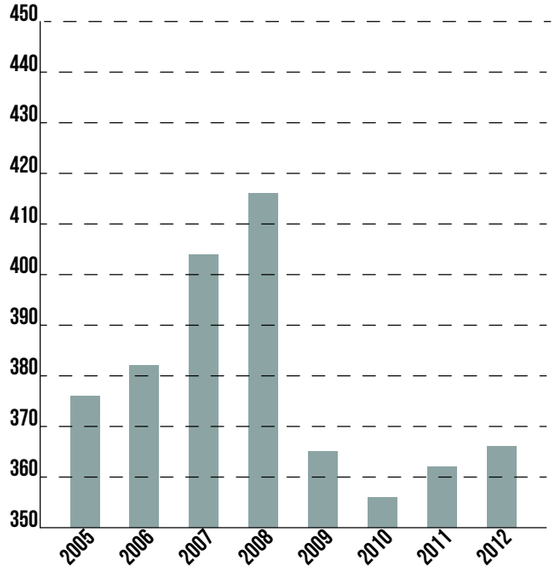
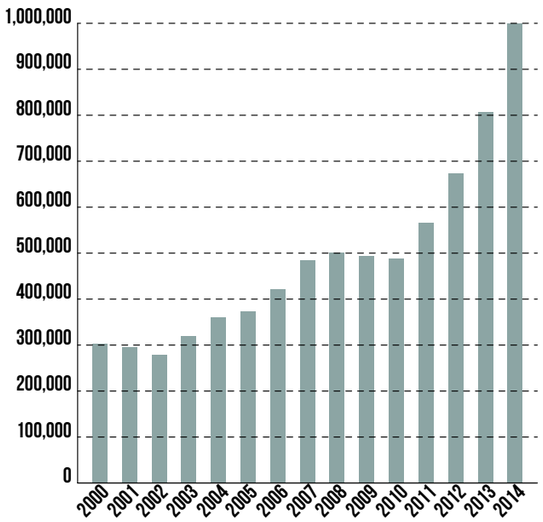


Fig. 08 - Hot water consumption

Hot water consumption
Iceland does not constitute building regulations of their own, but are rather guided by the European Commission. The hot water consumption exhibits a decline after the year of 2008, influenced by the energy regulation change in EU as Iceland applied for joining the EU in 2009. Otherwise the hot water consumption seems rather stabilized (Reykjavik.is).
It is worth mentioning that the water in Iceland is mainly heated by geothermal energy, being natural hot springs occurring in active volcanic zones.
The graph exhibits m^3 pr. resident across time.

It can be concluded that as the population is growing, the consumption of hot water is stabilized during the last four years. The source for hot water is through geothermal energy.

Fig. 09 - Tourism



Tourism
The graph illustrates the internation visitors to Iceland between 2000 and 2014. The average yearly growth rate is 9.3% (Ferdamalastofa.is).

It can be concluded that an international interest in Iceland is growing each year. Thus a thermal bath should function as both a local service and as a tourist attraction. This analysis gives insight in potential users of the project.

Climate analysis

Sun position
As Iceland is geographically located on far northern hemisphere, the angle of the sun can be rather low during cold season. The lowest angle about 3°, while the highest is about 48°. Throughout June there is about 20 hours of sunlight on a day, while during January there is about 4,5 hours on a day (Weather-Data|EnergyPlus; WeatherSpark.com).

It can be concluded that there is a limited amount of sunlight during winter, and mostly the angle is fairly low throughout the whole year.

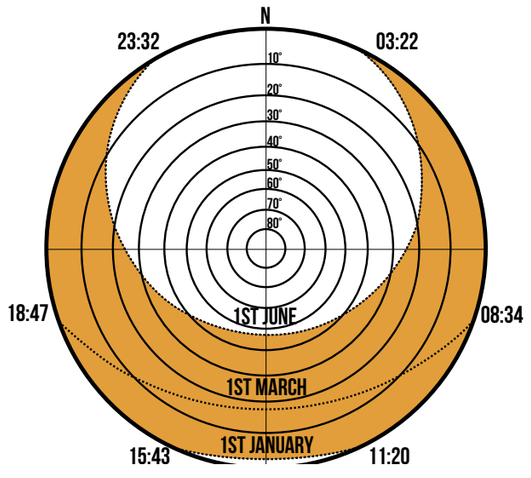
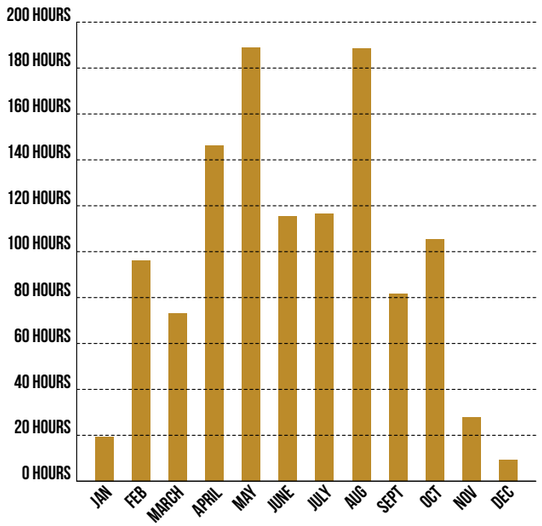


Fig. 10 - Sun position

Sunlight hours
The graph illustrates hours of sunlight throughout a year. January and December both have less than 20 hours during the months, while August and May both have more than 180 hours (Reykjavik.is)

It can be concluded that the there is an extreme difference of winter and summer in terms of sunlight, which will have a great impact on the architectural experience, both exterior and interior.

Fig. 11 - Sunlight hours



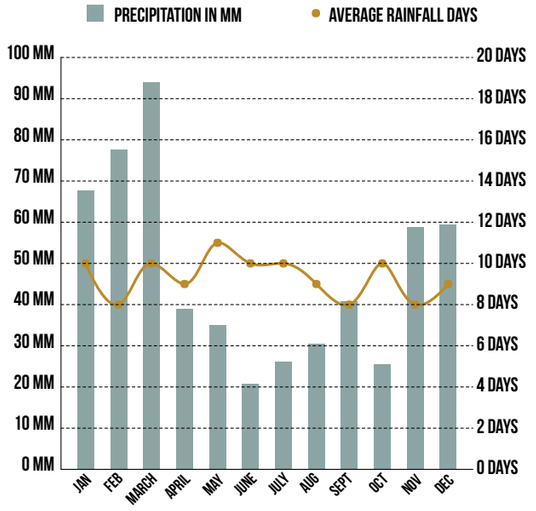
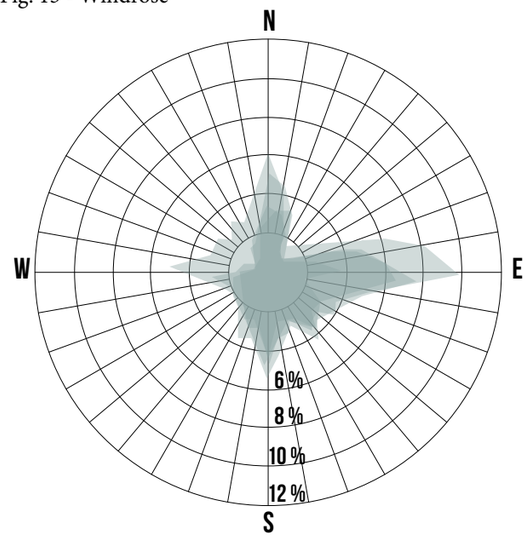


Fig. 12 - Precipitation

Precipitation
According to the graph, it rains at least 1/3 of the month and only during summer season that it rains less than 30 mm, otherwise it does not rain more than 40 mm through other seasons than winter (WorldWeatherOnline.com; WeatherSpark.com).

There is a possibility of dynamic climate experience during a month. It can be concluded that throughout summer there is both experiences of rainy days and non-rainy days. This will have an impact on the experience of views.

Fig. 13 - Windrose



Wind
The wind speed varies from 1m/s to 12m/s, which generally accepted as light air to strong breeze. The highest average is during winter and reaches 9m/s, which is a fresh breeze, while the average daily maximum is 11m/s, namely a strong breeze. The lowest average wind speed is of 5m/s, which is a gentle breeze, is during summer, where the average maximum is 7m/s (WeatherData|EnergyPlus; Weather-Spark.com).

It can be concluded that Reykjavik is generally windy, thus considering that the site is about 230 meters from ground level, the wind will have great impact, and should be taken into consideration.

Views and phenomenology

Phenomenological experience
Merely by sight of Úlfarsfell, one is astonished, and yet not too much excitement is evoked, as the mountain is adjacent to Mount Esja – a much bigger mountain. The journey starts by the parking, easily accessible from the main route. The parking is surrounded by trees and a smaller forest where a narrow river appears. As soon as one exits the parking, the topography begins picking up speed. Natural trails have been made between the conifers, which creates a tight and dark atmosphere, leading to the main sign. At this point one has the possibility to take the hard route, or the easy route. It was critical to know how hard the hard route was, as ipso facto the easy route would be easier. Here, one is led between the trees, guessing the way as the topography gets steeper and steeper. Between the romantic trees, smaller pathways by patrons were made visible. A sudden change in nature, both light and ground, hits at the end of the route, which at this point has only been 100 meters. The ground is now approximately 40 degrees steep and the light from the snow is lighting the atmosphere even more. A very narrow and steep trail occurs next to the big volcanic cliff, which has clearly visible layers of different stones. One is so occupied with the nature in front of oneself, that when reaching the top, and looking behind, everything has changed – the view is astonishing. The mountains surrounding Úlfarsfell has gotten both bigger and smaller. Observing and investigating the site was very difficult as it would require looking down and stay focused on the specific site. An interesting observation was that the view is even more spectacular over Mosfellsbær than over Reykjavik. The view over Mosfellsbær offers more extreme landscape, and the city is smaller and even more romantic. The size of Mosfellsbær makes the landscape look more extreme.

Climatic observations
As an advantage of building in desolate site, it is maximally exposed to the sun and wind. The site was visited the 27th of February, and the sun was out, using snow to reflect light onto the site. The advantage of Úlfarsfell is that though the sun is low in the winter, it is yet fully exposing the site. Also, the white snow reflects a lot of light. The wind was not as hard as expected – almost no wind. No conclusions can be made on the wind, as it might merely have been a non-windy day.

Exquisite corpse
By using the method of surrealism, named Exquisite Corpse, a poem was made by me, after investigating the site. A specific number of verbs, adjective and nouns had to be generated independently. A grammatical structure of 4 sentences was then made. The words would be filled in respectively. The method helps expressing the thoughts in metaphoric manner. The poem was made while enjoying hot coffee and food in a cold weather, and is presented on next page.

Analysis
A sense of being fully oriented occurs, and yet the exact opposite, being disoriented, reoccurs to me. In the same sense, everything seems big and yet so small. I can hear movement, yet everything is still. I lost all sense of time as a consequence of being overpowered sensuously, and to my further astonishment I conclude on two things; firstly, that Iceland is one of the most qualified countries to work with untouched nature in consensus with architecture as we know it by instinct – there is no artificial urban, nor topographic, setup. The nature is not following the architect, but architect must follow the nature. Secondly, I have to acknowledge that such an experience, with extreme topographic misfits compared to what I am used to, Denmark, I have a misfortune contemplating what I see. Giving everything a value, merely to revalue it at another sight, to further create a meaning, yet to reinterpret, what I sense. I can see everything and nothing.

A fragile nature ascends monolithically.

Feeling significant – an invulnerable mothers sense.

Landscape opened. Concealed belonging.

Incomplete anticipation. Consensus.

Materials

The following materials have been chosen according to the principle of dividing materials into two lists. A clear differentiation of the materials occurs in their roughness, referring here to tactility. Furthermore, in using materials that are not recognized as building materials, a new relation to the materials is assumed created between the user and the building. In terms of sustainability, the life cycle assessment is left out, although considerations of the materials technical properties and production are taken into consideration. The materials presented have different purposes, for instance wood and concrete are chosen for structural usage, whilst pumice, bamboo textile, cork and tuff are chosen according to the aforementioned principle from theory.

Fig. 14 + 15 - Pumice and concrete

Pumice and concrete - Found on Iceland

Pumice is a volcanic stone, with a characteristic low density, approximately 0,25g/cm^3 . As shown on the picture, the stone has a characteristic foamy configuration, due to rapid cooling and depressurization. As the gasses rapidly exsolve, the water and CO_2 creates inner bubbles, ultimately resulting in a form as presented. When mixed with concrete the material reaches a lightweight quality and easy to handle. Furthermore pumice has 4 times the R-value of regular aggregate concrete, meaning pumice provides less heat loss. It handles extreme weather very well (HessPumice.com). The main advantage of using concrete in Iceland is the thermal capacity, and the involvement of aggregates, such as aforementioned volcanic stones. Further advantage besides being a strong material, is the freedom of shape, as concrete can be cast in-situ. Considering the sustainable aspect of the material, concrete production produces relatively low CO_2 emission. Dealing with a thermal bath, considerations of moisture are taken account for, thus the choice for concrete (WBCSDCement.org).

Fig. 16 + 17 - Bamboo textile and cork

Bamboo textile

In order for the principle of sequences to be conducted, a new material has to be introduced. It is critical to introduce a material the users are not familiar with, while the material has to be sustainable. The term sustainable related to usage of materials refers to the emission of the production and the level of being an endangered material. The reuse of material has not been taken into consideration. Bamboo offers a strong textile, with fibers naturally rounded and smooth, without any chemical treatment. The material entails an antibacterial agent, naturally becoming healthy for the skin (Afrin, 2012; TheGreenLivingCenter.com). The majority of cork production occurs in Mediterranean countries, such as Algeria, Tunisia, Morocco, Spain, France and Portugal, and thus is not a local material in Iceland. More than 300,000 tons a year is harvest and 60% of the production is harvested in Portugal. Cork is the bark of cork oak tree, and it is highly renewable and sustainable, as no tree is cut down. A cork oak tree can live for about 300 years, and reproduces the bark each 9 years. The material properties entail both sound absorbing ability and tactile soft rounded material (CorcForest.org).

Geology

Iceland is a volcanic island, which originally was built by the collision of two tectonic plates; the Euroasian plate and North American plate. The interaction of these plates also gave birth to the Mid Atlantic ridge, on which Iceland is located on top of (Denk 2011, p. 17; IcelandOnTheWeb.com). The interaction of tectonic plates naturally creates volcanic tendencies, thus the rocks and ground of Iceland are of volcanic origin. The base of Iceland can be divided into 4 stratigraphic units; the Miocene-Pliocene Succession 16 – 3.1 Ma, the Pliocene-Pleistocene Succession 3.1 – 0.78 Ma, the Upper Pleistocene Succession 0.78 Ma to 11.5 ka and the Holocene Succession 11.5 ka to recent (Denk 2011, p. 17). Part of Reykjavik is located on Upper Pleistocene Succession. This group also covers now active volcanic zones, as shown on the map (Denk 2011, p. 19-21).
There are two volcanic rocks in the projecte context soil. The first is subaerially erupted lava flows formed during interglacial times. The other is "Palagonite Formation", which is named "Móberg" in Icelandic, and is the subglacial formation (Sigmundsson 2006, p. 33). Móberg and andosols, which has a dark color, is the main soil of Úlfarsfell (Chinci.com).

In brief, the soil of Úlfarsfell is mainly of volcanic origin, making it very hard to grow plants, as the aluminum content is high, although the soil typically occur in wooded areas. The soil is porous as it is made of volcanic ashes and tuff (Britannica.com). Furthermore it can be concluded that the geothermal possibility of the site entails a low-to-medium temperature, which means the temperature at 1km depth is less than 150C° (ONPower.is).

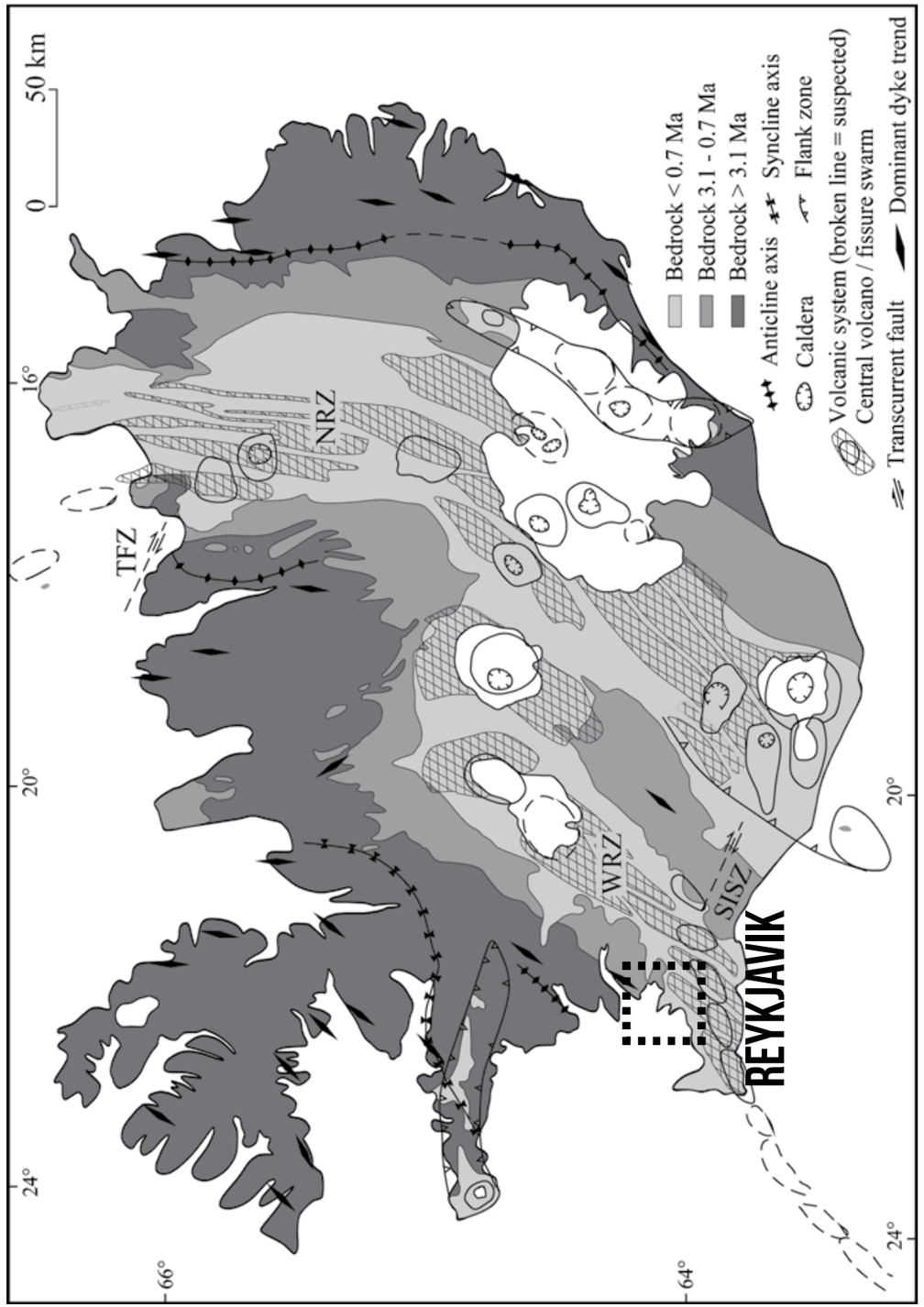


Fig. 18 - Geological map of Iceland

Topography

The topography of the chosen site is in extreme difference to the surroundings, making it an attraction itself. Úlfarsfell is the name of the mountain the site is located on, and as mentioned earlier, the mountain is about 297 meters in height. The site is located on less than 297 meters of height as it is placed at the inclination of the mountain, with a view across the Faxa Bay and other mountains nearby. Because of the extreme topography of Iceland, mountains near Reykjavik, such as Úlfarsfell, have become a popular site to mount for exercise. There are paths around the mountain suggesting interesting paths with extraordinary views. As most of Iceland and Reykjavik has varying topography, building on a slope seems rather natural. To access the site, one has to follow the existing path, which leads around the site, and ultimately one enters the site from the south-eastern direction.
Two sections are cut through Úlfarsfell to illustrate the angles of the slopes and the height differences.

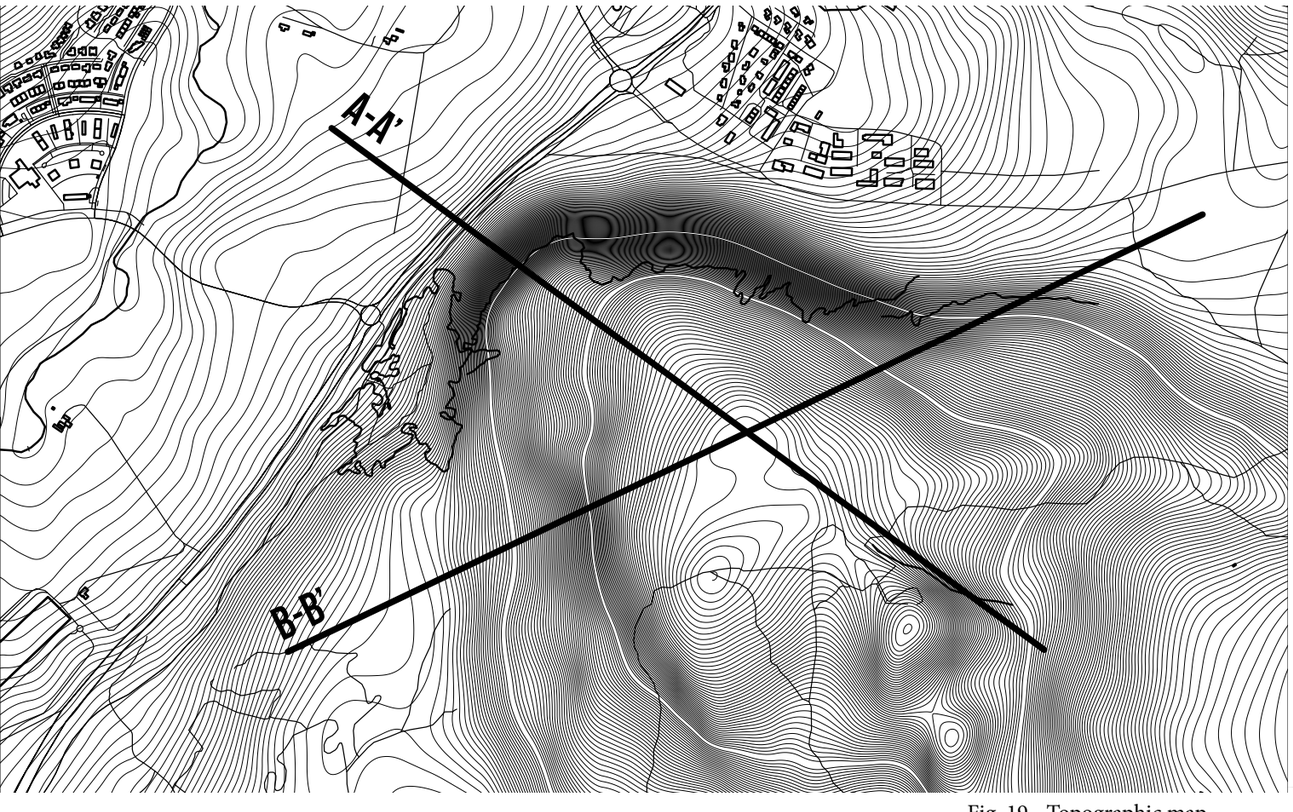


Fig. 19 - Topographic map

Section A-A'

Úlfarsfell offers very inclined slopes, up to 36 degrees, but on the site the inclination is about 5,8 degrees. The height of the site is about 234 meters.

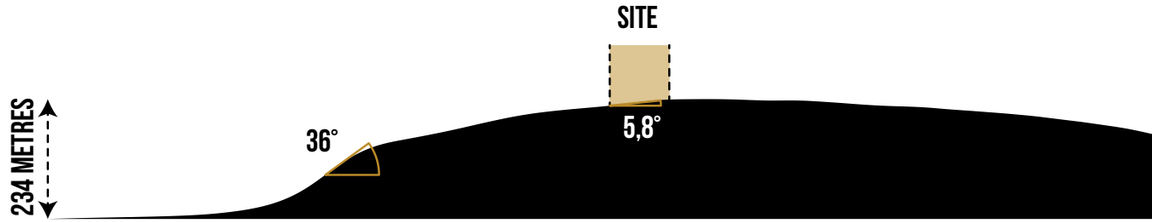


Fig. 20 - Section A-A'

Section B-B'

As the site slopes down and reaches a height of about 180 meters, it can be concluded that the site has a very high difference in levels, and thus should be taken into consideration throught the design phase.

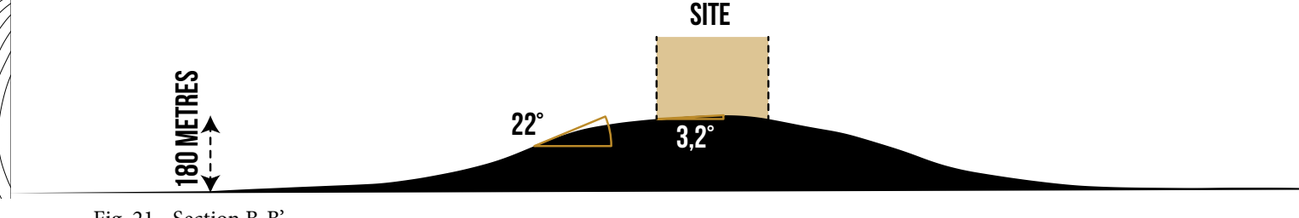


Fig. 21 - Section B-B'

Mapping

Infrastructure
There are a great number of trails with ecological and historical information around Mosfellsbær, suggesting informative walks around the city (PlanIceland.com). The most popular routes on Úlfarsfell are about 3 kilometers and situated on the northern side of the mountain. On the other side of the mountain, the mountain offers shorter routes, about 2,5 kilometers (TripCreator.com). The accessibility to Úlfarsfell is rather natural and easy, as you can enter a parking by the foot of Úlfarsfell, and continue by to the top by foot. It is possible to construct an off-road along the easy path.

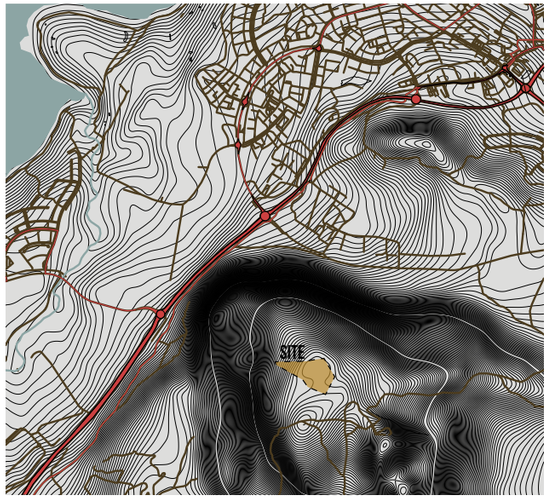
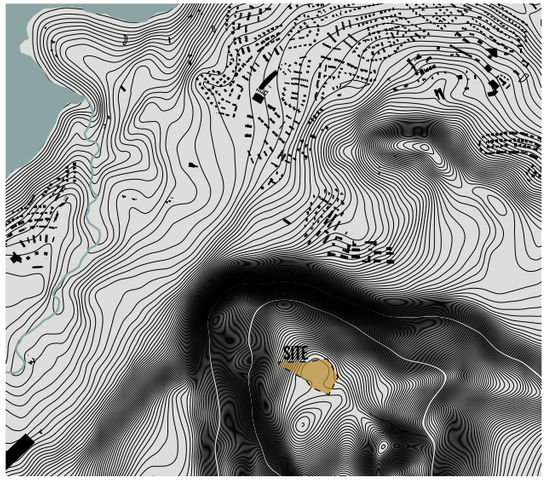


Fig. 22 - Infrastructure

Housing
As shown in earlier analysis, there is a fair distribution across age. There are no houses by the entrance of Úlfarsfell, but few houses occur on the north-west area of the mountain. Generally Úlfarsfell is situated between the border of the capital Reykjavik and the city Morsfellsbær in the capital region, thus it is surrounded by family housing.

Fig. 23 - Housing



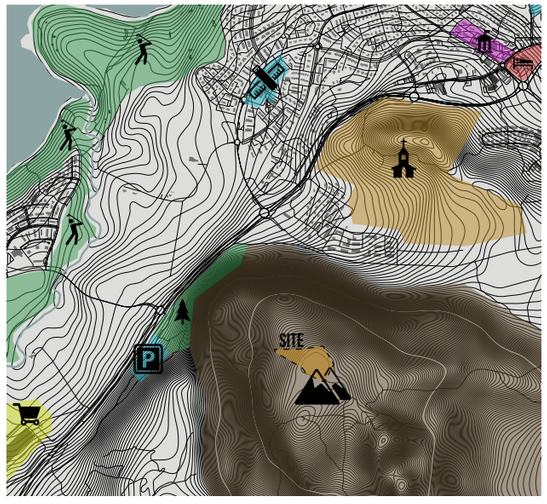
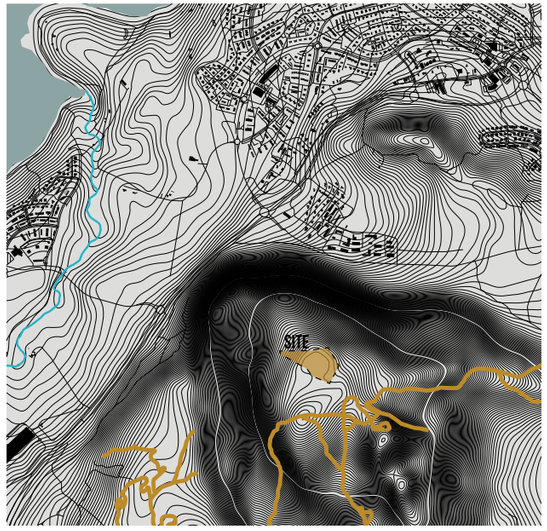


Fig. 24 - Local activities

Local actvities
In front on Úlfarsfell there is a parking for hikers, and for others who wish to use the site. North-west of Úlfarsfell a church is situated with its own graveyard. A few golf clubs are located at the harbor-line. Furthermore there are two schools in Mosfellsbær. A few hotels are not far away, approximately 3,4km away from the southern entrance of Úlfarsfell.

Fig. 25 - Routes and rivers



Routes and rivers
The main river running along Úlfarsfell is Ulfarsfellsa, which leads to a lake named Hafravatn. Ulfarsfellsa functions as a discharge for the lake. The water flows in from Seljadalsa, which is located south-east (Nat.is).

Úlfarfell is today mainly used a route for hikers. The outlined lines illustrate the most important routes. The routes are considered *Very Easy*, and takes about 2h to complete, as the distance from SW to SW again is about 8 km (BestHiking.net).

Choice of site

Introduction
The site chosen is both of climatic and topological reasons. The scale, the culture and the geology of this specific site makes it a unique, qualified and relative proposal to further investigate the developed theory.

Scale
Úlfarsfell has an immense size, and as the project context is situated on the mountain, it gives the advantage of being close and yet far from the capital. Views from Úlfarsfell will cover all Reykjavik. The difference in scale ensures a different experience than urban thermal baths and therefore advocates the envisioned unique experience.

Culture
Since the settlement of Iceland, thermal bathing has been enjoyed. The geothermal energy resources have been the foundation for the bathing culture in Iceland, creating more than hundred public pools. All ages participate in public bathing, as it has both health and social purposes. Destressing after a long day is usually a tour in public bath with friends. It is not unusual to stop by for a bath after work, or even before. The natural resource powering and heating Iceland takes great part in their culture, besides being a natural energy resource (VisitIceland.com).

Geology
Building in a country as Iceland, whom has a volcanic landscape, this site offers a soil relating itself particularly to Iceland. The soil of the site not only refers back to the origin of all Iceland, but also the geothermal resource, which powers and heats most of Iceland, including this project. It is important to relate the project to the landscape. Focusing on materials, a respect for landscape and culture is critical.

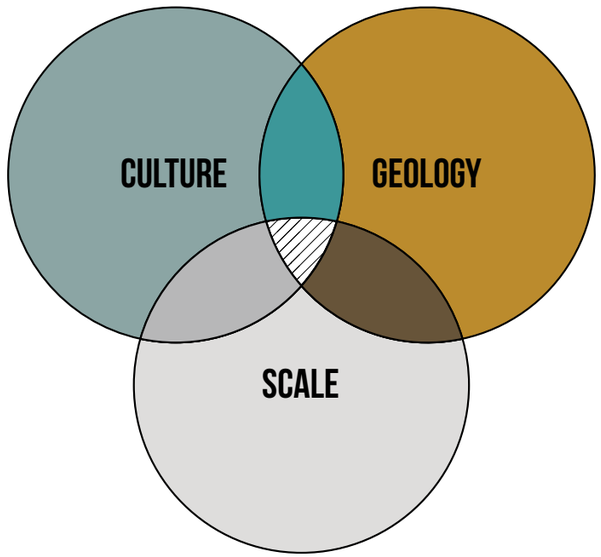


Fig. 26 - Culture, Geology and Scale

Icelandic materials

Introduction
As an important principle concerns usage of materials, the familiarity of materials within the culture becomes a critical point. This analysis will introduce the materials used throughout Iceland and thus they are the materials the Icelandic people are most familiar with.

Turf houses
The architecture of Iceland is younger than other European countries as Iceland was the last country to be settled in Europe. Most settlers came from Norway and brought their local building traditions, thus the first buildings were the turf houses. Langhús, which is longhouses, were built towards the end of 9th century and had a characteristic shape. As longhouses were built of turf and timber frames, when many of these houses were no longer in use, it merged back into its natural environment, explaining why there are not many turf houses preserved. During the 16th century the housing declined as a shortage of timber for building and heating occurred. Considering the thermal environment, the turf houses were poorly insulated and the indoor was usually just above freezing. The turf houses are perfect examples of the interaction between building and nature, merging topology and landscape with human needs. The turf houses are uniquely an Icelandic contribution to architectural history (Johannesson 2000, p. 9-11).

Timber houses
During the 18th century timber import by Danes commenced and housing started to incline again, only this time using timber as main structure. The construction of timber houses was noticeable. These building were tall, grand and had larger windows. Icelandic carpenters adopted the usage of timber and corrugated-iron cladding, leading it to become a characteristic of Icelandic architecture. Early 20th century, fires occurred and new law prohibited the usage of timber in built-up areas.

Stone houses
As timber was prohibited the usage of stone came in handy. It is mainly the Danes who introduced the usage of stone in Iceland. During the 19th century Icelanders were encouraged to build in stone and to learn masonry, explaining why most houses in Reykjavik, who resembles turf houses, are built in stone (Johannesson 2000, p. 12).

20th century - Concrete houses
At the beginning of the 20th century the nation was gripped by progress, and the architecture is clearly linked to the social changes. Since the 19th century, concrete became a characteristic building material as the advantages were both economical and thermal. Movements appeared, involving flat roofs, flexible interior and even traditional Icelandic architecture reappeared reinterpreted into modern and progressive ways (Johannesson 2000, p. 12-14). The last decade of 20th century a great diversity of materials, colors and styles commenced. Influences from traditional Icelandic architecture reemerge to be reinterpreted in progressive ways (Johannesson 2000, p. 15).

Subset
It can be concluded that the dominating characteristic materials of Iceland are:

- *Turf*
- *Timber*
- *Currogated iron*
- *Stone*
- *Concrete*

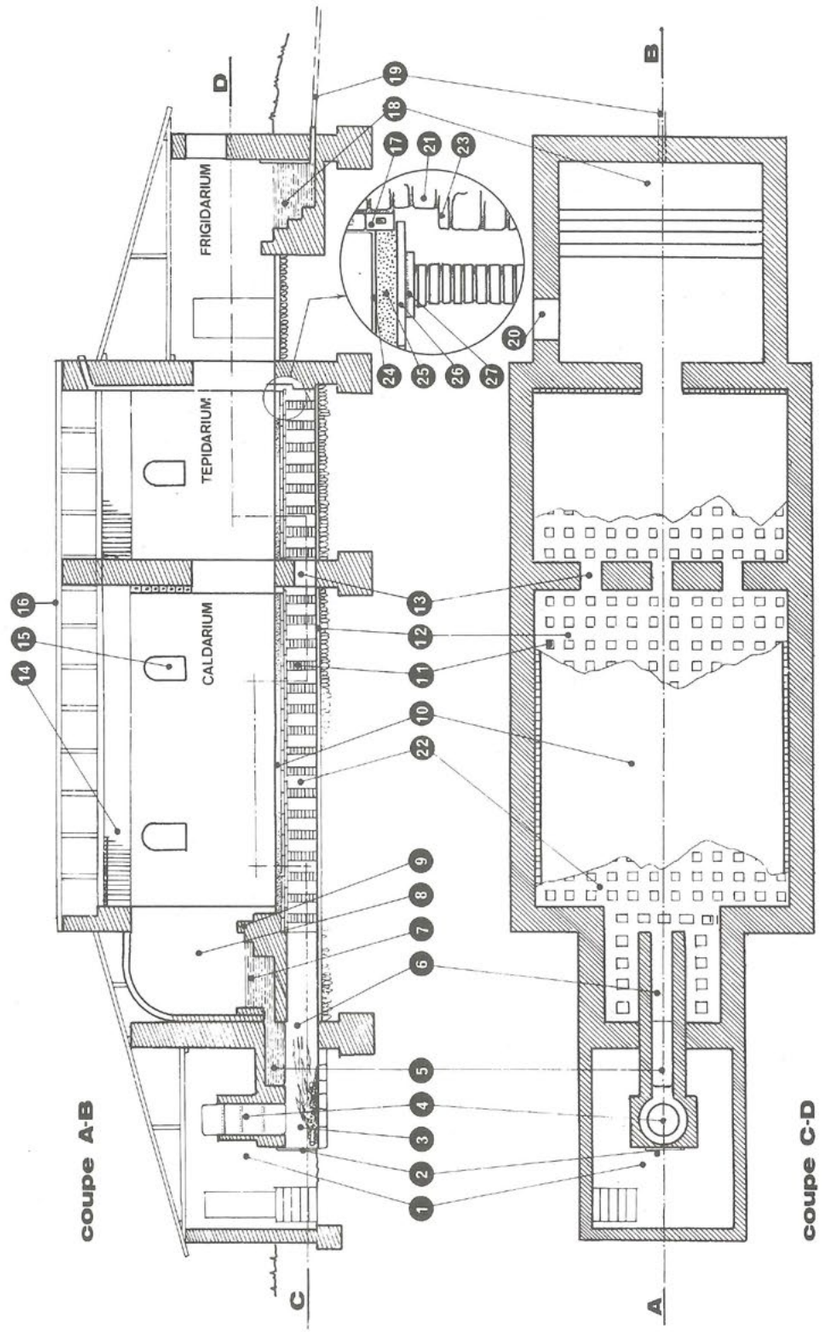
The people of Iceland are familiar with the aforementioned materials and thus has a bond to them. This information becomes critical when using the developed principles.

Thermae - Hypocaust system

Introduction
Interestingly, the thermal baths, or thermae, attracted the interest of many architects, engineers, philosophers and archaeologists, as it had a central role of the Roman society. An analysis of the Roman thermae will be reviewed, as a technical background of the project. The thermae not only had a central role in society but was also a matter of hygiene, social welfare and gathering; much like Icelandic culture. It was the municipal authorities who were to build the town thermae, usually luxurious, as it was an integrated part of the urban life. It was utilized *"normally in the afternoon, after work and before dinner"* (Nielsen 1990, p. 1). Bathing became as vital as eating, drinking and laughing and so on. Although not many thermae are well preserved, enough have been preserved to understand the individual function of rooms and the heating system.

Hypocaust system
The heating systems caused great discussion, but as Nielsen (1900, p. 17-18) argues, Fritz Kretzschmer, who was a heating engineer, should in particular be introduced. Generally, if comparing heating systems of Roman time to contemporary, one will find out that still in modern heating a centered hot body, such as a radiator, heats up the house, whereas Romans, and also most architecture of today, the heating system was spread on a larger surface, such as walls, floor and sometimes even ceilings. The system would be termed radiant heating system today. The fuel to produce heat, which took place in the *praefurnium* (see figure 27), was mainly wood. The heat gained in the praefurnium took time to start up, but was not put out, not even at night. Following figure 27, the principle system was that the heat from the praefurnium was drawn into the *suspensura*, where flues, being connected to the suspensura, reach through the walls both in the corners and diagonally of the suspensura. The flues work as heated walls and as insulation, to drag the heat as far into the bath as possible. The water from the boiler was connected directly to the pool via pipes, and was kept heated partly by flues and by the suspensura. Both the flues and the solar heat gains would help keep the bath warm. A drain is set up at the end of the pools. The system is called a Roman hypocaust system.

Subset
The hypocaust system is an excellent system for heating without a direct interference with the water. As the water from the geothermal source can be high in minerals, and not suitable for direct injection into the pool, this indirect heating system seems rather exemplary. Considering the ecological aspect, the heated water can be reused throughout the whole building, and heat more efficiently.



14 = vault, *15* = window, *16* = roof, *17* = tubulus, *18* = piscina, *19* = drain, *20* = entrance, *21* = wall in suspensura, *22* = suspensura, *23* = wall recess, *24* = flooring, *25* = concrete, *26* = tile slab, *27* = pila "capital". (Degbomont 1984 pl. 1.)

Fig. 14. Plan and section of a bath in its simplest form, with frigidarium, tepidarium and caldarium. *1* = stokery, *2* = damper, *3* = praefurnium, *4* = boiler, *5* = testudo alvei, *6* = heating duct, *7* = alveus, *8* = recess with alveus, *9* = balustrade, *10* = room floor, *11* = pila, *12* = suspensura, *13* = suspensura openings,

Fig. 27 - Section of thermae, Hypocaust system

Geothermal energy

Introduction
As Iceland mainly takes advantage of its geological location and uses geothermal energy to district heating and electric purposes and as the project requires a natural and sustainable ressource of heating and electric power using turbines, it is necessary to investigate the geothermal resource system to further analyze the possibility of building a geothermae. The possibility of powering the building by geothermal energy is investigated, followed by heating the pools through same resource. The network, in terms of pipes and heat loss, will also be analyzed. Naturally the size of such installation depends on the demands, both in heat and electricity, thus two solutions are applicable to the project:

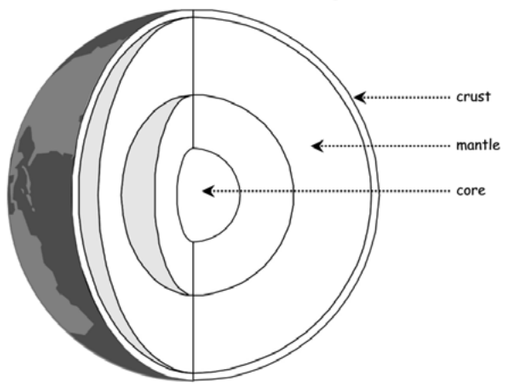
- Connect to the regional network of both heat and electricity.
- Create independent binary cycle power plant on closest flat area for electricity and water-source and/or ground-source heat pumps for heating.

The latter will not adhere to the framed site, as a flat land is required and possibly a connection to the parallel river, and also the geology of site needs to be inspected to estimate the possibility, if any, of geothermal energy production. The other solution depends on the distance from the resource.

Geothermal energy
Considering the fact that geothermal energy stems from the naturally heated soil, especially in volcanic areas such as Iceland, with an increasing in temperature by 30°C/km (Dickson 2011, p. 4), how is this resource renewable and sustainable? As the digging for geothermal energy only concerns the soil in the mantle, being the crisp of the globe, it is the obtainable temperature that defines the production. Throughout 3 billion years, the temperature of the mantle has only dropped by 300°C to 400°C, still remaining at 4000°C (Dickson 2011, p. 2). The world functions as a thermal engine, because of the temperature differences in the layers in the earth. See figure 28 for diagram. As the tectonic plates move few centimeters each year, heat coming from the deepest parts of earth are heating less dense rocks than the surroundings forcing an upwards movement, while the colder rocks tend to sink, reheat and rise when reheated (Dickson 2011, p. 5-6). Thus, the most important geothermal locations are situated around the margins of the tectonic plates. A critical reason for geothermal energy to be ascribed as a renewable resource is the rate of energy recharge, which depends on the advection of thermal water. Furthermore geothermal energy is also sustainable in the sense that it; "meets the needs of current generations without compromising the ability of future generations to meet their own needs" (WCED 1987, p. 45).

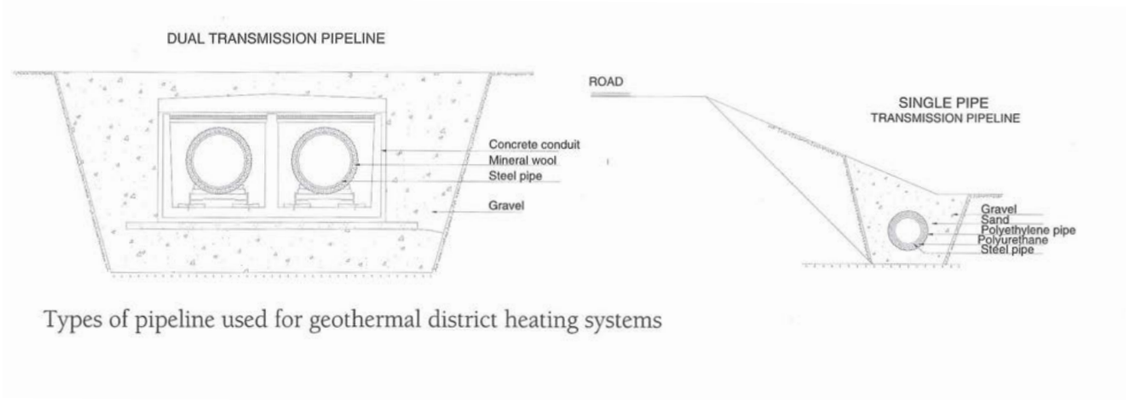
Binary cycle
Binary cycle is a method to gain electricity from geothermal resources. As concluded in "Geology"-chapter, the site is of low-to-medium temperature, meaning that when the binary plant, using a secondary working organic fluid, such as *n-pentane* (because of its low boiling point and high vapor pressure at low temperature), extracts the heat from the earth, the temperature has to range between 80-170°C to be fully efficient. The n-pentane is operated through a conventional Rankine cycle, which means the geothermal fluid yields heat to n-pentane through heat exchangers, where the fluid is vaporized and used to engine the turbine. Ultimately the fluid is cooled by air and condensed to go back to the heat exchanger in order to be reheated. The turbine generates the electricity. Naturally, the more ground heat, the more electricity can be generated as the pressure arises. Size of such installation depends on the electricity demand (Dickens 2011, p. 15-19).
A self-sufficient geothermae is most likely unobtainable as a binary cycle power involves large machinery and pipes with pipeline corridors of typically 3 m to 5 m in width (Dickson 2011, p. 15-16). Furthermore such a power plant installation requires flat large area (Dickson 2011, p. 156).

Fig. 28 - The Earth's crust



Heating system
Mosfellsveit is a low-temperature geothermal field north of Mosfellsbær, and has after 1970 been able to provide water of 85-100°C by 2000 l/s to Reykjavik (Gunnlaussgon 2004).
Considering direct heat uses from the geothermal resource, there are different methods of exploiting. The heating system operates through district heating for potable water and for heating the pools, whereas the cooling of pools will be through a reversed heat pump. The demand for heat also depends on the construction both in terms of thermal mass and transmission losses.
As the geothermal water in Iceland is generally potable, the system entails no fluid separation by heat exchanger, and the spent fluid can be directly re-injected using a drain. The cold water supply is also connected to the system, as the spent water, being 30°C to 40°C, is mixed with the geothermal water, creating a constant temperature in the heat exchanger, who is met by the municipal cold water supply for the hot water taps. This type of system requires a dual-pipe system. All excess return water is re-injected using a drain, and the colder the re-injection of water, the more efficient the geothermal exploitation (Dickson 2011, p. 59-61).

Pipe network
The distance from the site to the nearest geothermal power plant, being Nesjavallavirkjun, is about 23 ki-



Types of pipeline used for geothermal district heating systems

Fig. 29 - Dual-pipe system

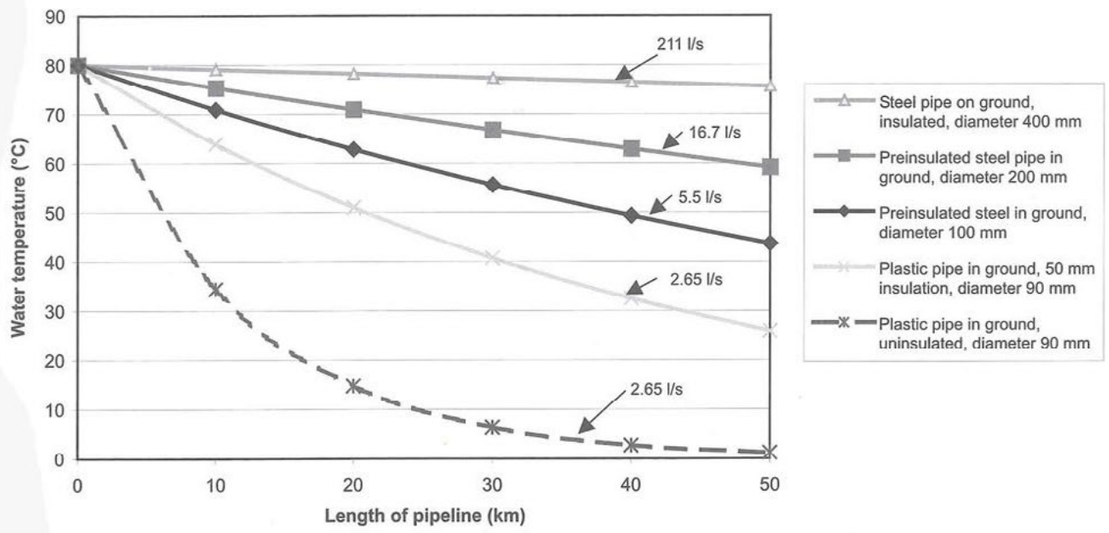
lometers. The issue of dual pipes - pipe transmission in general - is power of pressure, and thus diameter, and the heat loss in transmission. Important parameters of a dual transmission pipeline, as illustrated on figure 29, is the choice of material for piping, thickness of insulation, pressure of geothermal water and above/under-ground pipeline. Usual size of pipes for a larger complex lays between 32 mm to 100 mm, but this project considers a thermal bath, and therefore the sizes of pipes are expected a lot larger (Dickens 2011, p. 63). Figure 30 illustrates the transmission heat loss in relation to distance of transmission. The outdoor temperature is set to 0°.

Ultimate proposal

Dealing with both heated/cooled pools and space heating, the diagram (figure 31), which entails two closed loops, has been developed in order to deliver the demands. It has been suggested that the received geothermal water, being 80°, will be used to heat hot tap water and the water for the pools. After the pool water heating, the water is collected and reheated to required supply temperature. Then it is met by the cold water supply from the municipality. Also, the heated water for the pools is divided into separate heat exchangers for each pool. The temperature of the water will be controlled using a temperature valve.

It can be concluded that the best possible solution is to connect to regional network of both heat and electricity. Furthermore a diagram of the heating system has been developed.

Fig. 30 - Transmission heat loss



Heat loss in pipelines on the basis of 0 °C outdoor temperature

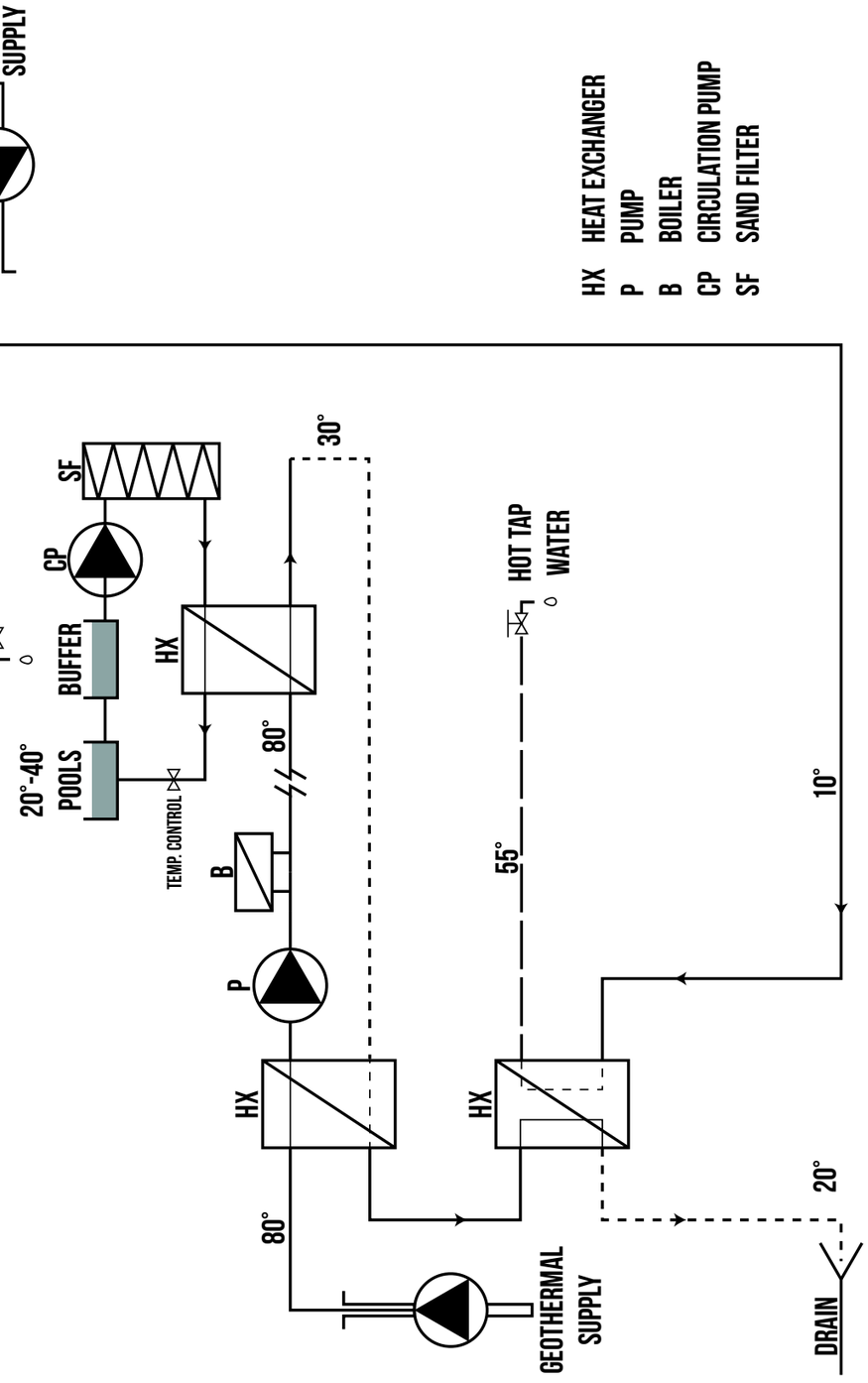


Fig. 31 - Simplified diagram of suggested heating system

EU Building regulations

Introduction
Iceland does not constitute their own building regulation in terms of energy consumption, but rather uses European Commission guidelines.

Characteristics of energy
80% of primary energy supply is from renewable resources, while the last 20% are imported fossil fuels, mainly for transportation and fisheries. In total, 99,9% of the electricity production and 99% of space heating is by renewable energy source. Considering heating it is 89% geothermal energy and 10% of hydroelectric energy, while electricity it is 73% hydropower and 27% geothermal sources. Approximately 67% of final energy consumption is of renewable energy sources (Screening Report Iceland - Chapter 15, 2011). Iceland is not a member of the European Union, but has been integrated with EU through membership in the European Economic Area (EU, 2016), although Iceland was granted derogation from Directive 2010/31/EC on Energy performance of buildings because of its energy situation, as the energy situation of Iceland is extraordinary. Iceland does not have a formal national energy saving target (Screening Report Iceland - Chapter 15, 2011). There are no minimum levels for the use of renewable energy in building regulation codes in Iceland, as the efficiency is about 99% in both heating and electricity and is available for all users (The Icelandic National Renewable Energy Action Plan, 2014). But as Iceland is part of the EEA-agreement, certain legislations do apply to the buildings in terms of energy in Iceland.

From the Directive 2010/31/EU on the energy performance of buildings, certain legislations will be highlighted:

Article 8; 1:
The system requirements shall cover at least the following:

(a) heating systems;
(b) hot water systems;
(c) air-conditioning systems;
(d) large ventilation systems;
or a combination of such systems.

Annex 1 Common general framework for the calculation of energy performance of buildings; 3:
The methodology shall be laid down taking into consideration at least the following aspects:

(a) the following actual thermal characteristics of the building including its internal partitions:
(i) thermal capacity;
(ii) insulation;
(iii) passive heating;
(iv) cooling elements;
and (v) thermal bridges;

(b) heating installation and hot water supply, including their insulation characteristics;
(c) air-conditioning installations;
(d) natural and mechanical ventilation which may include air-tightness;
(e) built-in lighting installation (mainly in the non-residential sector);
(f) the design, positioning and orientation of the building, including outdoor climate;
(g) passive solar systems and solar protection;
(h) indoor climatic conditions, including the designed indoor climate;
(i) internal loads.

Annex 1 Common general framework for the calculation of energy performance of buildings; 4:

The positive influence of the following aspects shall, where relevant in the calculation, be taken into account:
(a) local solar exposure conditions, active solar systems and other heating and electricity systems based on energy from renewable sources;
(b) electricity produced by cogeneration;
(c) district or block heating and cooling systems;
(d) natural lighting

Conditions
Despite no conditions for an energy frame, other conditions have been established and are expected to be met.
Article 8; 1: Mentioned aspects will be implemented into the building simulation as running systems.
Annex 1; 3: These aspects will be met by developing detail of exterior wall and by simulating the thermal conditions using BSim.
Annex 1; 3: Light analysis will be covered and furthermore the building simulation will cover the rest of the mentioned aspects.

Building as landscape

Potential
As Frampton stated during an interview, it is fascinating how Icelandic architecture has potential - not what had been built, but what can be built (Schmal 2011, p. 35). The context Iceland offers is of rare sight. The strength of the landscape lays in its qualities of different nature, including warmth, shelter and intimacy in scale and form. The link between what is man-made and nature-made is at collision, where the ultimate goal is to reach convergence (Schmal 2011, p. 43). One has to understand the poetic qualities of the extraordinary Icelandic landscape, in order to further grasp its vastness, quality of light and shelter from its harsh nature (Schmal 2011, p. 37). That, is an additional aim of this thesis.

Expression
Observing Úlfarsfell from afar, there are very clean directions of the site; very clear verticality ascending from the trees and clear horizontality from the volcanic layers occurring on Úlfarsfell. As shown on figure 33, the blue lines depict verticality, orange depicts horizontality and the red line depicts the transition, which also is a path up to the site. The transition becomes a critical point as the major change in gesture has a great impact on the visual stimuli. Thus, the path from the arrival spot, up to the site, offers the two contrasts of vertical and horizontal, respectively. The site, figure 31, is rather bumpy, with an uneven ground. Furthermore, the site is interwoven with a natural path created by visitors. The directions indicated by the lines depict the ground form and natural direction of the site, which are all yet very horizontal.

Subset
It can be concluded that the landscape of Iceland is rather unique, proposing an extraordinary context, which entails a potential landscape as suggested by Frampton. As the context is unique, there should be taken advantages of the suggested strengths of the landscape, namely; warmth, shelter, scale and form. Furthermore, there is a clear change in gesture of the site, coming from the vertical forest to the horizontal site. This point becomes critical as the change from the vertical to horizontal, entails a storyline, which is of much use. This analysis will be used as an substantiation of using horizontality as a “direction” of the building.

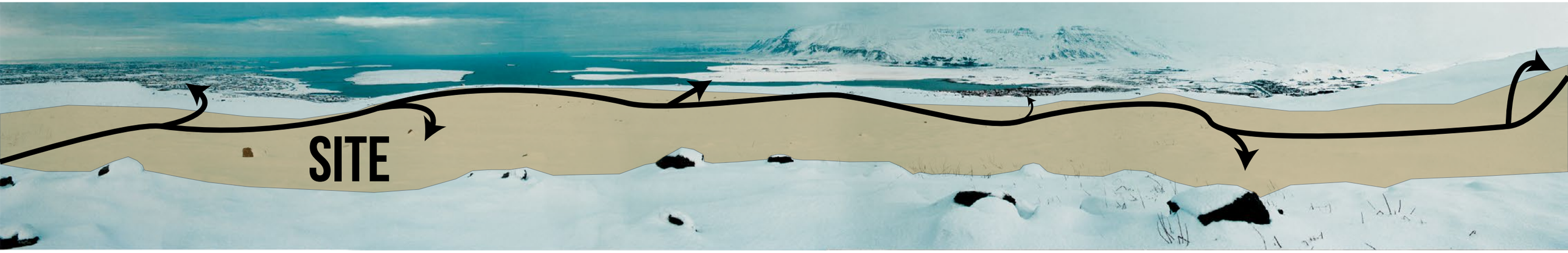


Fig. 32 - Vectors expressing the directions of the site

Fig. 33 - Vectors expressing the directions of the site

Room program

The following room program should be interpreted as a suggestive program, merely setting initial aims.

	Degrees (Celsius)	*Light condition*	*Character*	*m²*
Entrance	Not heated	2% DF	Simple shapes	350
Reception	24,5 ± 2	4% DF	Object recognition	100
Staff room				70
Cafe/Lounge				50
Toilets				40
Restaurant(150 pers)	24,5 ± 2	12% DF	Fictive motion	
Kitchen				70
Dining				180
Toilets				40
Storage				20
Changing rooms	24,5 ± 2		Object recognition	250
Toilets				40
Indoor pools				
1st conditioning pool	30 (Water)	1% DF	Jagged	30
2nd conditioning pool	35 (Water)	2% DF	Jagged and rounded	30
3rd conditionning pool	40 (Water)	4% DF	Rounded	30
Experience pool	Varies	Varies	Varies	50
Main pool	32 (Water)	8% DF	Horizontal lines	200
Lava pool	42 (Water)			50
Ísinn pool	14 (Water)			50
Steam		Dark	Rounded	50
Sauna		Dark	Rounded	30
Hot shower	36 (Water)	Light	Rounded	10
Cold shower	14 (Water)	Light	Rounded	10
Hot stones	32 (Stone)	Light	Rounded	20
Transitions				
4 transition spaces	28 ± 2	Varies	Varies	20
Technical room				200
Total				**2110**

Summary

The project is located on Úlfarsfell, Mosfellsbær, Iceland, with a view over Mosfellsbær, Reykjavik and the belonging harbor. Apart from Mount Esja, few mountains can be spotted by the naked eye towards the north. Mosfellsbær offers many hiking routes, inter alia those on Úlfarsfell.

In Mosfellsbær there is a fair distribution throughout the ages, although a slight dominance of youth is apparent. It has been discovered that Iceland contains more than hundreds of public baths, mostly available also for kids, thus the minimum age has been taken into consideration. It has been envisioned that the project should be a unique experience, offering a progressive proposal of both architecture and thermal bathing, thus the minimum age is set to 18 years old. Also the general tourism of Iceland is increasing – doubled since 2010 and tripled since 2003 – therefore considerations of accessibility to site and usability of building is in focus. The application for membership in EU changed the hot water consumption, but plays no bigger role in energy consumption as all energy resources of Iceland's production is renewable and sustainable. The geothermal energy is the reason for granting Iceland derogation from energy legislation in EU.

According to the climatic analysis, the biggest climatic challenge is related to daylight/sunlight hours. The sun is very low in the winter season, about 3°, and there is less than 20 hours of sunlight both during December and January. The site gives the advantage of no shadow from adjacent buildings or forest and total exposing of the building to the sun. The precipitation indicates a lot of rain, mostly moderate rain, up to 1/3 of a month. The wind can give issues, as it varies from 1m/s to 12m/s – light air to strong breeze – and especially when being located approximately 230 meter above ground. The wind mainly comes from east. To meet the conditions established on daylight, orientation will be considered as a critical attribute.
Úlfarsfell offers a soil of volcanic origin, making it hard to grow plants, but not trees. The soil is porous and mainly made of móberg and andosol. The topography of the site is extraordinary and offers steep ground, which is the natural flow of the site. The design will take this into consideration and use it in advantage.

The site offers a spectacular view over both Mosfellsbær and Reykjavik, although the sight over Mosfellsbær is preferred, as Mosfellsbær has a simple and manageable infrastructure presenting a less complex picture. Furthermore, Mount Esja is visible towards Mosfellsbær. The journey of visiting the site has starting point in the parking easily accessible from the main highway. The vertical forest creates anticipation only to emphasize the horizontal view on Úlfarsfell. The view will be considered as a critical attribute to assemble an unique experience.

Considering the infrastructure running through the site, there is great possibility of integrating roads to certain distance of the site. Also hiking routes are available. These should be used and preserved. Housing in general is close to the site, making it more local to Mosfellsbær than Reykjavik, although there is less than 10 minute drive from city center of Reykjavik to Mosfellsbær. The cities are at this point very connected.

Technically, when using the hypocaust system, the outlet air can be further used to heat radiantly in different spaces throughout the building. Also, in using the hypocaust system, there is some right about naming the project a thermae – Geothermae.

Objectives of project
Major objectives of the projects is to include the 4 principles, namely the *sequence order*, *ambiguous belief of navigation*, a *thermal perception list* and *fictive motion*, in a coherent manner. As described in the introduction, the principle of sequences will be used to condition the user and create anticipation. The list of perception must be used to guide the users and relate perceptions, tactile, thermal, geometric and light, to each other, to further reintroduce them in different relations. The relation between sensory perception leads towards a metaphorical conception of each perception. The fictive metaphoric motion should thus also be included. The ambiguous belief in navigation will be used as an amplifying device emphasizing the ambiguity in the project, and furthermore used to reset place and sensory. Thus the project is envisioned to offer these specific focuses:

Light condition
A linear increase in lighting conditions;
- A minimum of 2% DF in receptions and restaurant, with an overcast sky.
- A recurring 2% DF in transitional spaces, with an overcast sky.
- Approximately 1% DF in 1st conditioning pool.
- Approximately 2% DF in 2nd conditioning pool.
- Approximately 4% DF in 3rd conditioning pool.
- Approximately 1% DF in Experience pool.

Thermal perception of materials
A linear change in roughness/hardness of materials.
- Very rough materials must be used in 1st conditioning spaces.
- Rough materials must be used in 2nd conditioning spaces.
- Soft materials must be used in 3rd conditioning spaces.
- Very soft materials must be used in 4th conditioning spaces.

Sequence order
A linear change in geometric expression.
- A change from jagged to rounded geometry must be attributed to the conditioning spaces.

Ambiguous belief of navigation
Questioning of place.

Thermal perception of temperature
A linear increase, until 4th conditioning;
- 30 degree celsius water temperature of 1st conditioning pool.
- 35 degree celsius water temperature of 2nd conditioning pool.
- 40 degree celsius water temperature of 3rd conditioning pool.
- 30 degree celsius water temperature of 4th conditioning space and Experience pool.

Fictive motion
Fluent dynamic form and space, insisting on a fictive metaphoric motion.

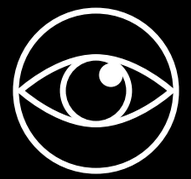
Further objectives:
- Using the views
- Using the topography
- Using climatic conditions for minimizing energy demand.

The project can be evaluated according to these objectives.
The following vision is how the project is envisioned to be experienced by the users.

III

Vision

A manuscript of the vision of the project



”Vision is the art of seeing what is invisible to others.”

Jonathan Swift

The Vision

1. INT. ÚLFARSFELL, REYKJAVIK – ASCENDING TO THE GEOTHERMAE

February 2016. 7 o'clock in the morning. It is foggy and dark. There is snow everywhere, creating a white scenery in front of Úlfarsfell. The parking has a moderate number of cars parked and little to no snow is on the parking area. There are still people arriving to the parking – some by foot others by car – all going in the same direction; a slender opening in the woods. There is a distinct chattering blended with the sound of wind and a narrow river in the forest, whispering in the sound of silence. The smell of conifers and wet moss is rather piercing. The atmosphere is redolent of a sectarian ritual early in the morning.

Your partner, whom you came with, Virgil just closed the car doors and has a bag over his shoulders.

Virgil
(Looking at you, smiling)
It's something else, huh?

YOU
(Nodding slowly while observing Úlfarsfell)
So far it is. I didn't expect this sight.

Virgil
(Observing Úlfarsfell from the parking – long pause)
The best is yet to come.

You are approaching the slender opening in the woods. A path in the snow inside the forest has been made clear by prior people. It gets even darker in the forest, and the smell and sight of trees intensifies. You and Virgil enter and start walking up the steep forest.

YOU
(Closely investigating the height and bark of the conifers)
Does this wood always smell this intense of conifers?

Virgil
Yes, usually after rain or snow. Why?

YOU
I guess I couldn't see the forest for the trees, but now it's all I smell.

Reaching the end of the forest path, a steep staircase appears, and it gets less dark as the white snow reflects the bits of light. The staircase has been carved out from the mountain. Traces of visitors are visible. The scent dissolves. You and Virgil start walking up the staircases.

Virgil
(Walking ahead of you, starts gasping for breath)
I hope this is worth your effort!

YOU
(While giggling and gasping for breath)
Anticipation is the greater part of pleasure, they say!

Reaching the top, a building, poetically interwoven with its landscape and view over Reykjavik and Mosfellsbær with Mount Esja, reaches consensus. The horizontality and length of the

buildings relaxes the landscape, dumping all aforethought expectations. The materials, the size, the form is different; nothing resembles the buildings of Reykjavik. The uniqueness is tempting and daring, and yet all trust is put into the experiences to come, fully believing that it will treasure the quest of new experiences throughout of your grand tour. A few visitors are in sight contributed by a distinct whispering. The silence emphasizes the importance of the experiences. Ascending Úlfarsfell made you feel confident, only to be met by the grandeur of nature, overpowering the status you have crowned yourself. You enter the Geothermae.

2 HOURS LATER.

You and Virgil exit the Geothermae, following the path towards the forest again. It is midday, and the sun shines. The snow is even whiter than before. Both of you are silent. You notice that Virgil is giving up his ghost slowly. You and Virgil reach the parking.

Virgil
(Slowly dying)
Silence has so much meaning.

YOU
(Reassuring)
Silence is also speech.

Virgil
(Whispering while slowly dying)
I suppose it's a matter of meaning.
(Virgil vanishes into the air)

YOU
(Looking back to the forest and observing Úlfarsfell)
The scent and sight reminds me of everything and nothing.

You have come to realize that Virgil was a representation of your inner certainty, which you have perplexed and questioned the silence of.

IV

Concept

Concept development and contemplations

”An idea that is not dangerous is unworthy of being called an idea at all.”

Oscar Wilde

Theory to concept

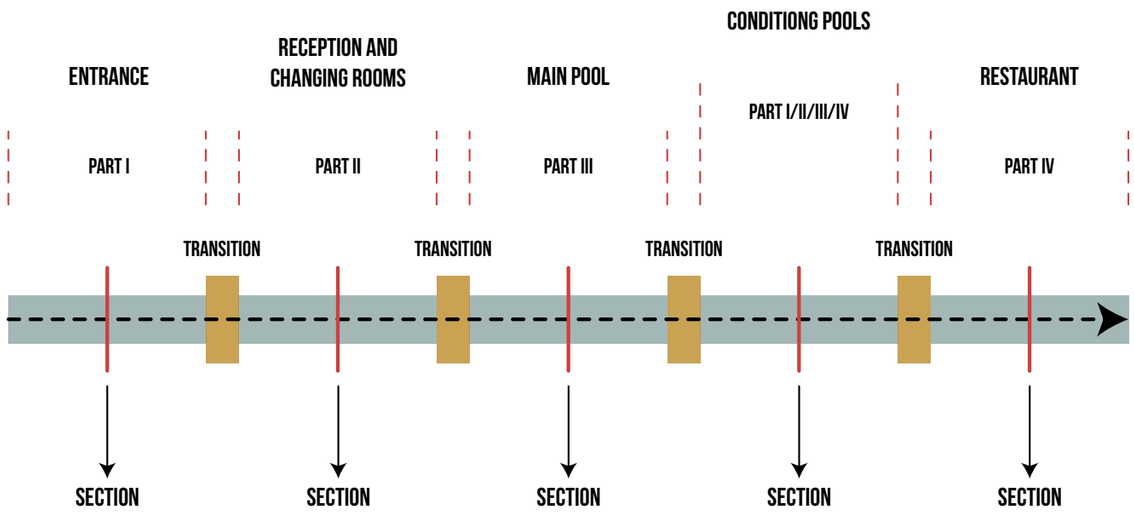
Sequenced order is not directly measurable nor assayable, neither is the *ambiguous belief of navigation* and *fictive motion*. But as they have been defined in chapter "Theory to practice", the sequenced order can be grasped architecturally as an insurance of separation of spaces. By separating the spaces, each space becomes an individual sensory experience, only related to previous and next space through anticipation, and it is the anticipation that is partly controlled through the principle of *thermal perception*. Thus the materials of the architecture become the conductor of the narration and ultimately the impetus of an ambiguous experience – a narration of anticipation. To further emphasize the ambiguity in the architecture, the two principles, *ambiguous belief of navigation* and *fictive motion*, are used to solve the spaces. By using a principle that has the capability to bewilder the user by visually feeding navigational information, will ultimately activate more sensory, which leads towards a possible cross-activation as described in chapter "Theory to practice". The cross-activation can be grasped as a metaphor, because it is defined in aforementioned chapter, as a crossing of two, or more, independent sensory. Therefore the principle of fictive motion can be used as a geometric character, merely implying movement – a metaphoric gesture.

Here, the notion of linearity becomes ideal. Taking starting point in the anticipation, a linear growth of significant qualities must occur, simultaneous with the metaphoric gesture and ambiguous navigation, will conveniently be anticipated. Thus only one significant quality must ultimately fail in linearity, forcing a reinterpretation and questioning of the spatial perception. That one quality has been chosen to be the temperature, as the project concerns a thermal bath. Following qualities have been integrated in the linearity:

- Light
- Geometric character
- Material tactility
- Temperature

Both the whole building and the conditioning pools have been separated into 4 parts. Figure 34 illustrates the division.

Fig. 34 - Diagram of function division



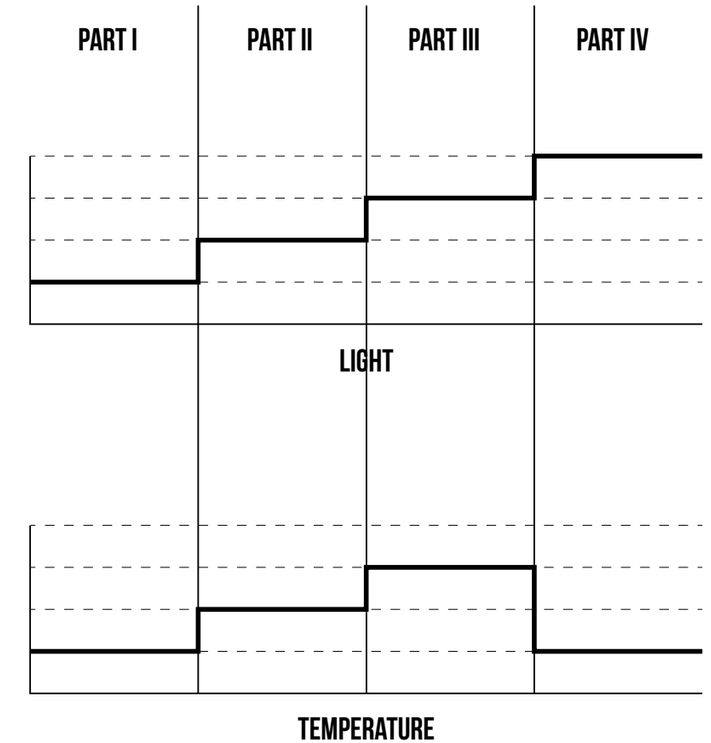
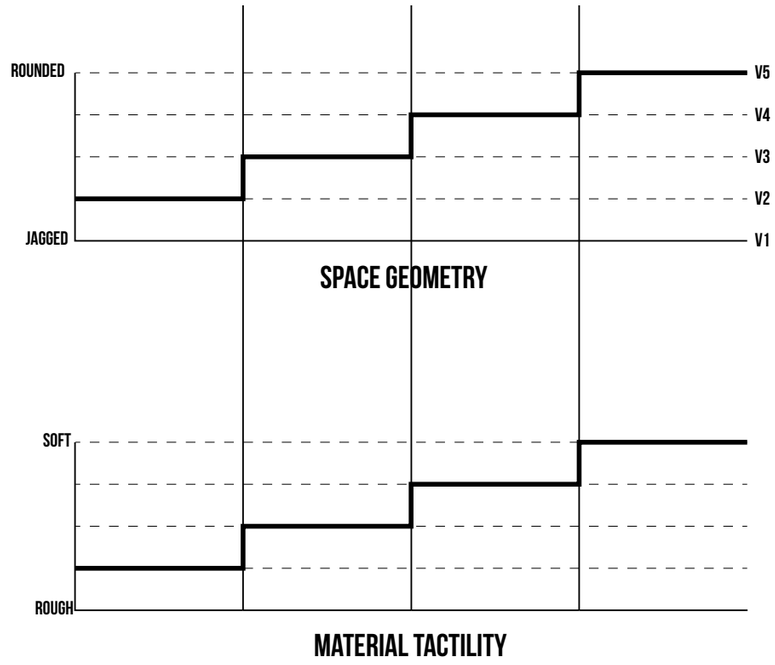


Fig. 35 - Diagrams of linearity



Focusing on the conditioning pools, to assure the linear growth of light, a particular focus must be on the façade and the openings. To ensure a linear growth in geometric character, a division of the visual receptors in visual center has been made. The approach to creation of spaces has been through sections rather than plans, as the spaces are easily read from sections. As described in the theory, the visual center interprets the image captured by the eyes. The order can be approximated as following:

- Part I V1: Recognizes straight lines
- Part II V2+V3: Involved in recognizing objects.
- Part III V4: Recognizes colors.
- Part IV V5: Recognizes movement.

The tactility of materials starts by being rough and hard, to smooth and soft.
The temperature slowly increases in the conditioning pools, going from 30°C to 35°C and 40°C in the first three parts. The fourth part, being the failure of linear growth, resets to 30°C. This will be result in a questioning of the assigned and anticipated meaning of the space, leaving the space with two interpretations. The space will become ambiguous, as either the thermal receptors will follow the anticipation or the actual sensory. The thermoreceptor discharges have been illustrated in figure 36, where the red line designates the anticipation.

3 spaces can give 1 space 2 meanings.

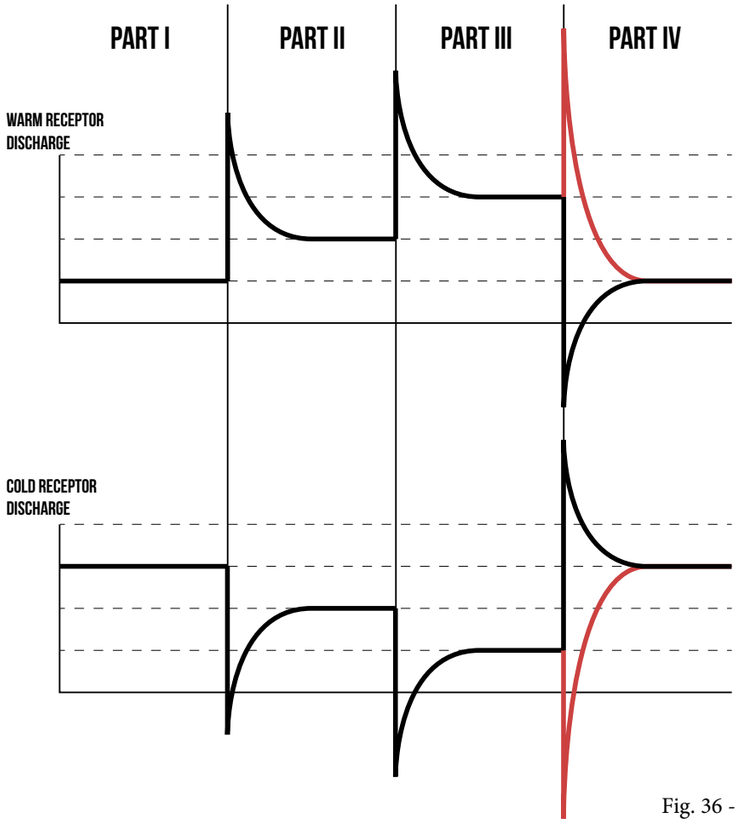
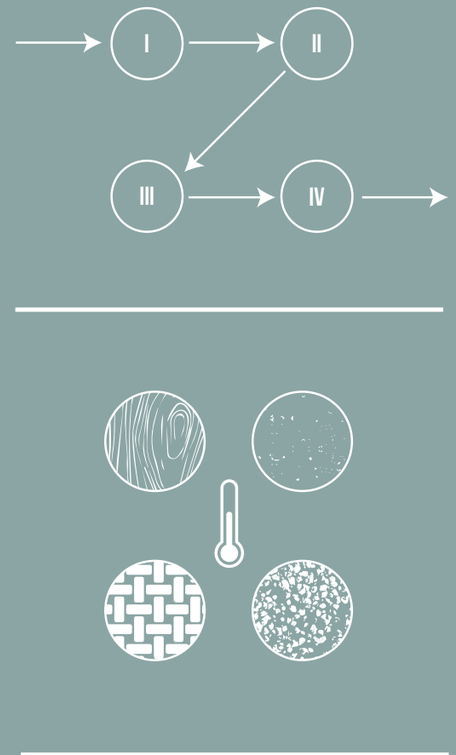


Fig. 36 - Diagrams of linearity



V

Design process

The process behind different parts of the project

"I put my heart and soul into my work, and have lost my mind in the process."

Vincent Van Gogh

Commencing forms

Three forms are developed from earlier models and further evaluated to find a final form. The critical points of evaluating are here elaborated:

- Integrating views

How well does the form create view platforms? Does it integrate itself to the views? How well does the form use the direction of the views?

- Integrating topography

How well does the form take advantage of the topography? Does it follow the topography or obstruct it?

- Integrating light

Does the form create shadowpits with no sun exposition? How good is the general form exposed to the sun? Does it take advantage of it? How well is the form exposed to the sun during winter (15th to 21st December)?

- Possibility of sequenced order

How well does the form allow discontinued spatial interference in order to change sequence?

- Possibility of fictive motion

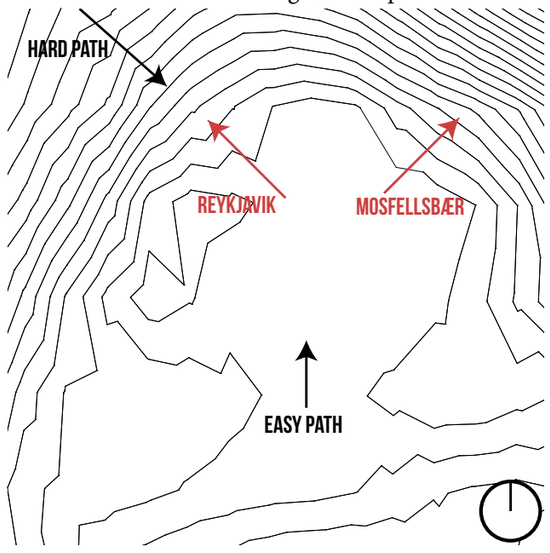
How well does the form intend any structural fictive motion? Does the form imply motion?

- Possibility of ambiguous navigation

How well does the form allow spaces to interfere? Does it connect spaces in all directions?

The map illustrates the important directions, in terms of topography, views, entrance/exit and solar exposure. The map will be used on the commencing forms in order to evaluate them for further analysis. The roughly improved forms are taken to further analysis to ensure the intentioned qualities.

Fig. 37 - Map for evaluation



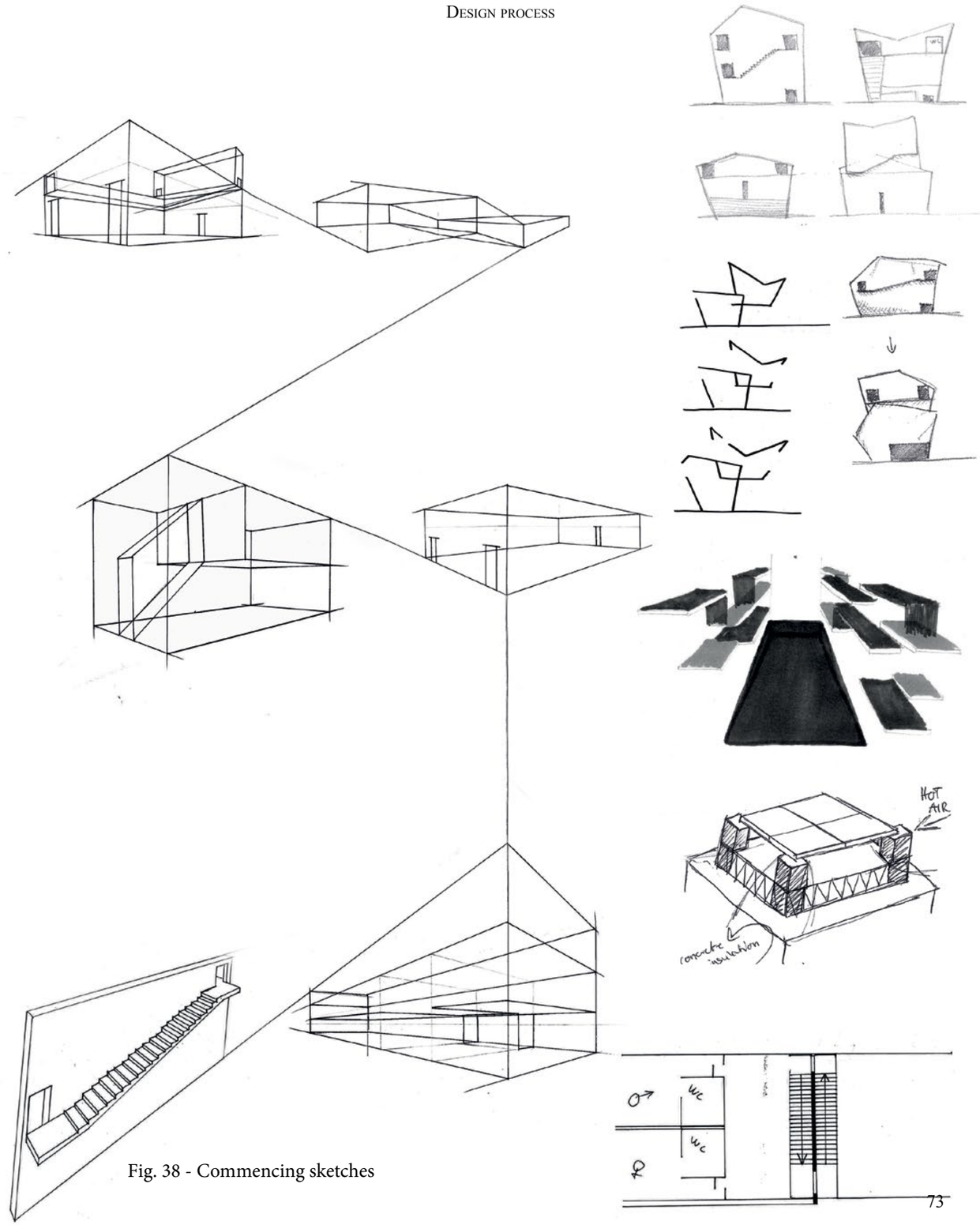


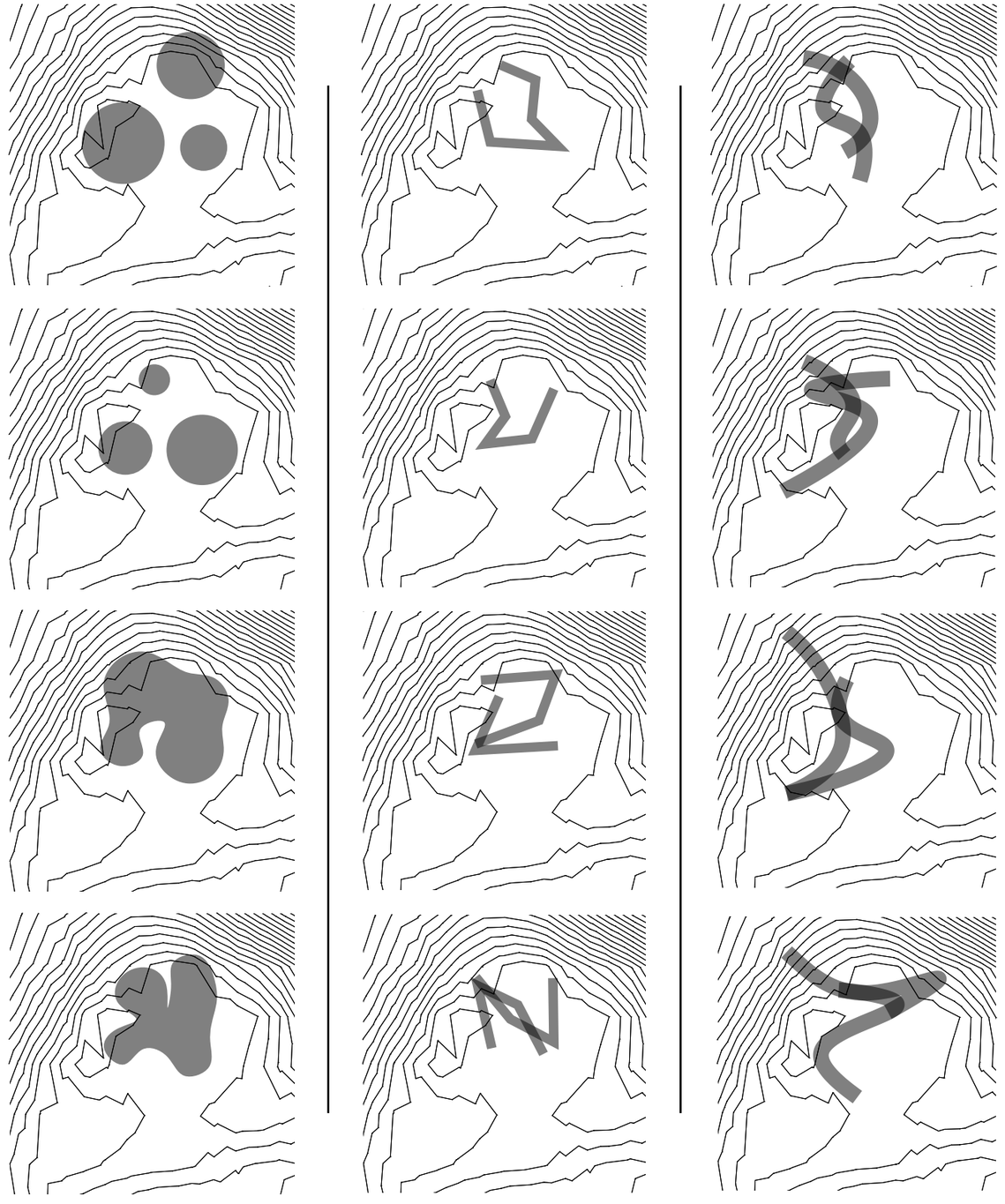
Fig. 38 - Commencing sketches

Circles
The initial circles were suggested mainly because of their rounded form and geometric advantage of connecting. Bigger circles were suggested to be located towards south for solar radiation. A singular circle did not comply according to sequenced order, thus more circles were introduced adjacent to each other. A smooth transition between the circles was further introduced to substantiate the sequenced order. Yet the circles failed to enlarge the integration with the topography, and integrating the views. Stacked circles seem to be more fulfilling.

Broken line
Focusing on the sequenced order, the 'line' has the advantage of organizing spaces conditionally. Using only one line creates difficulties in integrating views, and the jagged edges do not comply with the topography. The long side of the line is oriented towards south. An additional line is introduced to investigate the possibility of integrating the views. The possibility of ambiguous navigation is improved when the two lines intersect. Furthermore the line creates great possibility of fictive motion, yet the broken line fails to respect or adhere to the topography.

Fluid lines
In using the advantage of lines and the topography, the fluid lines conforms the views, the topography and the sequence order. Also, when allowing the lines to overlap, it gives better possibility of ambiguous navigation. Furthermore, the dynamic movement of the fluid lines gives better possibility of fictive motion. The fictive motion can be emphasized through the facade. Considering the light exposure, the southern facade is oriented towards the south again. This shape is more in harmony with the topography and fulfills the criteria better.

Fig. 39 - Commencing models



Evaluating forms - Three stacked slices

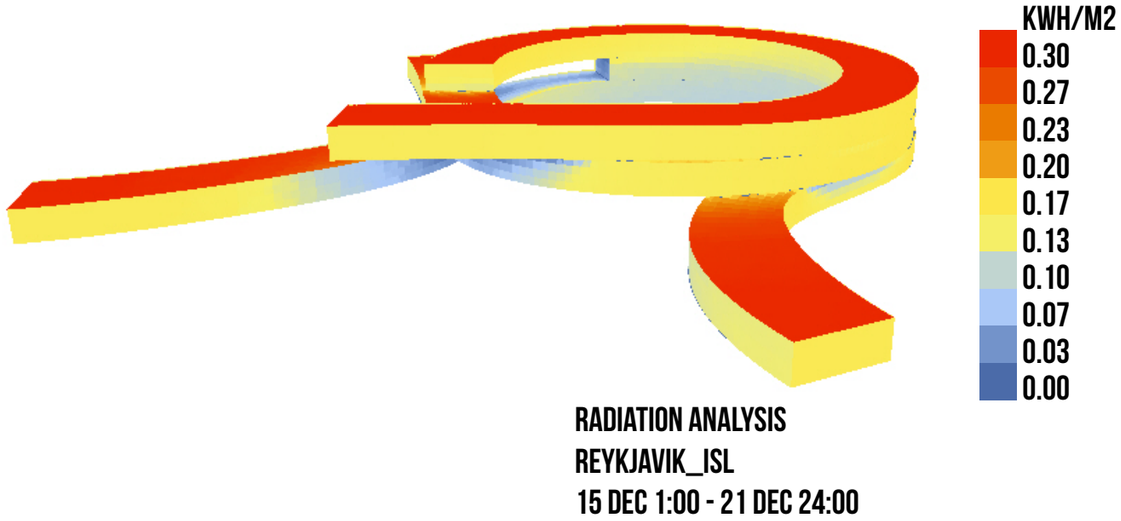


Fig. 40 - Radiation analysis

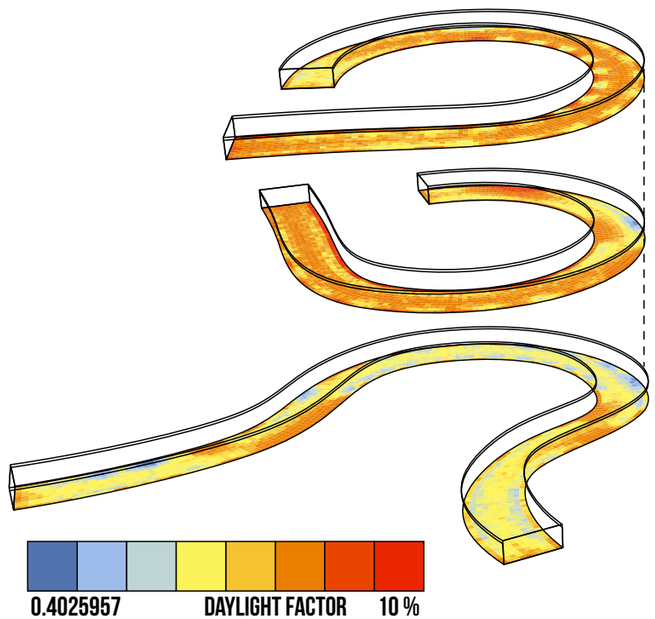


Fig. 41 - Daylight analysis

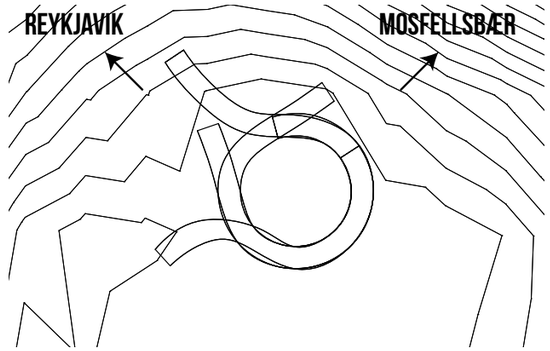


Fig. 42 - Views and topography analysis

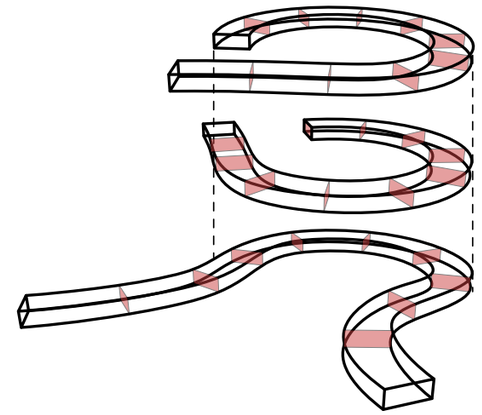


Fig. 43 - Possibility of sequenced order

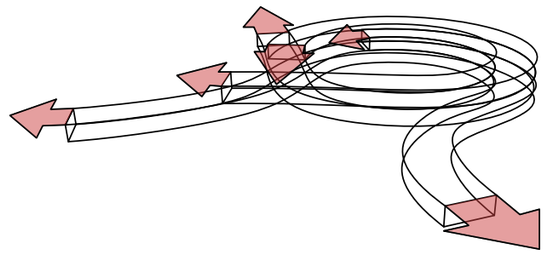


Fig. 44 - Possibility of fictive motion

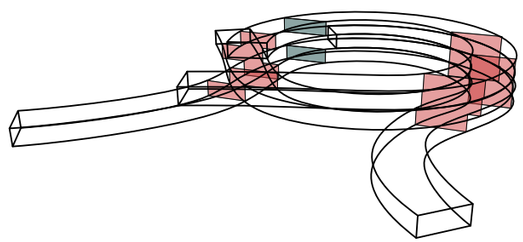


Fig. 45 - Possibility of ambiguous navigation

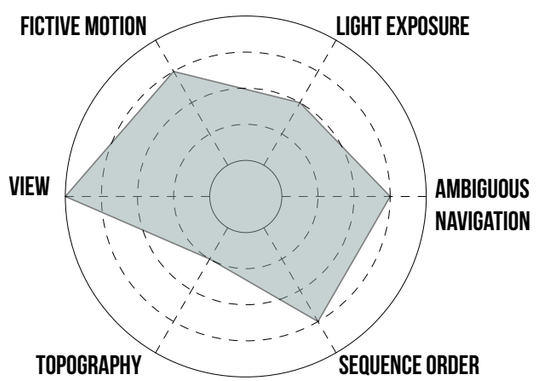


Fig. 46 - Spiderweb diagram

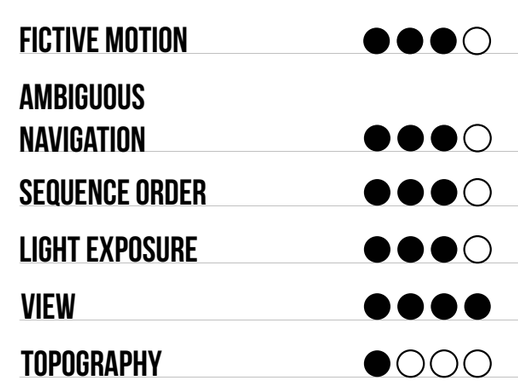
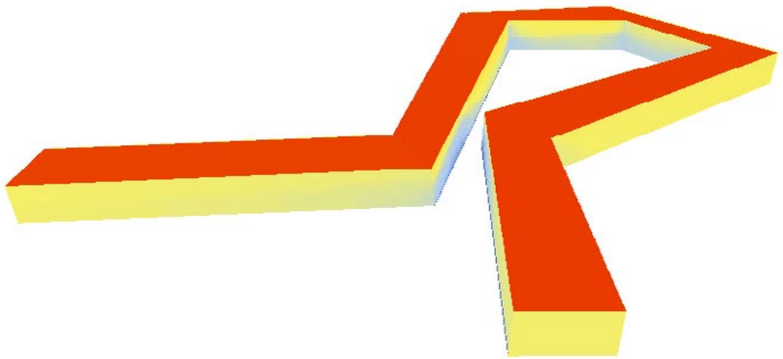
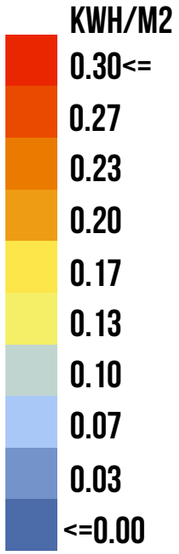


Fig. 47 - Pointlist diagram

Evaluating forms - Jagged duct





RADIATION ANALYSIS
REYKJAVIK_ISL
15 DEC 1:00 - 21 DEC 24:00

Fig. 48 - Radiation analysis

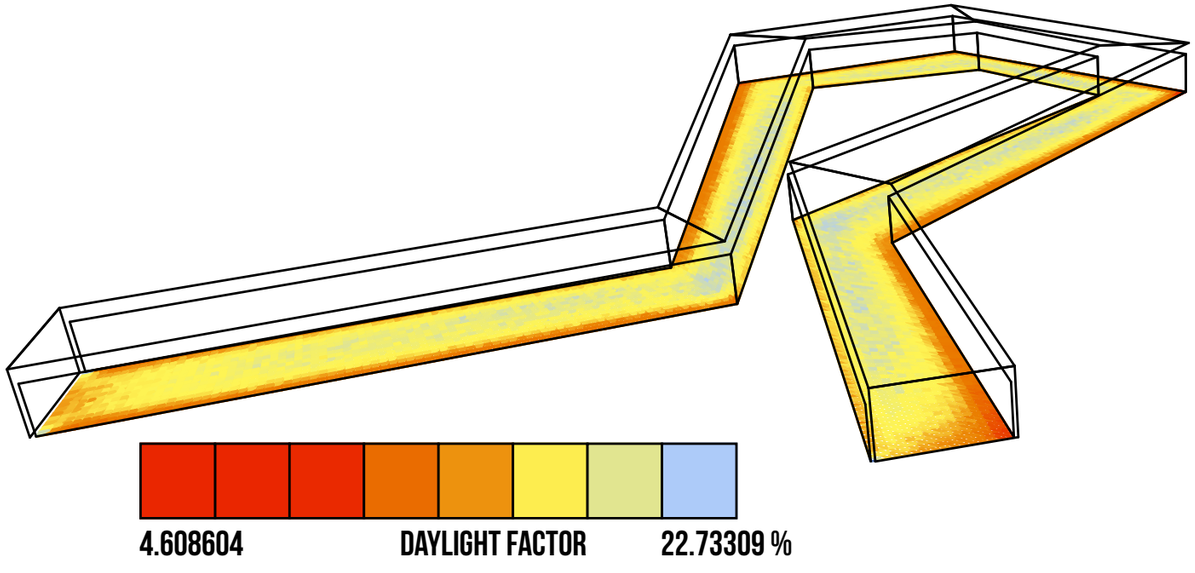


Fig. 49 - Daylight analysis

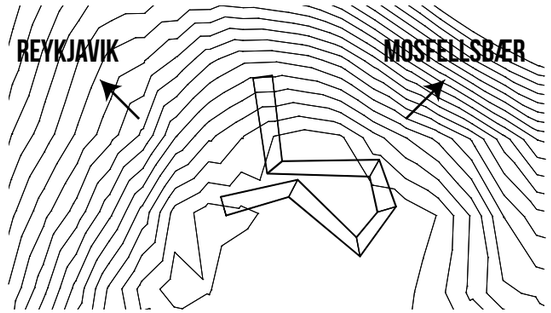


Fig. 50 - Views and topography analysis

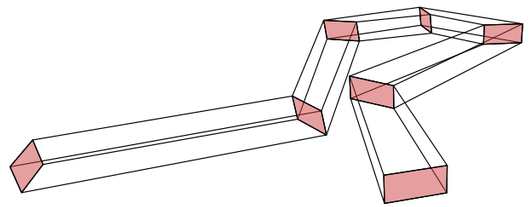


Fig. 51 - Possibility of sequenced order

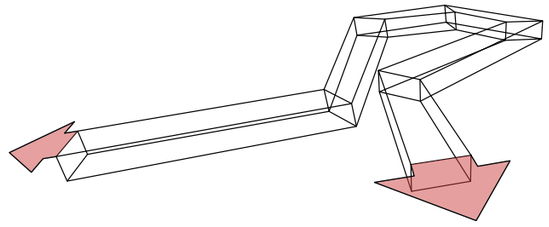


Fig. 52 - Possibility of fictive motion

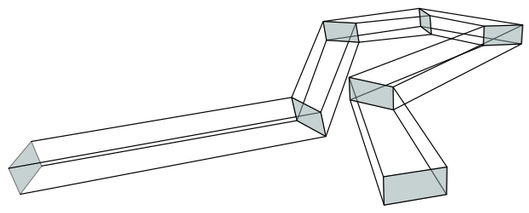


Fig. 53 - Possibility of ambiguous navigation

Fig. 54 - Spiderweb diagram

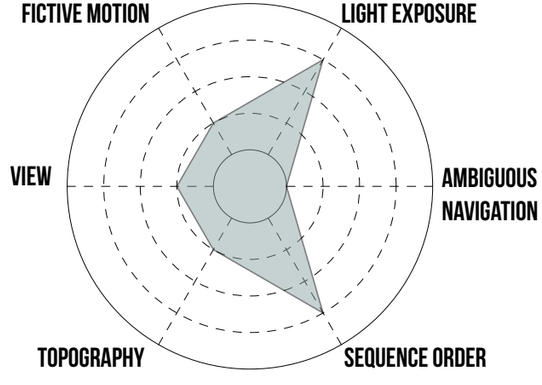
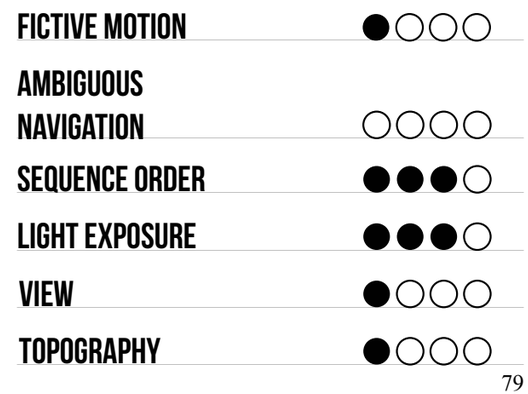


Fig. 55 - Pointlist diagram



Evaluating forms - Elongated ducts

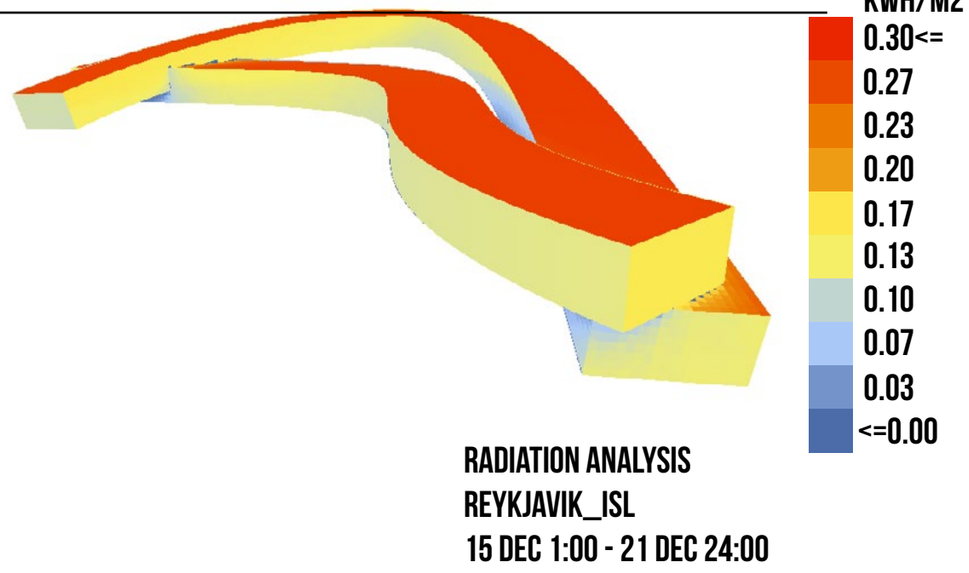


Fig. 56 - Radiation analysis

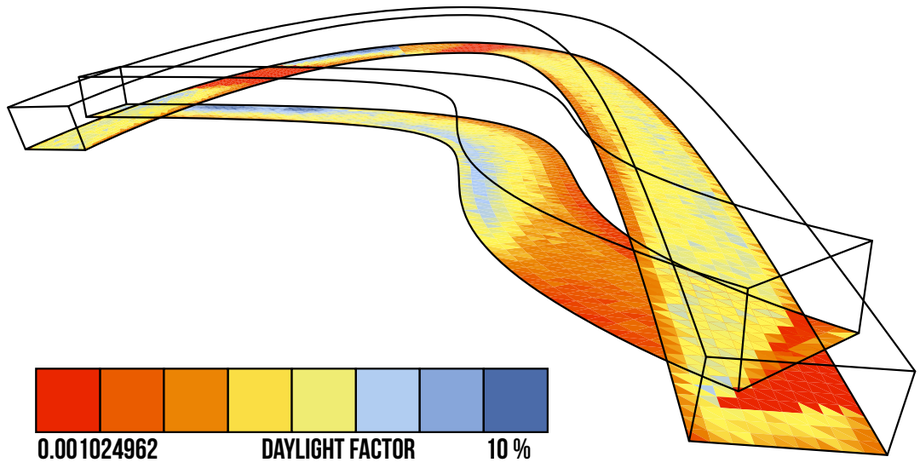


Fig. 57 - Daylight analysis

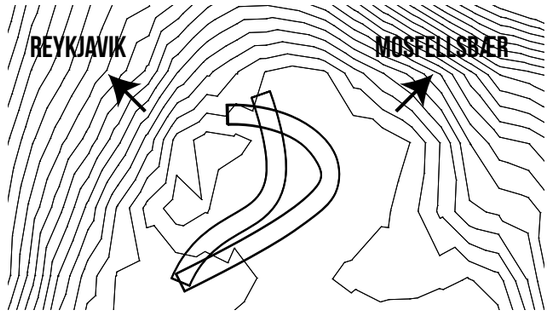


Fig. 58 - Views and topography analysis

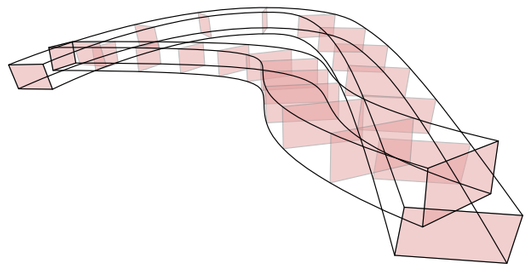


Fig. 59 - Possibility of sequenced order

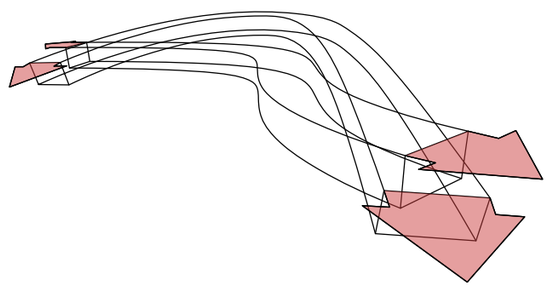


Fig. 60 - Possibility of fictive motion

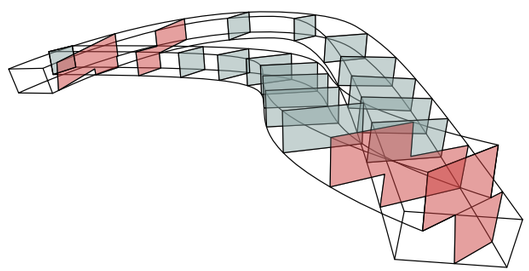


Fig. 61 - Possibility of ambiguous navigation

Fig. 62 - Spiderweb diagram

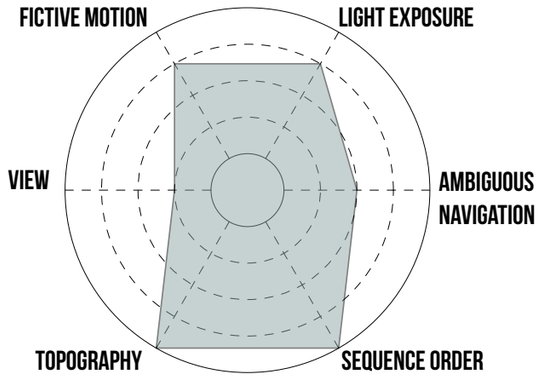
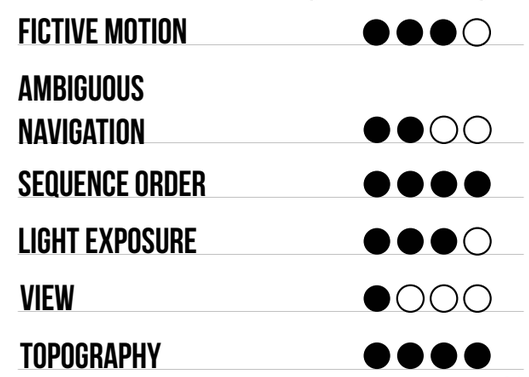
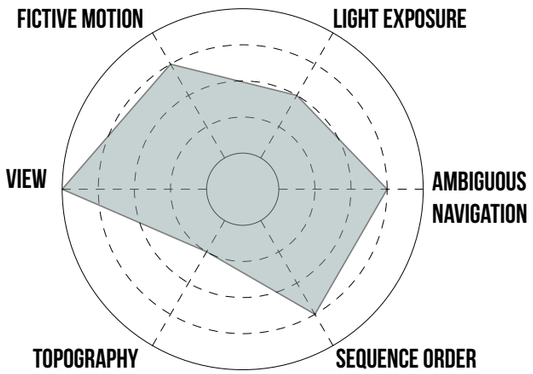


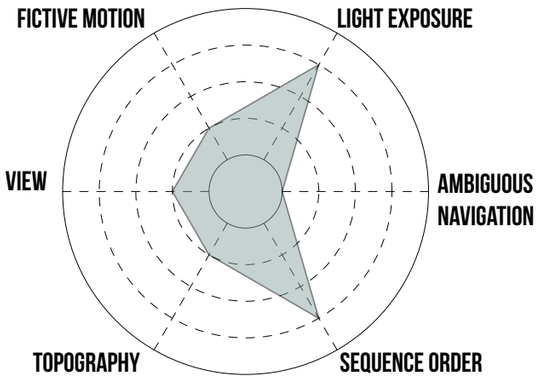
Fig. 63 - Pointlist diagram



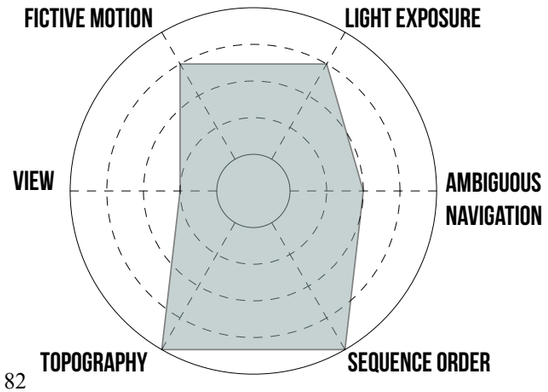
Evaluation



Three stacked slices
The advantage of the form is the integration of views, the possibility of ambiguous navigation, the possibility of sequenced order and the fictive motion.
The disadvantage of the form is the respect of topography and light exposure.



Jagged duct
The advantage of the form is the integration of the possibility for sequenced order and high solar radiation exposure.
The disadvantage of the form is no integration of the views, topography, fictive motion and possibility of ambiguous navigation.



Elongated ducts
The advantage of the form is the integration of the possibility of sequenced order, integration of topography, sequenced order and high solar radiation exposure.
The disadvantage of the form is the lack of integration of views and possibility of ambiguous navigation.

Plan workshop

Problem:

How can one best integrate the spaces for more functional results, while still obtaining the sequenced order? Should one follow through with theory or go for more functional spaces/connections?

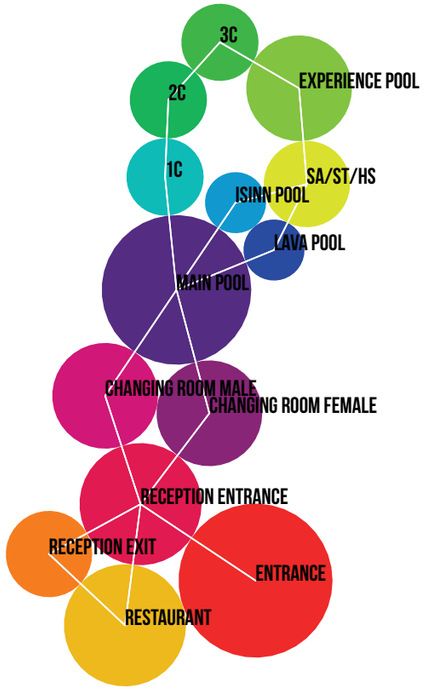
Focus point:

Integration analysis
Sequence order

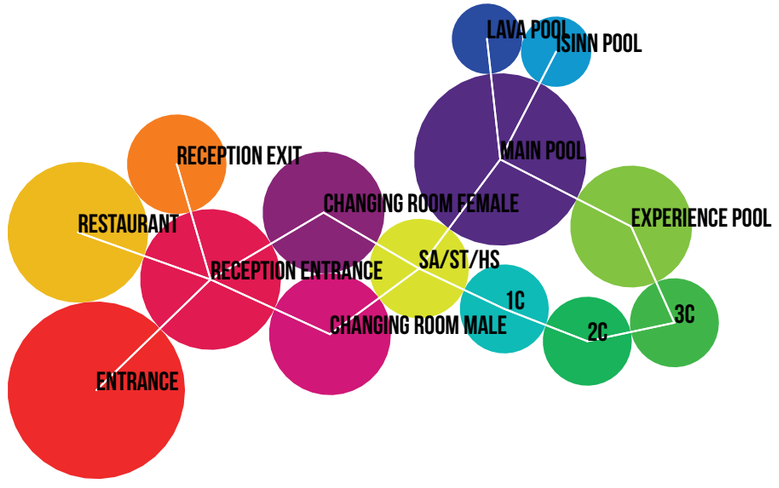
Approach:

By using the integration analysis developed by Bill Hillier as described in "Social logic of space" the level of integration is found.
The further from 0, the more communal the space.
The closer to 0, the more private the space. The goal is to find the best starting point for a plan that simultaneously complies with the principles.

Proposal 1 & 2



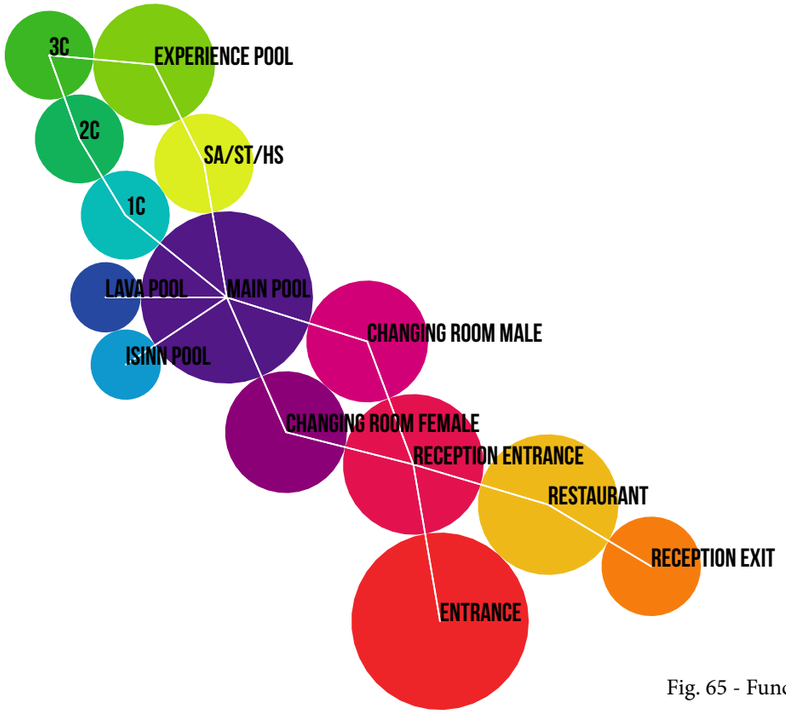
INTEGRATION ANALYSIS
MAIN POOL: 1.601
CHANGING ROOM MALE: 1.224
CHANGING ROOM FEMALE: 1.224
1C: 1.041
LAVA POOL: 1.041
ISINN POOL: 1.041
RECEPTION ENTRANCE: 0.991
SA/ST/HS: 0.832
2C: 0.771
EXPERIENCE POOL: 0.65
RESTAURANT: 0.65
RECEPTION EXIT: 0.65
ENTRANCE: 0.631
3C : 0.631



INTEGRATION ANALYSIS
SA/ST/HS: 1.601
CHANGING ROOM MALE: 1.224
MAIN POOL: 1.224
CHANGING ROOM FEMALE: 1.224
1C: 0.991
RECEPTION ENTRANCE: 0.991
EXPERIENCE POOL: 0.832
2C: 0.718
LAVA POOL: 0.718
ISINN POOL: 0.718
ENTRANCE: 0.631
RESTAURANT: 0.631
3C : 0.631
RECEPTION EXIT: 0.631

Fig. 64 - Function diagram and integration analysis

Proposal 3



INTEGRATION ANALYSIS

MAIN POOL: 1.734
CHANGING ROOM MALE: 1.301
CHANGING ROOM FEMALE: 1.301
RECEPTION ENTRANCE: 1.041
SA/ST/HS: 1.041
1C: 1.041
LAVA POOL: 0.867
ISINN POOL: 0.867
2C: 0.743
EXPERIENCE POOL: 0.743
RESTAURANT: 0.694
ENTRANCE: 0.65
3C : 0.578
RECEPTION EXIT: 0.495

Fig. 65 - Function diagram and integration analysis

Evaluation

Comparing the 1st proposal to the 2nd the most integrated space is respectively the Main Pool and the Wellness area. Allowing the Main Pool to become the most integrated space makes more sense as the Main Pool is more likely to become a greater space than the Wellness area. Furthermore, the sequenced order is more evident in the 1st proposal, as each space is more integrated into the order, rather than becoming dead-ends. The 1st proposal has been used for further development, and after certain amount of iterations, the final proposal, being the 3rd proposal, is an optimized function order.

Facade workshop

Problem:

How do one ensure an increasing daylight at a given time of the day for all the pools?

Focus points:

Daylight
Orientation
Size of windows

Approach:

Two proposals are investigated, both with an increasing window size, 2.5%, 5% and 10% of the roof area. The orientation is simultaneously reoriented to investigate the effect on daylight. The goal is to find how much window area is needed in each space, according to its orientation, to reach an increasing percentage of daylight, as stated in the concept.

PERFORATED

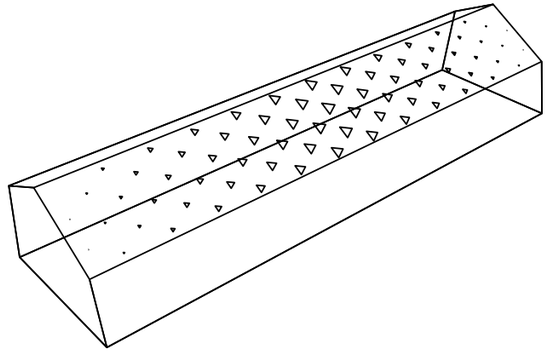


Fig. 66 - Perforated openings

GILLS

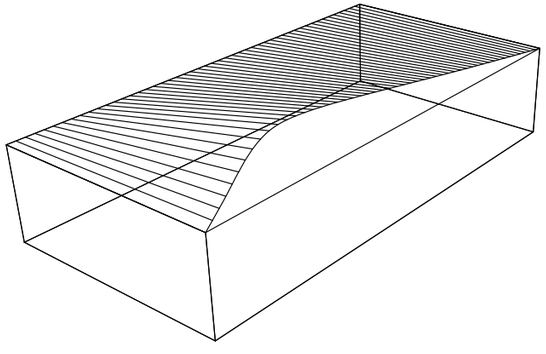
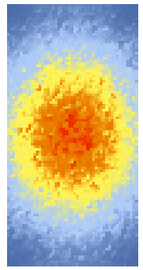


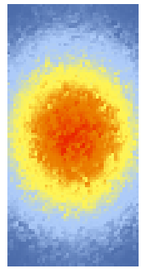
Fig. 67 - Gills openings

Perforated

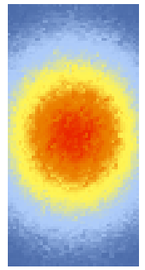
East



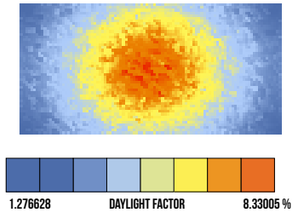
East



East



North



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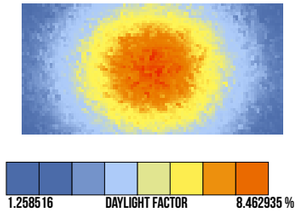

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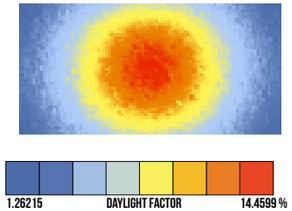

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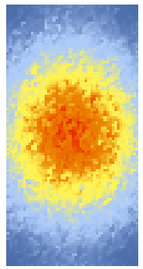

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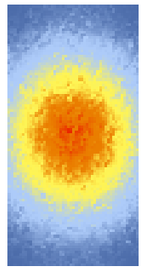

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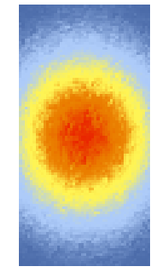
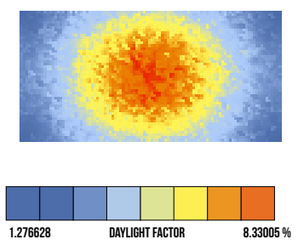


South



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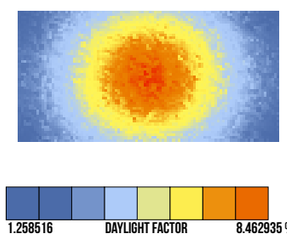

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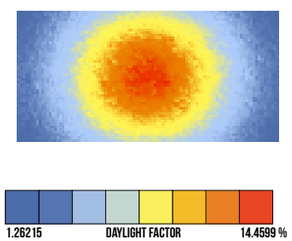
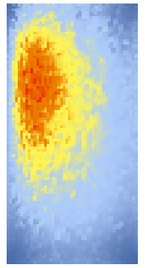


Gills

East



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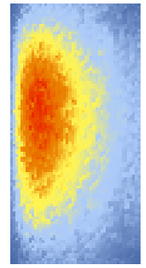

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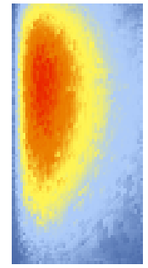

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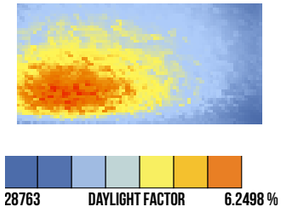

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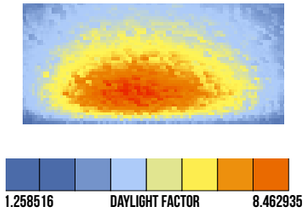

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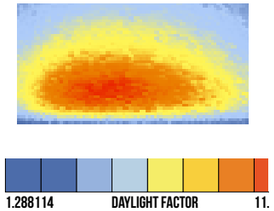

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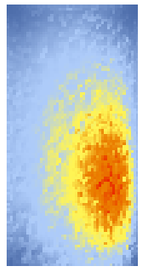

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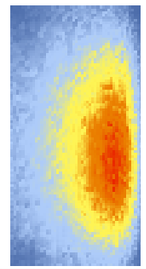

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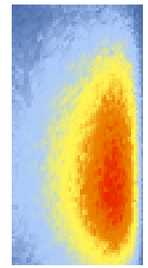

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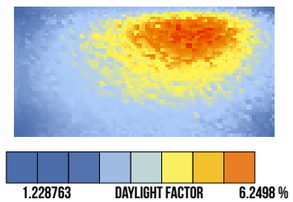

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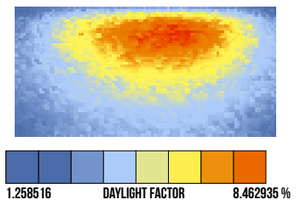

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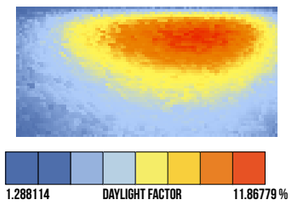


Evaluation

Daylight

The perforated windows allow to precisely adjusting the daylight whilst maintaining the pattern. The first percentage to evaluate is the 2.5% windows of the roof, which measures 200m². In every orientation the daylight factor was 3.8% inside the space, indicating that the orientation does not affect the daylight with the simplified geometry. The minimum sunlight was, also in every case of orientation, approximately 1.2% with a maximum of 8.3%. When the window area reaches 5% the daylight increases to 5.7% regardless of orientation. When reaching a ratio of 10% window area, the average daylight in the space increases to 9.8%. It is important to notice that the windows are placed as roof windows/skylight.

When evaluating the gills, the orientation plays a bigger role, as the opening is oriented towards a certain direction, instead of the z-axis. With 2.5% window of the roof the daylight reaches 6.2% as maximum, while 5% windows reaches 8.4%, showing a very low difference. The daylight gets past the 10% when reaching a window ratio of 10%.

Expression

The gills have a linear expression, easily followed and understood. The curve of the gills emphasizes the motion of the opening and the direction of the whole building, which complies very well with the "Fictive motion" principle. The downside of the linear opening is the possibility to see outside and orient oneself, which is not wanted at all times. The perforations do also create a gesture of motion, as the size slowly increases to a maximum, and then decreases, in a fluent manner. This also complies very well the aforementioned principle. The view is disturbed here and thus the perforation should only be used in spaces where it is not wished to have a view.

Conclusion

It can be concluded that the perforated windows are independent of orientation and thus a better starting point for the plan of the pools. The gills, despite having an expression that complies with an important principle, is too dependent of the orientation, and will thus be used in that manner. The scheme illustrates the differences. The differences are needed to be larger. This will be taken into consideration when designing the façade.

For perforated windows:

Percentage windows of roof	Average daylight
2.5%	**3.8%**
5%	**5.9%**
DIFFERENCE	**2.1%**
5%	**5.9%**
10%	**9.8%**
DIFFERENCE	**3.9%**

For gills windows:

Percentage windows of roof	Average daylight
2.5%	**2.6%**
5%	**4.7%**
DIFFERENCE	**2.1%**
5%	**4.7%**
10%	**7.4%**
DIFFERENCE	**2.7%**

VI

Presentation

Presentation including sections, plans, rendering and masterplan

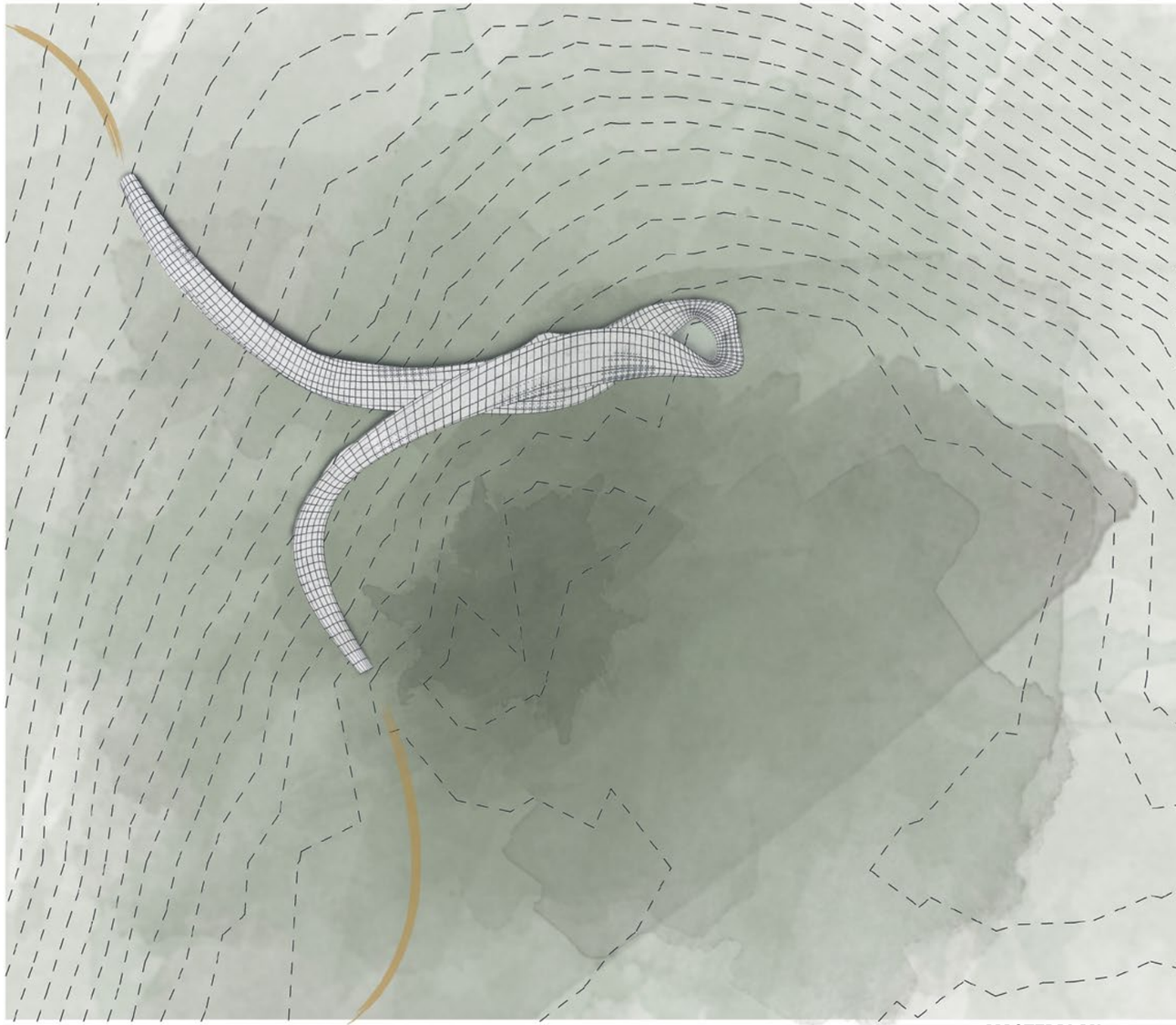
”Genius is the ability to put into effect what is on your mind.”

F. Scott Fitzgerald

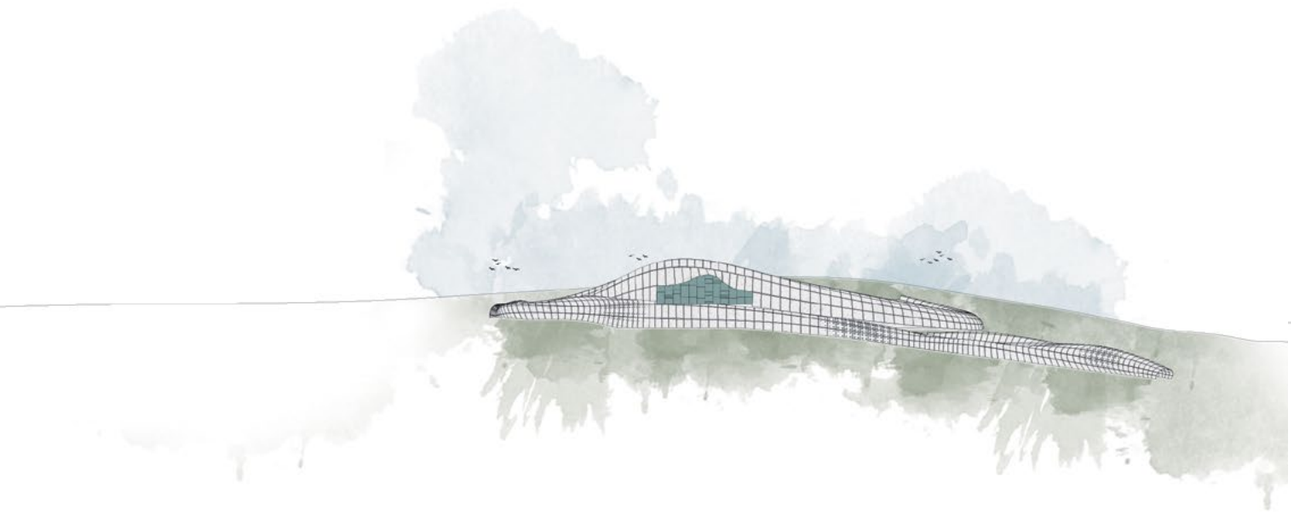
Presentation

The plans are here cut off short only illustrating the important parts of the specific level. Materials have been in particular focus and thus been applied. The complete plans are attached in the drawing case.
As the geometry of the building is rather complex, the sections have been important in particular to illustrate the depth and important lines. The following sections and elevations have also materials applied.

As shown on the masterplan, there is the possibility to enter the building from a hard path and an easy path. The hard path includes a rail of 40° inclination, while the easy path inclines to a bit more than 12°. The easy path brings one up to the exit-tunnel, which further both lead to the restaurant and the reception of the thermal bath. The rails of entrance and exit are designated by the orange lines on the masterplan.

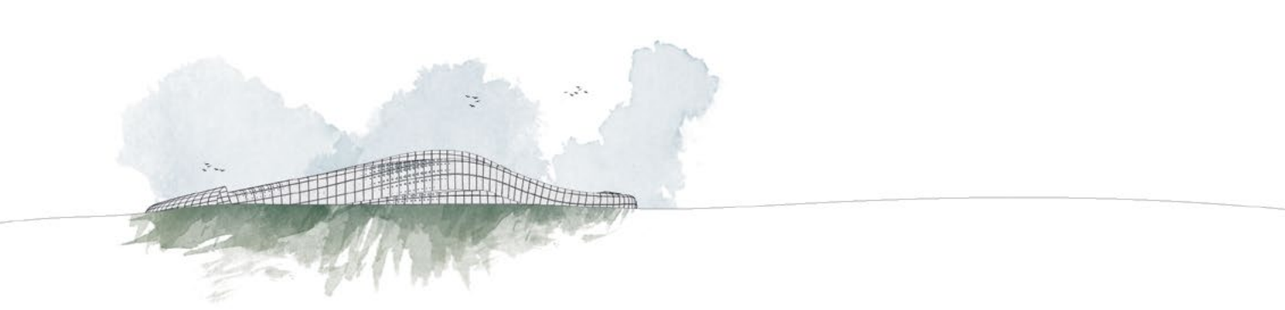


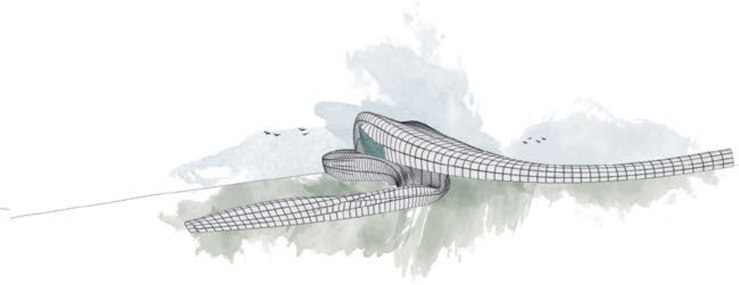
MASTERPLAN
1:2000



NORTH ELEVATION
1:2000

EAST ELEVATION
1:2000





SOUTH ELEVATION
1:2000

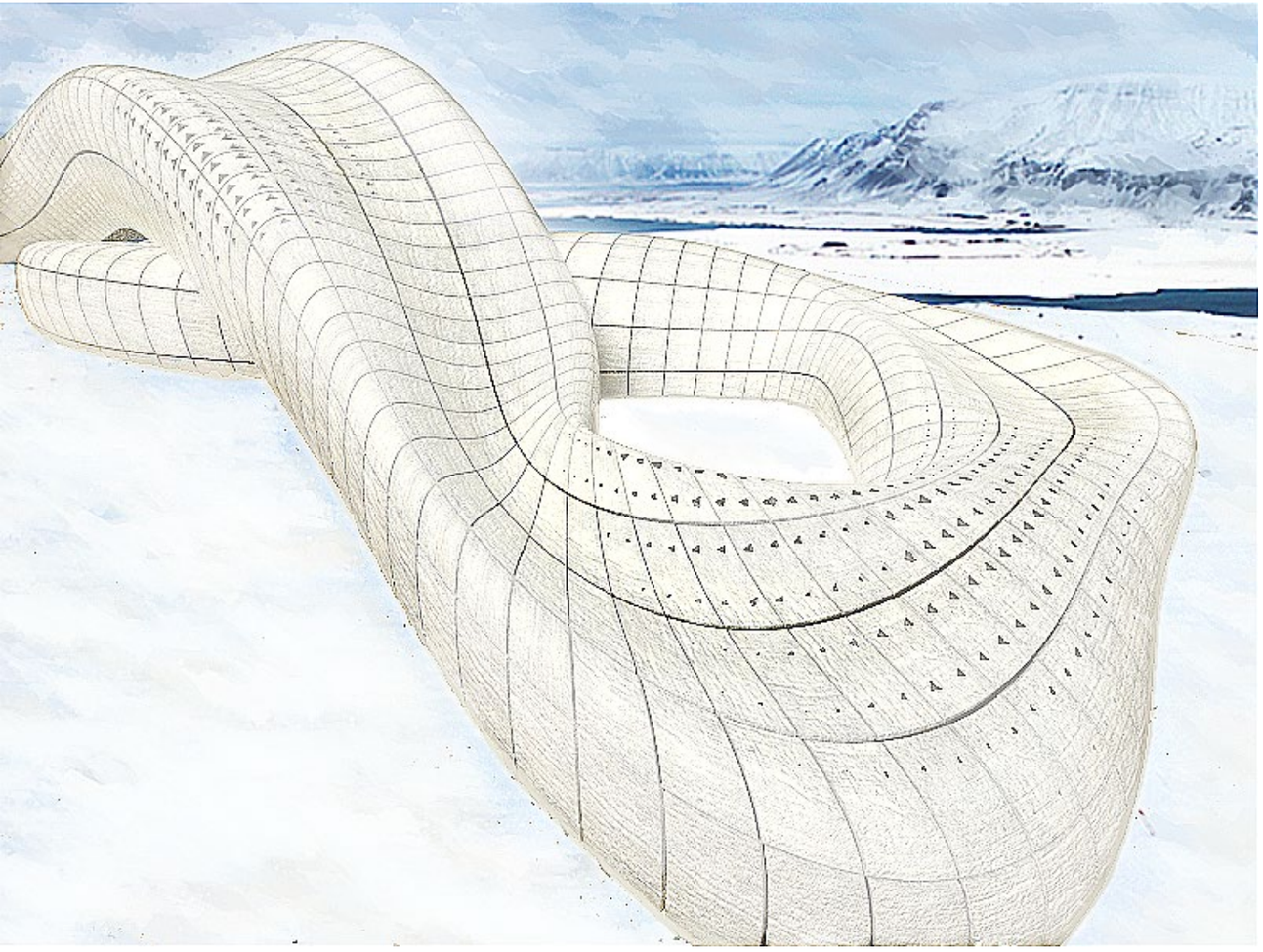
WEST ELEVATION
1:2000

SECTION A-A'
1:200

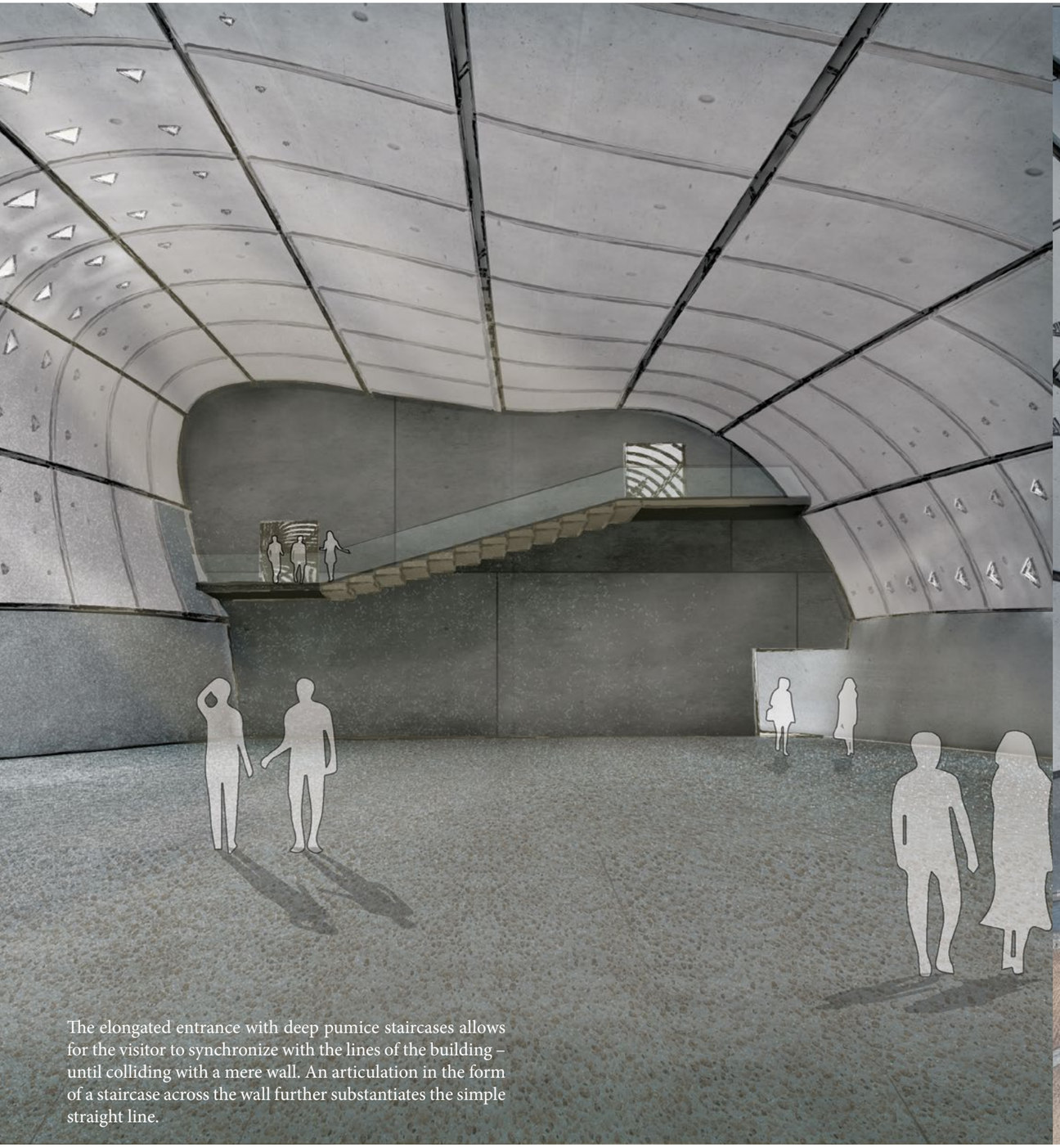
SECTION B-B'
1:200

SECTION C-C'
1:200

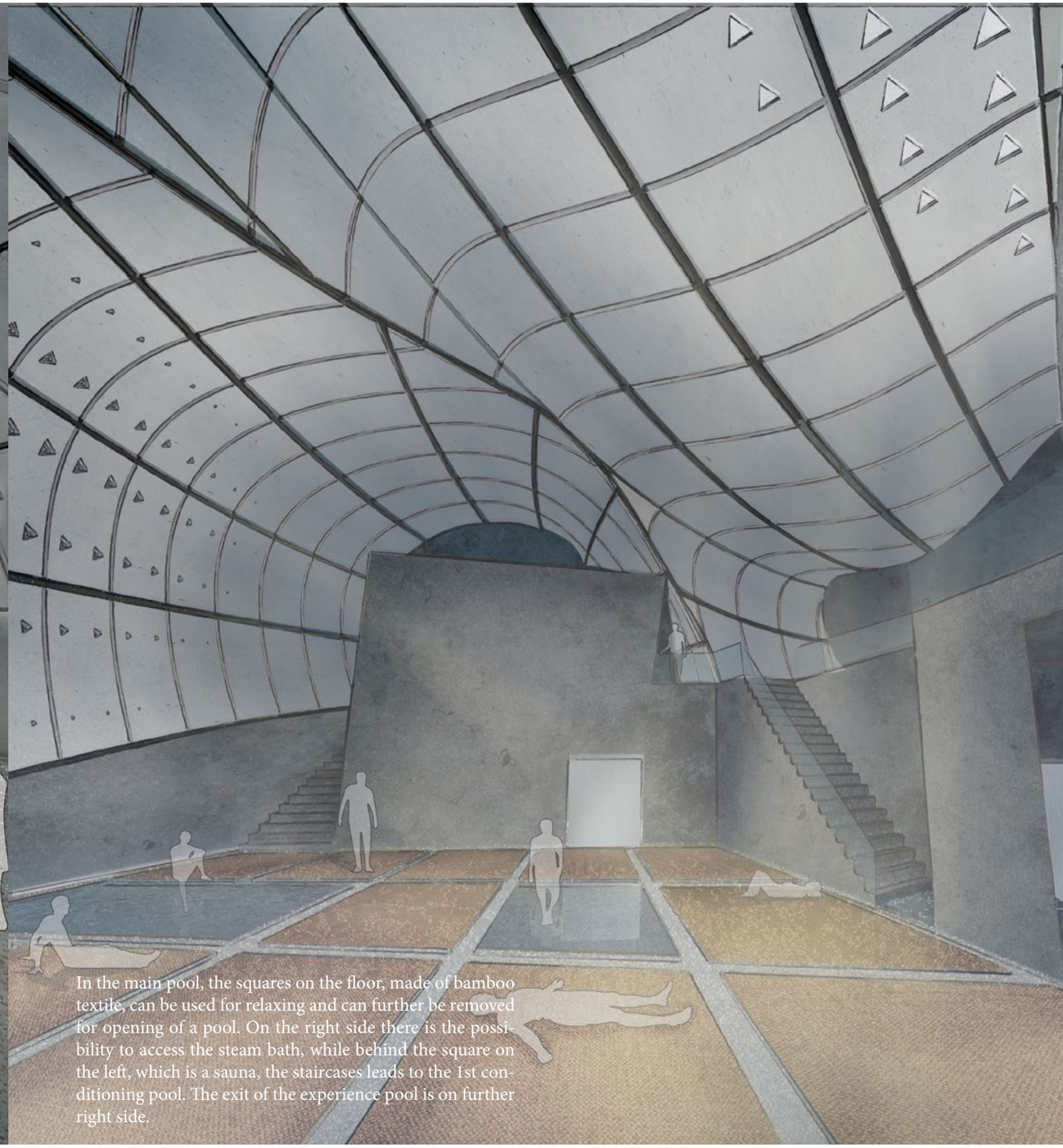
SECTION D-D'
1:200



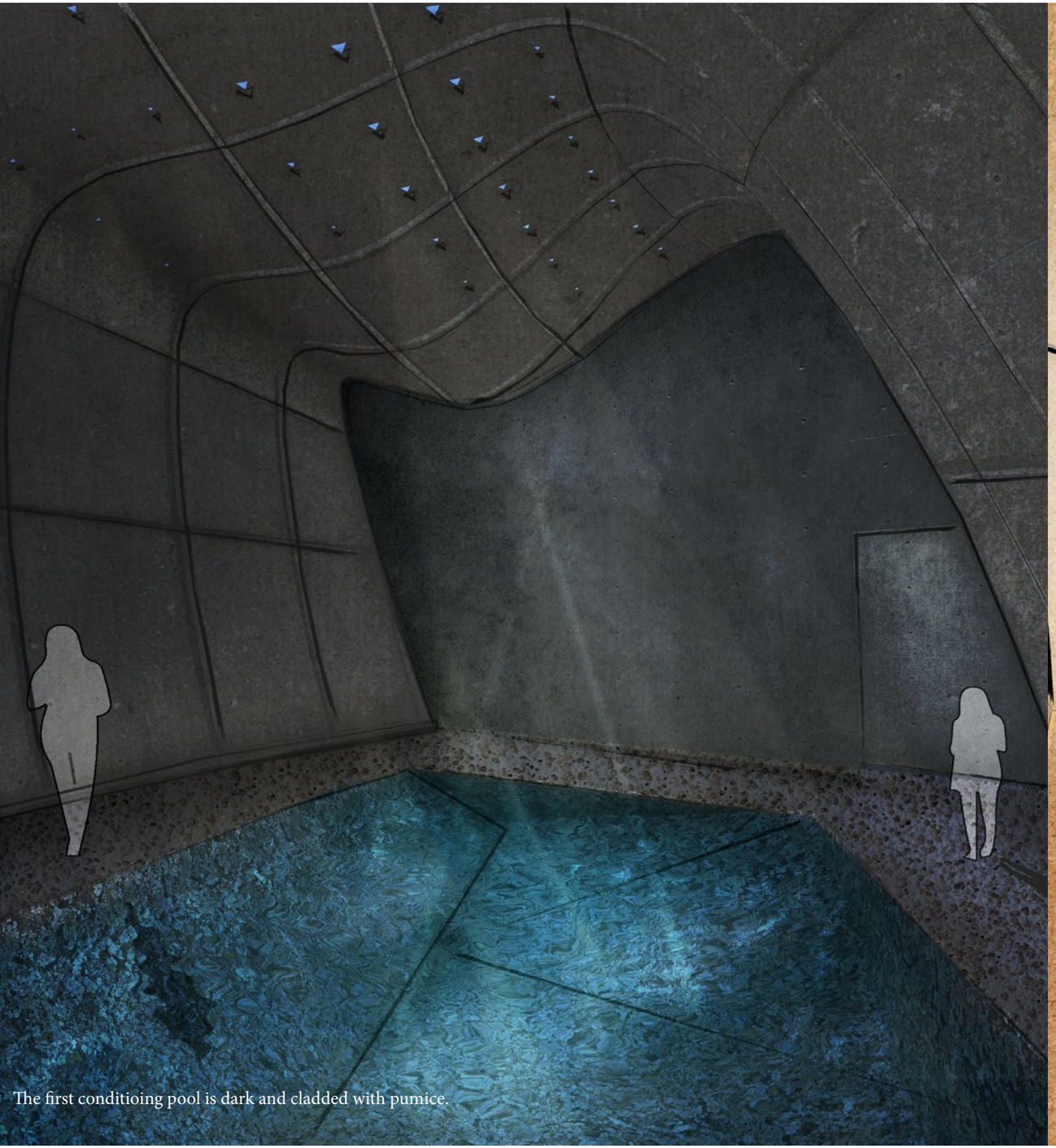
Situated on top of Úlfarsfell, the new Geothermae creates an impression of movement emphasizing the uneven topography of the mountain. It is laying as a defeated creature for the ascenders to relish, after a rightful mount. The form flows with the natural lines of the ground and yet disobeying the opened landscape, merely to become a monolith.



The elongated entrance with deep pumice staircases allows for the visitor to synchronize with the lines of the building – until colliding with a mere wall. An articulation in the form of a staircase across the wall further substantiates the simple straight line.



In the main pool, the squares on the floor, made of bamboo textile, can be used for relaxing and can further be removed for opening of a pool. On the right side there is the possibility to access the steam bath, while behind the square on the left, which is a sauna, the staircases leads to the 1st conditioning pool. The exit of the experience pool is on further right side.



The first conditioing pool is dark and cladded with pumice.

The third conditioning pool is very light and cladded with cork.

A

A'

ENTRE

1:200
LEVEL 0

WOMEN

MEN

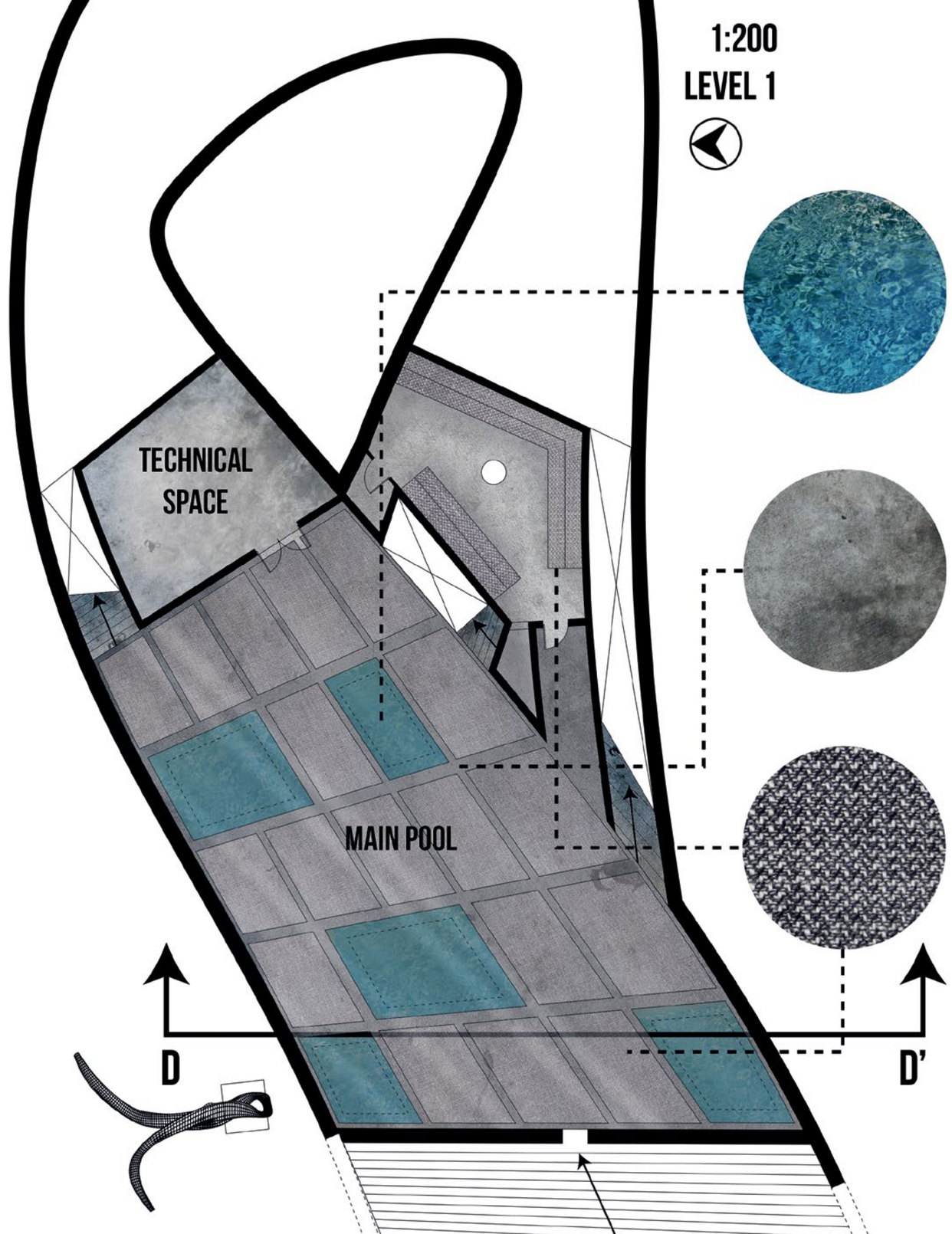
C

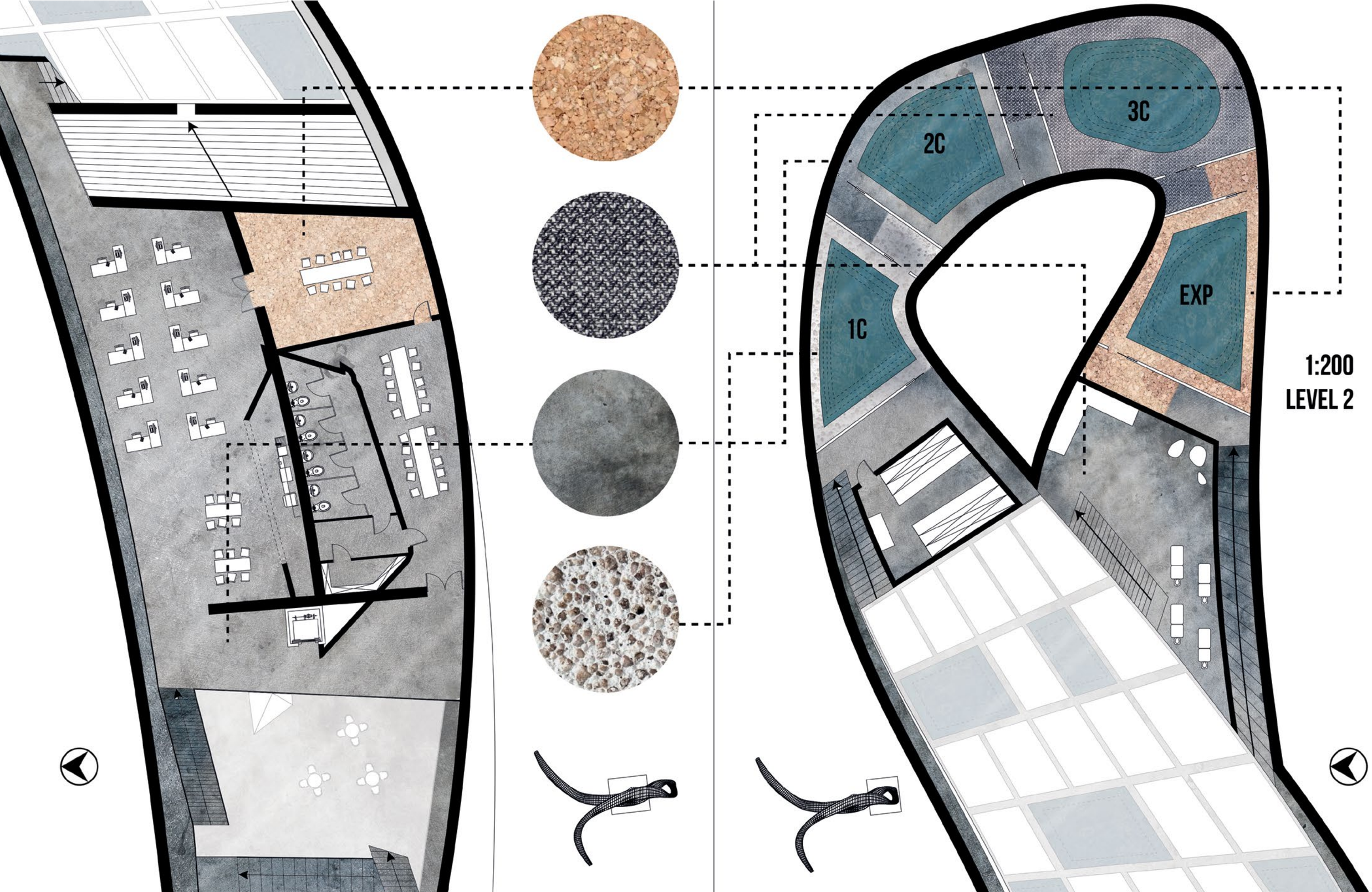
C'

RECEPTION

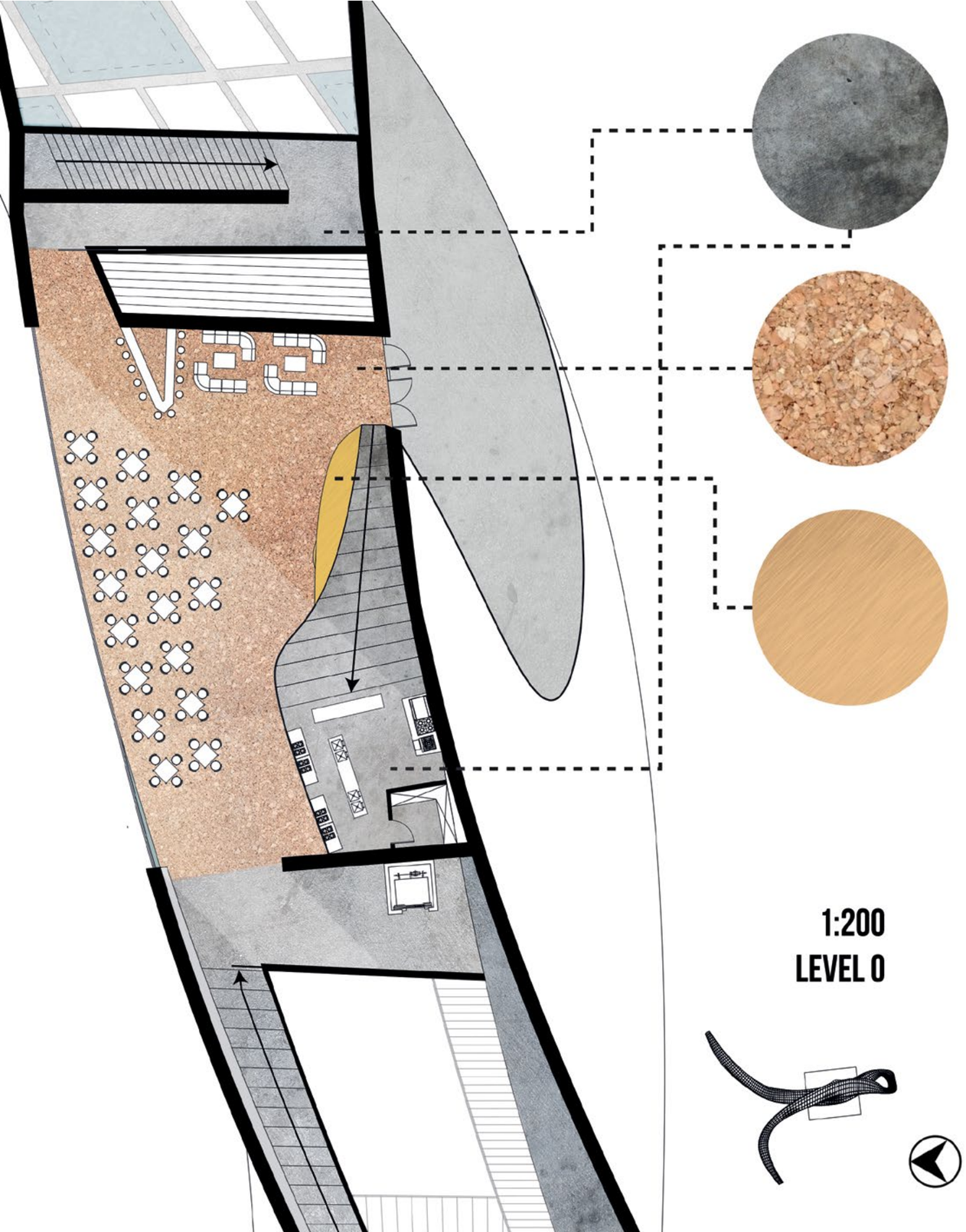
B

B'


1:200
LEVEL 1
TECHNICAL SPACE
MAIN POOL
D
D'



1:200
LEVEL 2

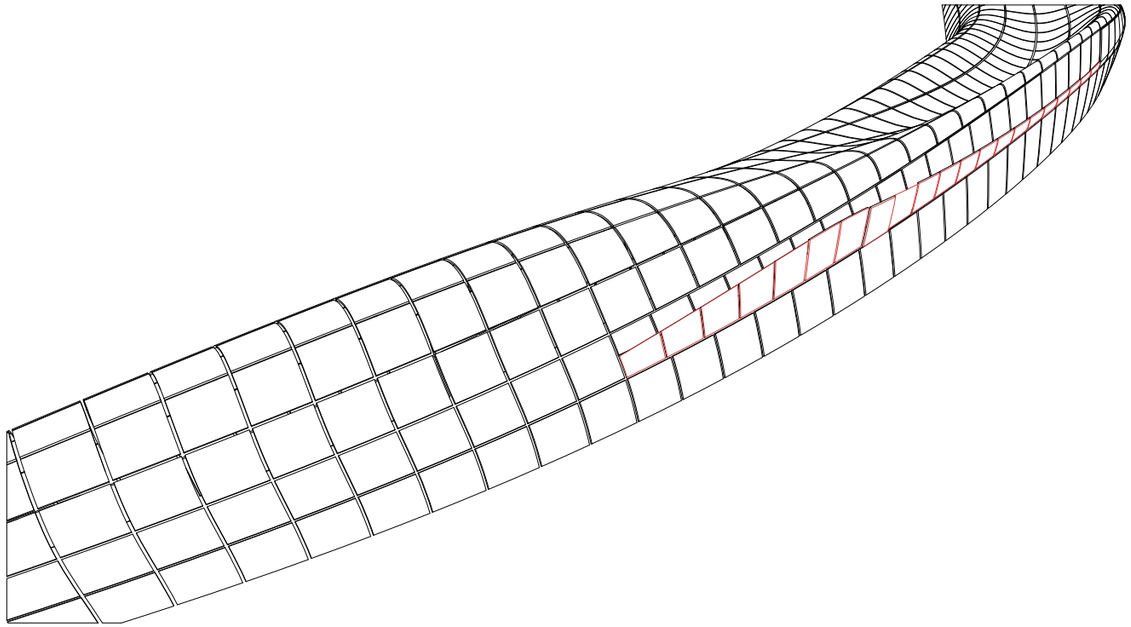


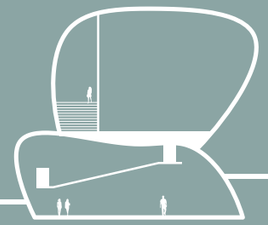
1:200
LEVEL 0

Entrance

Being the first part of the thermal bath, the light condition, the temperature, the geometry and the materials are at their first step, which means that the space is envisioned to be darker than the next, which is the reception. The space is not heated, and thus is envisioned to be colder than the reception, and also the materials chosen for this part are pumice and concrete, hard and rough materials. Considering the visual aspect, very simple lines are present both in the exit and entrance, as depicted on the abstract sections to the right. In terms of light, early in the entrance a slice cutting open the southern façade has been made, and can easily be controlled to be congruent with the desired light condition.

Fig. 68 - Slices





Reception and restaurant

As object recognition is in particular focus in this part, a reoccurring and penetrating object has been situated through the reception and offices. As the user approaches the reception, the object will be easily recognized as a cause of the change in material, wh-cih is steel, and color. The doors and openings in the object are made as simple geometries removed from the object, as this part still is concerned with simple lines. Furthermore, the cubic subtraction emphasizes the object recognition as the subtraction will be rec-ognized as a cube. The object functions as a gathering of downpipes, reaching up to the restaurant, includ-ing the kitchen. The geometric character relaxes from upward, meaning the top of the object is of smooth curves. Both the reception and restaurant are heated spaces, but in terms of light, perforations have been made on both the southern and northern façade to allow light inside. The possibility of looking out has been minimized, to substantiate the principle of am-biguous navigation.

Fig. 69 - The lower part of the object

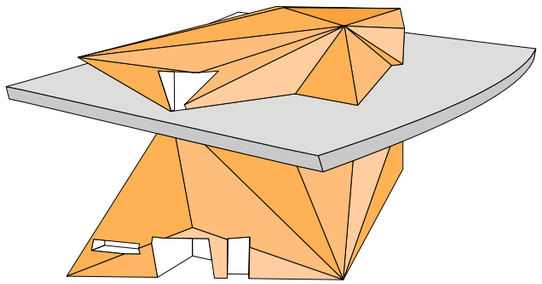
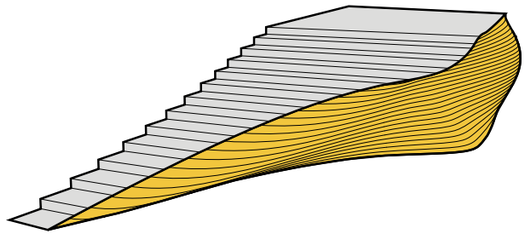


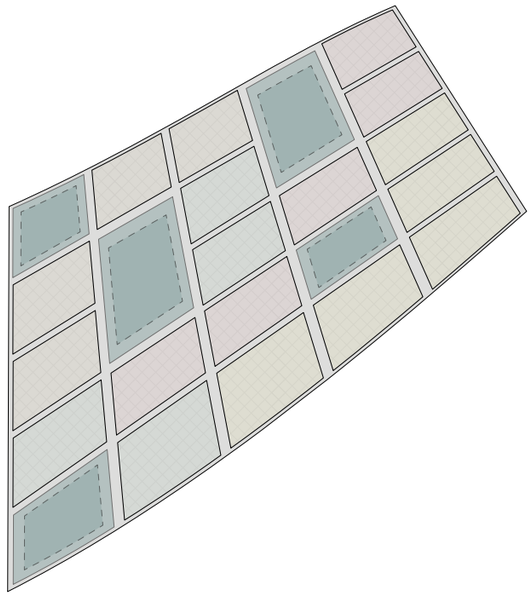
Fig. 70 - The higer part of the object

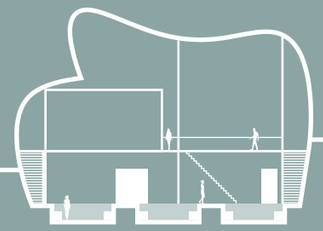


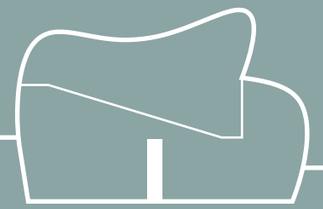
Main pool

After the changing rooms, which presumably were hotter than the previous space, as people are less clothed, following the linear growth of temperature, the main pool is the next space in the sequence. The temperature continues the growth and reaches a higher temperature. Here both cold and hot tubs are present. Figure 71 shows the textile panels on the ground which can be removed for an extra tub. Otherwise the textile panels are soft and can be used to lie down, stretch out or having a chat. The textile color has very low saturation, only implying a color, which presumably will make the user stare to figure out whether it is colored or not. This will lead to a forced activation of the V4 area in the visual cortex. Furthermore, long development processes of the section of this space lead to the abstract sections shown to the right, where the upper section shows in one direction of the space, while the lower section shows the opposite direction. Clean lines, some diagonal lines and strict composition will substantiate the activation of V3. The light conditions are also higher than previous space, shining light rays from the perforations through the accumulated fog.

Fig. 71 - Main pool panels







Conditioning pools

Each conditioning pool has different material, light conditions, bath tub geometry and temperature. Starting by the first conditioning pool, the temperature reaches 30 degrees, and has a sharp and edgy bath tub. The materials used are pumice in the tub and concrete on the wall for transition. These materials are rough and hard materials, being the first segments of the material tactility development. The conditions are very low, only reaching 1.2%DF. Going through the transition space, which is made of concrete, leads to the next space of the sequence. The 2nd conditioning pool is less edgy, yet a bit hard in it is geometric character. The materials used are concrete, which is the second segment of the material tactility development. With a temperature reaching 35 degrees, a clear sense of change in temperature is evident. Furthermore the light condition is increasing, reaching 2.1%DF. The 3rd conditioning pool reaches 4.3%DF and 40 degrees. The whole space is made of bamboo textile, including the tub. The smooth tub gives an impression of the relaxed geometry. The last space, which is the space where temperature fails to follow the linear growth and rather resets to first segment of the growth, is made entirely of cork. Cork is a smooth and soft material, indicating the last segment of material tactility development. At this point, light condition and material tactility and geometric character all continues their growth, but temperature fails to increase and resets to 30 degrees, being the first segment of temperature development. The user is expected to question the thermal sensory and assign either the anticipated experience and/or the actual experience, leaving the space with more than one meaning. The ultimate effect of ambiguity is described in PART I, the theoretical approach of the project.

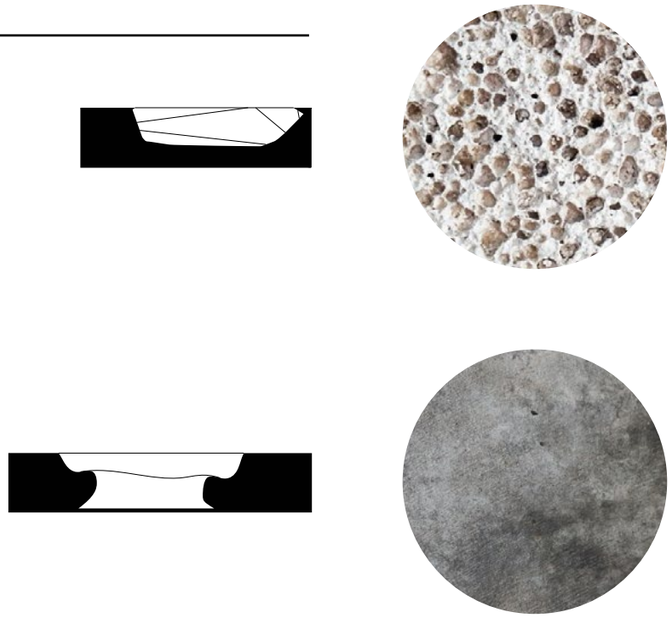
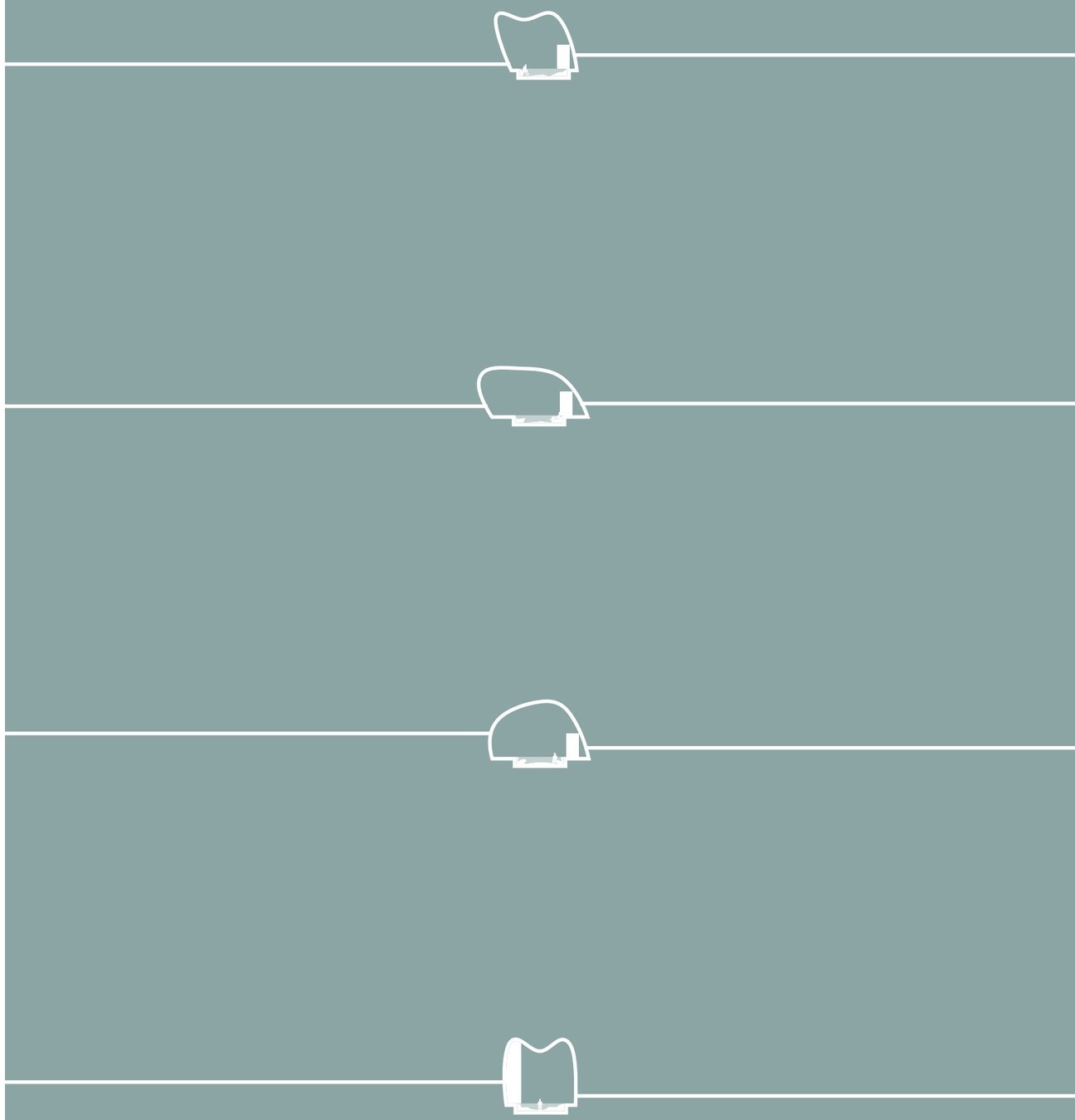


Fig. 72 - Sections and materials of tubs



Form

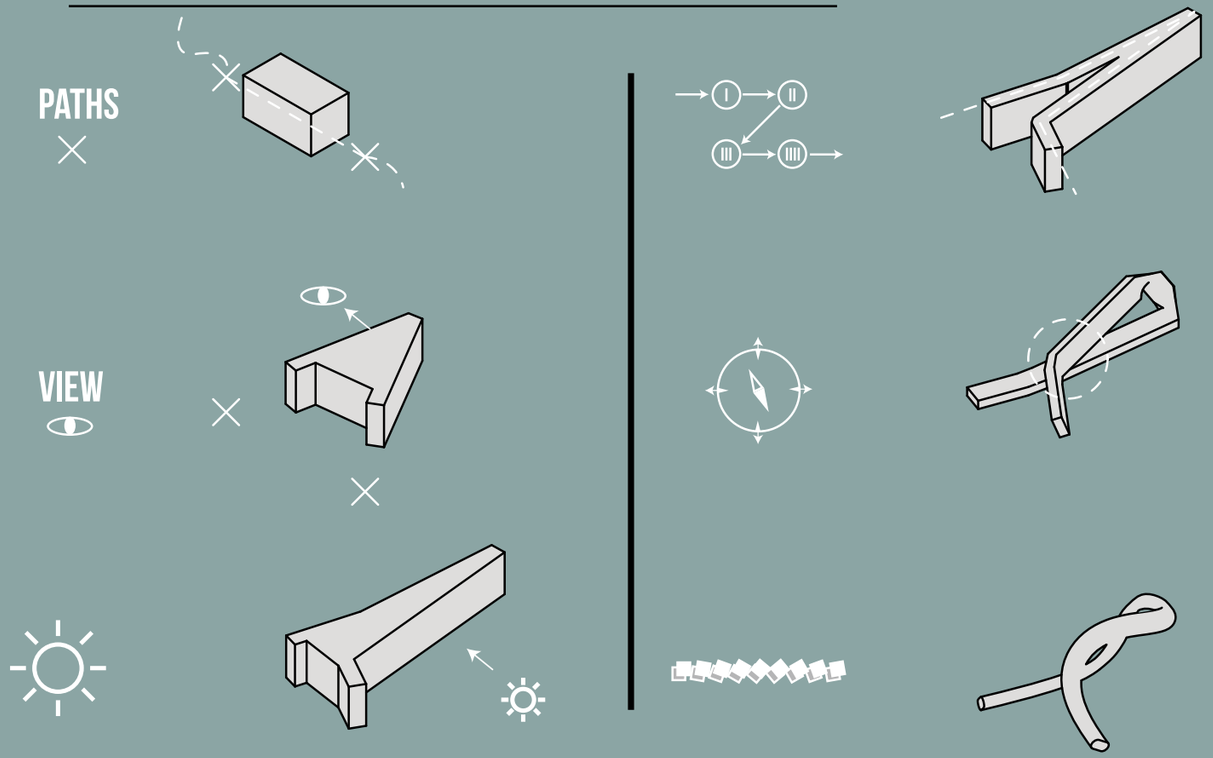


Fig. 73 - Form development

With the knowledge acquired through the design process, the diagrams here shortly explain the development of the final proposal. Each proposal has equivalent development, but as this design was chosen, the development is presented. As described in the “Concept”-chapter, the integration of principles are here explained. The preexisting paths are connected, while providing a view over both Reykjavik and Mosfellsbær. An enlarged southern façade will ensure light and solar heat gains, and instead of having a solid mass, the thermal bath has been elongated to a line of sequences, emphasizing the principle of sequenced order. By overlapping the geometry, the possibility of having ambiguous navigation is greater. Finally, a rounded geometry has greater ability to express a motion and emphasizes better the context, thus the “relaxation” of the geometry. Ultimately the thermal bath becomes a result of the principles and contextual qualities.

Functions

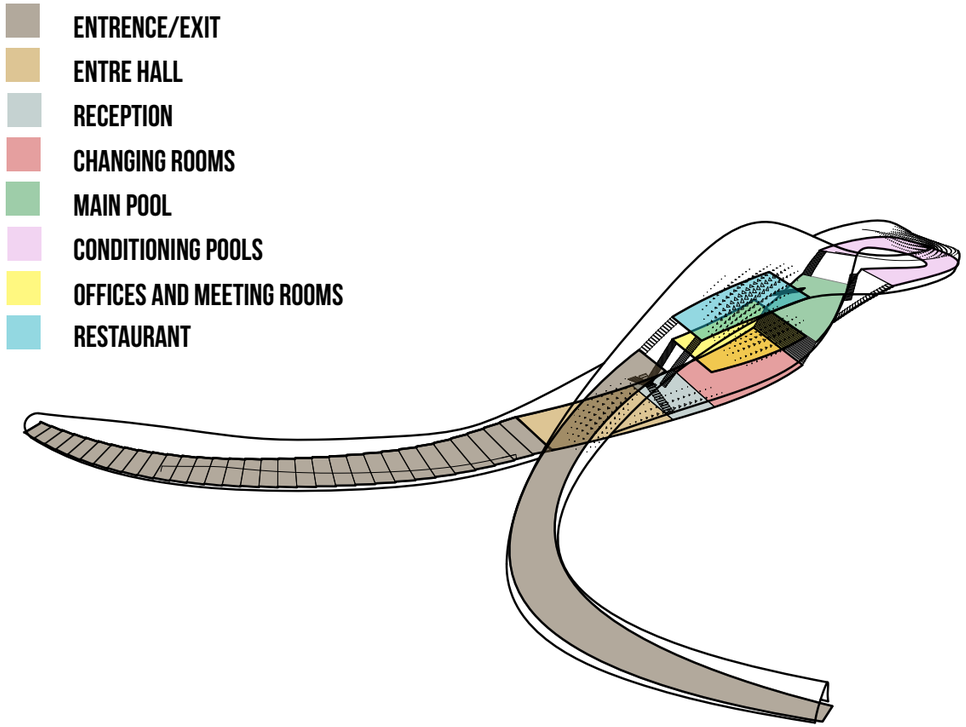


Fig. 74 - Function diagram

Having the possibility of entering the thermal bath both from an easy and a hard path, the building divides the entrance and exit into two functions. Entering from the hard path, staircases are implemented as the inclination is very steep, while for the exit a ramp has been implemented. Both for handicaps, who are expected only to approach the bath from the easy path, and goods delivery to the restaurant, the ramp is more useful. Passing the entre hall, one reaches the reception, where the flow divides into male and female changing rooms, staircase to the reception and staircase to the restaurant. Standing in the ground floor looking up, one can observe the staircase connecting the exit and restaurant, and other aforementioned staircases. After the changing rooms the flow collides into a big staircase and a great wall with a narrow slit leading into the main pool. In the main pool, one has the possibility to go to the sauna, the wellness area, which includes hot stones and massage, the steam bath and the 1st conditioning pool. After the conditioning pools, one is lead back to the main pool. Going back to the changing rooms and reception, there is the possibility to go to the offices, and further to the restaurant, for eventual breaks. The reception also leads directly to the restaurant. The building has also been equipped with an elevator, connecting the reception, offices and restaurant. All connections are also described in the “Plan workshop”-chapter.

Structure

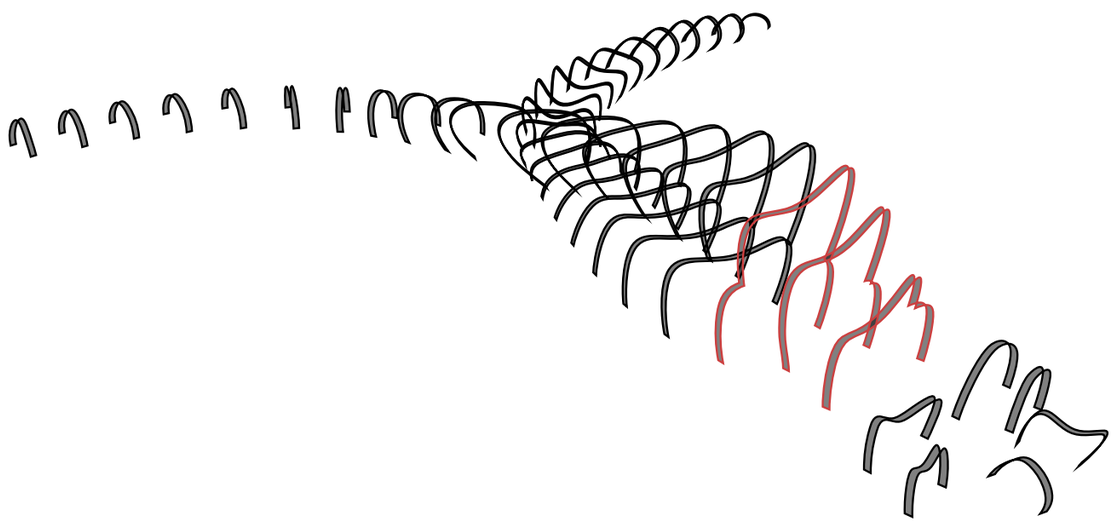


Fig. 75 - Perspective of steel frame structure

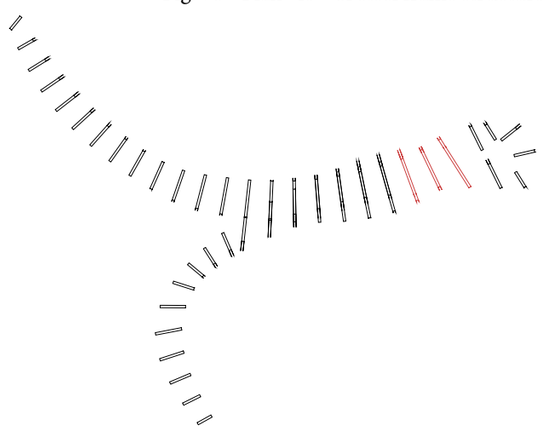


Fig. 76 - Plan view of steel frame structure

Bended HEB-steel beams will work as frames holding the concrete panels together. For more detailed solution about the concrete panels see detail drawing, although the detail drawing is in an early stage of development. The challenged steel beams, being the red frames in the diagram, have awkward connections, which are the only structural challenges within this building. It is anticipated that reinforced welding will solve the continuous forces. Otherwise all steel beams have direct connection to the ground, carrying forward all the normal forces towards the ground. To eliminate the moment forces smaller steel rafters have been connected transverse of the main steel frames, being able to carry forward lateral forces onto the next frame. The concrete panels will be located both on top and beneath the steel rafters. The concrete panels have no structural effect.

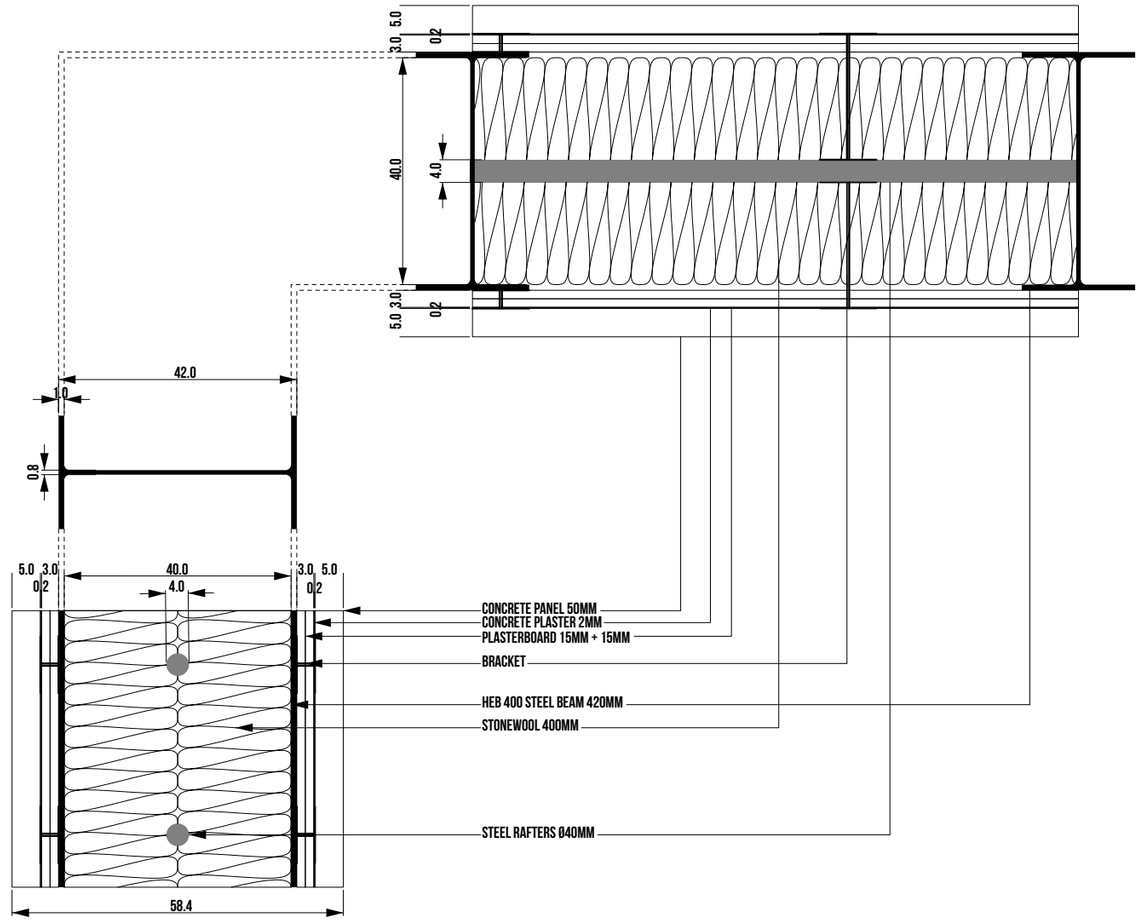
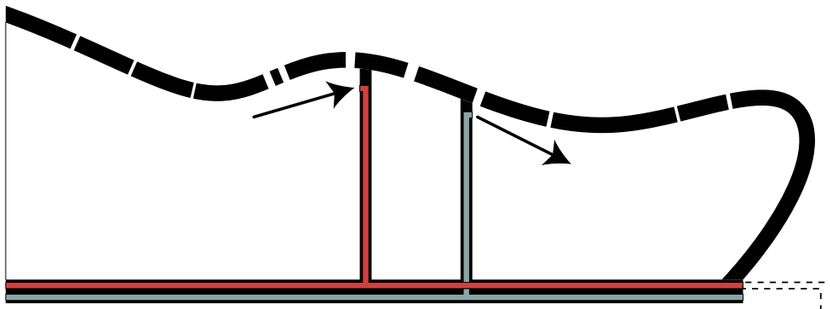


Fig. 77 - Detail of exterior wall. Out of scale.

Windows are located within the panels, and are prefabricated to align with the window frames. As the windows are part of the panels, they can easily be replaced by screws if any damage occurs. The mounting of panels outside is identical to the panels inside. Two layers of waterproof gypsum have been placed on the inside, on top of the HEB-steel beam and furthermore a layer of concrete plastering. Hereafter the vertical bracket will be placed to hold the concrete panels. The concrete panels are double curved, thus the solution of panels, as they can easily be 3D-printed in a factory day and night under safe conditions. The panels can then be transported to the site and assembled.

Ventilation strategy



As the technical space has been strategically situated very close and beneath the most demanding spaces, the ventilation pipes can easily be led under the pools and up through the walls of the transitions. As the transitions each have two walls, one wall will be used for inlet amd the other for outlet, as shown on diagram above. The inlet air will be blown in at high velocity outside the occupied zone, which will lead the existing air to entrain the inlet air and ultimately change the air. The method of ventilation is mixing ventilation. The outlet air is led through a heat exchanger to heat the inlet air for the rest of building. The outlet is not yet released, as it still contains heat. It will be used, as the hypocaust system, to heat the floors of the building, but instead of having suspended floor, the heat will be led through pipes, very close to the floor-finish as illustarted on the diagrammatic-detail. The red and blue colors are not to be grasped as cold or warm air, but as inlet and outlet. The outlet air is reused for floor heating.

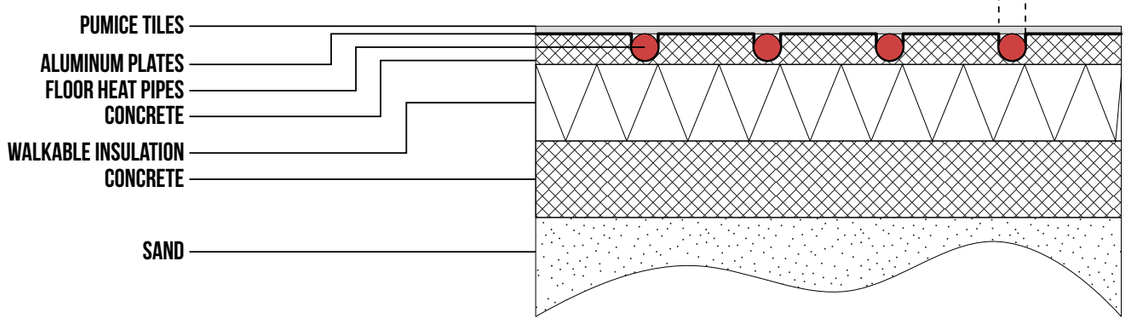


Fig. 78 - Diagrammatic detail and section of conditioning pools

Daylight

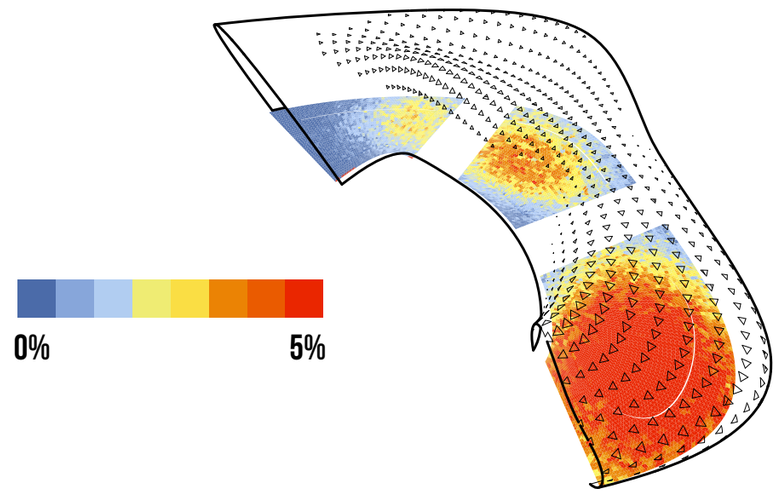


Fig. 79 - Daylight analysis of the conditioing pools

As the concept indicated, the daylight must be increasing from pool to pool. Here the diagram shows the increasing daylight, where the perforations have been used to allow light inside. The qualities of the perforations are the uncomplicated manner of placing them and reaching the desired daylight, while the increase and decrease of size further substantiate the principle of fictive motion. It is documented that the amount of light is increasing, going from 1.2% to 2.1% and ultimately reaching 4.3%. The “Façade workshop”-chapter created the idea of locating the conditioning pools separately and further gave an idea of the orientation.

Space	DF%
1C	1.3%
2C	2.1%
3C	4.3%

Thermal comfort evaluation

In order to make sure the temperature, moisture, CO_2 and ventilation work as intended in the four pools, the spaces has been simulated in BSim. As all spaces to be simulated are rather large for 8 persons the CO_2-levels are less critical, and thus a calculation of the relative humidity is in focus. The CO_2-levels will be checked to document the concentration is less than 900 ppm. What is in the scope of interest with the simulation is:

How well do the spaces keep the desired temperature or at least a temperature difference by 5 degrees Celsius?

Is it possible to keep a fair air change rate while deviate the temperatures by 5 degrees at all times?

Do the CO_2 levels exceed 900 ppm with the required air change to suppress the relative humidity?

Is it further possible to keep the relative humidity between 60% and 80% the whole year?

The "Façade workshop"-chapter showed a window area of 10m², which has great possibility of radiating a colder temperature than intended. Thus a radiation average temperature has been made, merely to document the effect of having 10m² windows in a pool. See Appendix 1 for calculation. The conclusion of the radiation average temperature, gave a deviation of approximately 0.5°C, which is an acceptable temperature deviation.

As earlier anticipated, the relative humidity will be the greatest challenge to maintain between 60% and 80%, as the moisture load is rather big from each pool and from the 8 persons. The moisture load has been calculated as documented in Appendix 4. To suppress the relative humidity level the moisture content in the air outside, used for indoor ventilation, and the humidity ratio of the indoor air needs to be known. Using the Ix-diagram, see Appendix 2, the outdoor humidity ratio was found to be 0.006 kg/kg at 10°C, while the indoor humidity ratio in 3rd conditioning pool, was calculated to be 0.0285 kg/kg at 40°C. Following formula has been used to calculate the required air flow rate (EngineeringToolBox.com):

$$L = \frac{G}{x_r - x_m}$$

L: required air flow (kg/h)
G: moisture production in space (kg/h)
x_r: humidity ratio of room (kg/kg)
x_m: humidity ratio of inlet air (kg/kg)

For further calculating the air change:

$$h = \frac{L * \rho}{V}$$

h: air change per hour (m³/h pr. m³)
ρ: air density (kg/m³)
V: volume (m³)

As the scheme in Appendix 3 documents, the air change levels are supposedly within a reasonable range, therefore a simulation in BSim has further been made to document the temperature, humidity, CO_2 and air change relations. The BSim file can be found on the USB.

The spaces, in BSim are divided by walls, as it is assumed the pools do not mix air. For simulating the pools themselves, floor heating has been used to heat the spaces imitating the heat source, furthermore moisture load, depending on the space, has been implemented into each thermal zone. The size of windows has been sized according to the roof area and the desired percentage found in the "Façade workshop"-chapter. The heat sources are mainly the people, the heated water, solar heat gains and heated air from ventilation.

Temperatures

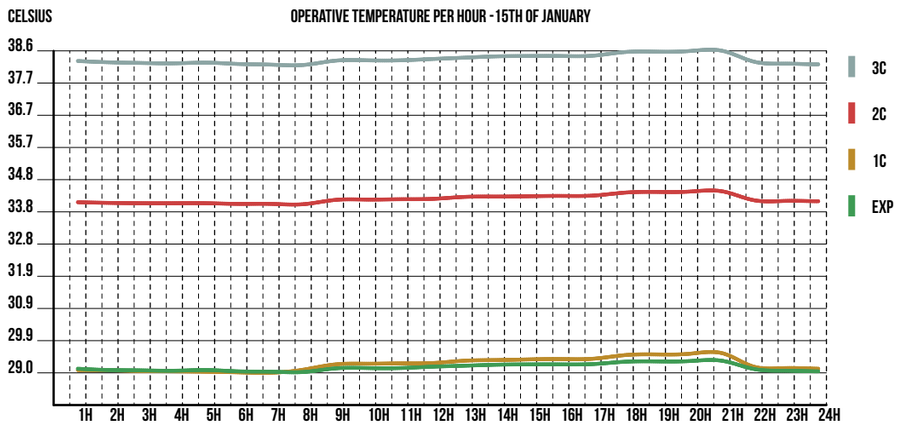


Fig. 80 - Operative temperature - 15th January

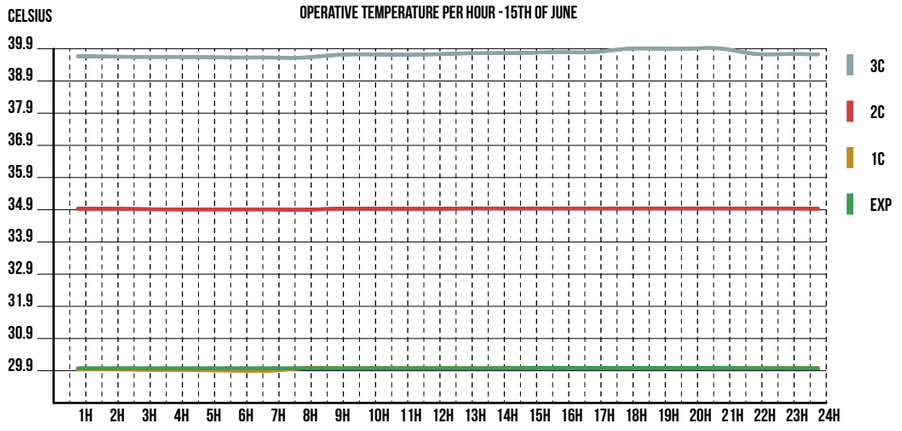


Fig. 81 - Operative temperature - 15th June

The simulation documented that, both on a warm day and cold day, the temperatures deviate by approximately 5 degrees consistently. The warmest pool, being the 3rd conditioning pool has a consistent temperature around 39-40°C, which is acceptable as the temperatures are synchronized. In the summer the ventilation does not heat as much as in the winter, giving a consistent temperature. It is the difference that is in particular focus. Furthermore it has also been documented that the temperature of 1C and the experience pool are very alike, if not overlapping. In conclusion to this paragraph, the temperatures work as intended causing no problems, neither on a cold day nor on a warm.

CO_2, AIR CHANGE AND HUMIDITY

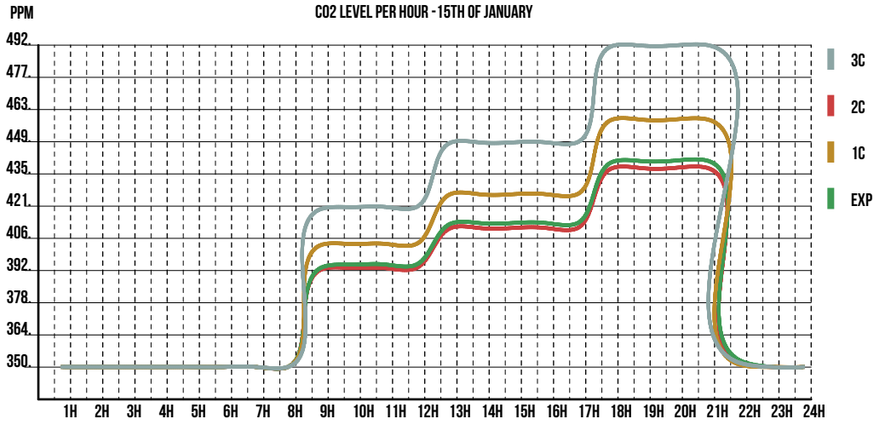


Fig. 82 - CO_2 levels - 15th January

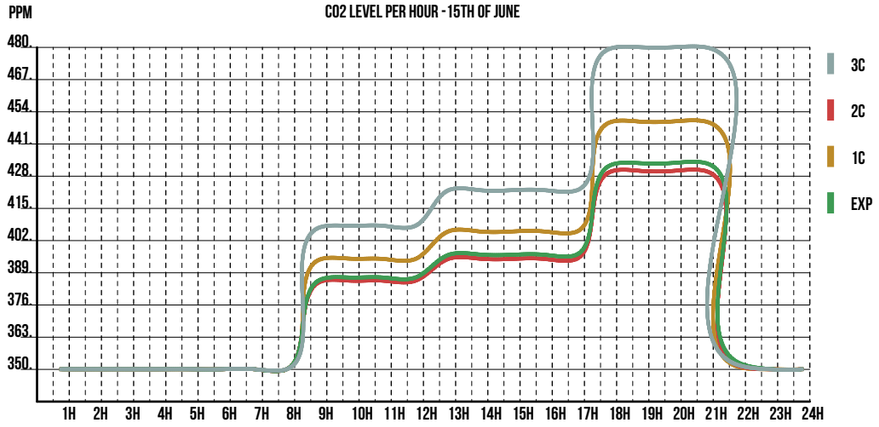


Fig. 83 - CO_2 levels - 15th June

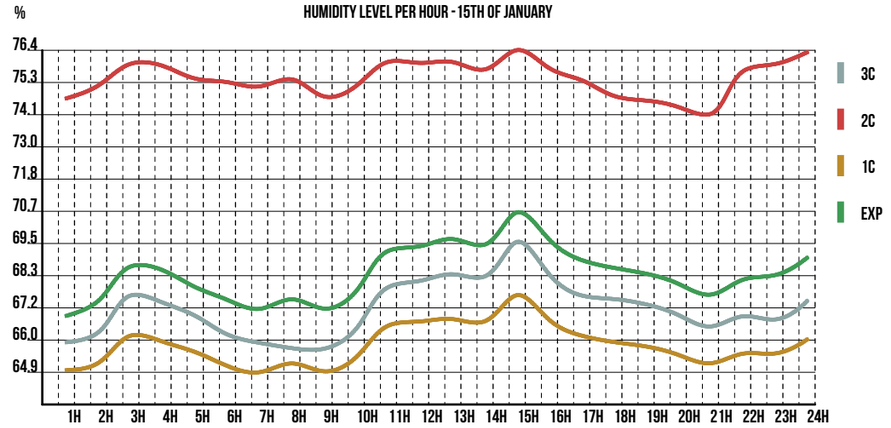


Fig. 84 - Relative humidity - 15th January

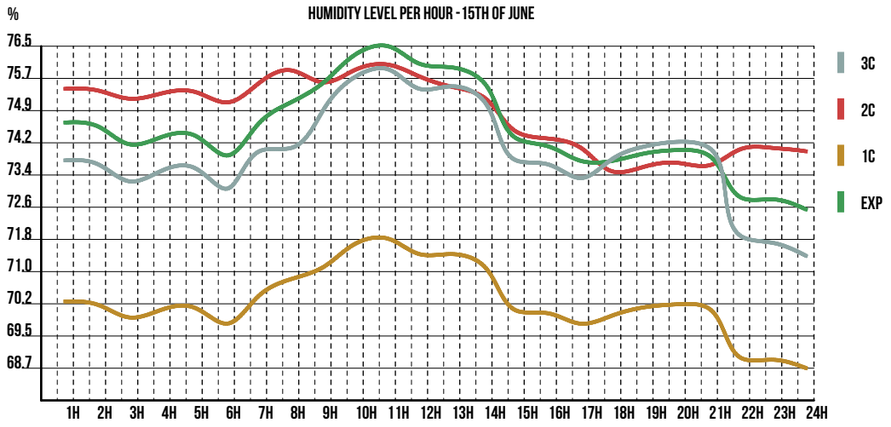


Fig. 85 - Relative humidity - 15th June

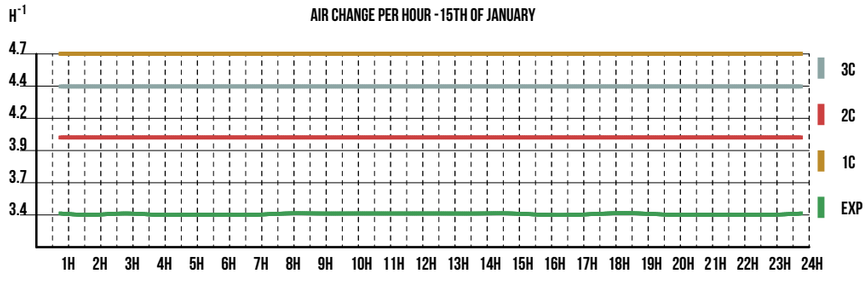


Fig. 86 - Air change rate - 15th January

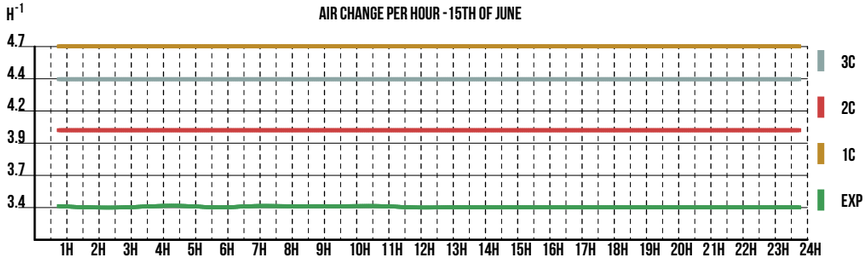


Fig. 87 - Air change rate - 15th June

Considering the CO_2 levels, as illustrated on the graphs, it does not exceed 900 ppm. The CO_2 levels are very low, as low as 500 ppm, because 8 persons in such great volumes are not too many people, and thus should not be considered a great risk. What was correctly anticipated was the humidity levels would be great values. In the winter, the 3rd conditioning pool has a greater relative humidity percentage, as the high air temperature allows a higher humidity ratio. In the summer, none of the pools exceed 80% in relative humidity, although they are very close. Comparing the humidity and air change of the spaces, it can be documented that the air change is very consistent and although the air change is the same in the summer and the winter, the ventilation succeeds in suppressing the humidity levels and CO_2 levels. It can thus be concluded that the conditioning pools function as intended:

The temperatures deviated by approximately 5°C. Although they are not always at the desired temperature, the temperatures are synchronized, giving a difference between the spaces of approximately 5°C.

The air change levels are at a reasonable level, but can be reduced by either increasing the volume or lower the moisture load. The moisture load depends on the area of the pool and the temperature of the water, and as the temperature is essential in this context, mainly the area of the pool can be changed.

Also the CO_2 levels are suppressed when ventilating by the required air change. The CO_2 levels do not exceed 500 ppm.

Furthermore the relative humidity, which did cause issues early in the process, can be suppressed to less than 80%, also on a summer day.

Recovered energy

It is here the intention to compare the thermal bath to another thermal bath situated in an approximate climate. Using the article by Arto Saari and Tiina Sekki “Energy Consumption of a Public Swimming Bath” (Saari and Sekki, 2008), it is possible to compare the energy consumption to heat the areas that are not part of the baths, such as offices, reception, meeting rooms and transitions. By calculating the amount of square meters that needs to be heated and calculate how much heat has been recovered from the heated pools, it can be estimated how much the recovered heat can heat the rest of the building.

The total heated square meters of the building reaches 2586m² while it was intended to reach 2100 m². Removing the area of the pools in general, the square meters that need to be heated are introduced:

$$2586m^2 - 384m^2 - 277m^2 - 70m^2 = 1855m^2$$

Comparing the total square meters to Kirkkonummi, a swimming bath in Helsinki which has approximately the same climate as Reykjavik:

$$3535m^2 - 2586m^2 = 949m^2$$

It has been informed that Kirkkonummi uses 479kWh/m² in total, including heating the pools, which takes up 143kWh/m² and has an area of 1140m² (Saari and Sekki, 2008). The area to heat up then:

Space	Square meters
Reception	241m²
Changing rooms	389m²
Main pool	384m²
Technical space	62m²
Offices and meeting rooms	514m²
Conditioing pools	347m²
Restaurant	371m²
Transitions	278m²
Total	**2586m²**

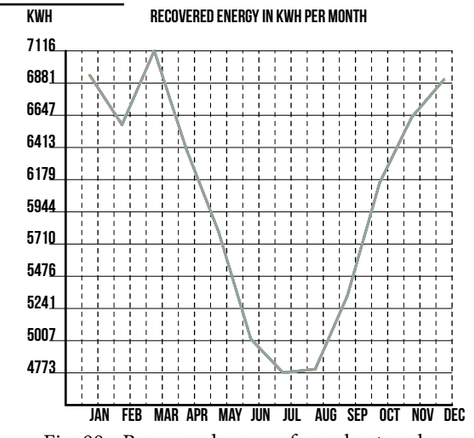


Fig. 88 - Recovered energy from heat exchanger

$$3535m^2 - 1140m^2 = 2395m^2$$

$$479\frac{kWh}{m^2} - 143\frac{kWh}{m^2} = 336\frac{kWh}{m^2}$$

When excluding the pools, it takes 336kWh/m² to heat up 2395m². Analyzing the recovered kWh from the heat exchanger in the ventilation of the conditioning pools, it can be documented that approximately 72447kWh has been recovered, but depending on how the method of reinstating the heat, some kWh will be lost. If anticipated that the reinstating has 0% loss;

$$\frac{72447\ kWh}{1855\ m^2} = 39\frac{kWh}{m^2}$$

$$\frac{39\frac{kWh}{m^2}}{336\frac{kWh}{m^2}} * 100\% = 11.6\%$$

If the project building had energy consumption as Kirkkonummi in Helsinki, the recovered energy from the conditioning pools would be able to heat up 11.6% of the building. Although, as mentioned in “EU building regulations”-chapter, Iceland has access to an excessive amount of geothermal energy, which is both sustainable and renewable.

VII

Epilogue

The project in retrospect and references

"This blank page gives us the right to dream"

Gaston Bachelard

Conclusion

In an attempt to make partly neurophysiological and partly architectural principles converge with climatic, social and thematic analyses, different methods of investigations were adopted. The time spent to find the right questions for the emerged issues, returned unexpected results, certainly evident in the presentation. The journey to Úlfarsfell gave authentic insight to Iceland and a vast understanding of the context. To fathom the atmosphere of the site has been crucial for the decisions throughout the process. The social analyses were used inter alia to determine minimum age and further to determine who the potential users were. For instance, it was concluded that the tourism was increasing, thus the Geothermae should be easily found and accessed. Narrowing the spectrum and concluding on the form of the building, climatic analyses, including views and topography, have been used actively to shape and argue the form. Crucial analyses, which gave way to the atmospheric influence of the building, were the phenomenological aspect and the exquisite corpse, as these were the strongest inspiration source. It is believed that the analysis of the materials in Iceland granted the argumentation for the final chosen materials. Notable analyses, such as "The choice of site", "Geothermal energy" and "Building as landscape", offered background knowledge and can be considered to be partly actively used analyses.

The most actively used analyses are the principles, which are believed to have succeeded in integrating into the architecture. To evaluate the principles, which means they are needed to be interpreted, was possibly the important step for integrating them. This step is not considered an actual success, as the field is quite undiscovered, but it is believed that the interpretations are a proper step towards an interdisciplinary architecture. The division of the building into parts, with each its property, have developed an interesting output, which is worth further studying. The entrance, the reception, the changing rooms, the main pool, the conditioning pools, the offices and the restaurant are all part of a greater cycle, depending on each other, and yet independent.

Ultimately, after introducing a different approach to architecture, and actively using the principles in the design process, gave rise to a project, which has not used inspiration and thus independent, that is beyond any expectations. The process was started different than afore. Consistently, clues and ideas dominate the initial design process, whereas at this particular project, no clues or ideas of a terminate building was envisioned. Throughout the design process the project started taking form, both answering initial questions, but also asking new ones. When the building came into existence, qualities came to evidence. The project in general can be conceived as an early stage of interdisciplinary architecture, leading the architect through the unknown.

Reflection

Reaching convergence in architecture with principles, whose roots are from another field – the neurophysiological field – gave rise to a different, and almost surreal project. Using the knowledge about the mind is an old journey in architecture, but only to become an irrational field. It should be understood that architecture itself is an interdisciplinary field, mainly mixing art and engineering; an irrational and rational field. When introducing neurophysiology, being a scientific field, to architecture, the whole aspect is in upheaval. Going from unmeasurable and abstract spaces, only designing by personal empirical data, to taking advantage of measured consequences of space that the majority agrees about, is a paradigm shift in architecture. Although, more research within this interdisciplinary field is needed to answer rudimentary questions. Related to this particular project, one could ask questions as; *what are the significant qualities than one is able to anticipate in linearity? How many linear expansions can one anticipate? If the number of qualities is increased, will it lead to emphasizing each other or neglect each other?* This project leads to very rudimentary questions in the field of neurophysiology and architecture that are needed to be answered.

Going from a theoretical approach to a practical process has more disadvantages than advantages. Great meaning responsible for the principles got annihilated throughout the design process, either by virtue of unprecedented attempt or a lack of development in the principles themselves. The principles are ultimately interpretations of neurophysiological discoveries, developed to accommodate architecture. Perhaps the transition is a research itself.

Considering the whole project in retrospect, including the theoretical framework, it is possible to discover how an interdisciplinary approach can influence the architecture in a manner that is not yet discovered. The thermal simulations and other measured properties, such as daylight and structure, only substantiate the projects fullness. What is meant by fullness is how many increased measurable properties can be implemented into a design, reaching a level that is superior than afore.

The whole project becomes a discovery.

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Illustrations:

Figure 01-04 Own ill.

Figure 05 Google Earth

Figure 06-13 Own ill.

Figure 14 http://previews.123rf.com/images/mexrix/mexrix1012/mexrix101200207/8486477-Pattern-of-pumice-stoan-texture-for-background-Stock-Photo.jpg

Figure 15 http://www.em01.co.il/f-users/user_105096/website_101287/images/0_0123.jpg

Figure 16 http://www.bamboo-china.com/product/image/bamboo%20charcoal%20fabric.jpg

Figure 17 http://www.noctua-graphics.de/images/download/tex/wood/kork03.jpg

Figure 18 Geology - Denk, T. (2011) Late Cainozoic Floras of Iceland: 15 Million Years of Vegetation and Climate History in the Northern North Atlantic (Topics in Geobiology). 2011 Edition. Springer.

Figure 19-26 Own ill.

Figure 27 Hypocaust system, p. 60 - Nielsen, I. (1990) Thermae Et Balnea. Aarhus: Aarhus University Press, 1990. Print.

Figure 28 http://cnx.org/resources/85b49f0e95d25474594f626b448c88518c00d27f/graphics1.png

Figure 29 Heat loss from pipes - Dickson, M.H. (2005) Geothermal Energy: Utilization and Technology. Edition. Routledge.

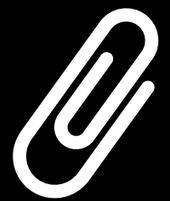
Figure 30 Heat loss from pipes - Dickson, M.H. (2005) Geothermal Energy: Utilization and Technology. Edition. Routledge.

Figure 31-88 Own ill.

VIII

Appendix

Calculations, schemes and graphs



"Whatever good things we build end up building us"

Jim Rohn

Appendix 1

Radiation Average Temperature

As calculated in the window workshop, there will be s roof area reaching 10% windows, and as the indoor temperature reaches 40 degrees Celsius while the outdoor temperature is anticipated -12 degrees Celsius, the difference can give issues with the sensation of the temperature. Taking the worst case, which is the 3rd conditioning pool having 10m² windows in total on the roof and a temperature of 40 degrees Celsius, if this space is acceptable it is assumed to be so as well in the other spaces.

The operative temperature is estimated to be as close as possible to the desired temperature of the space, which in this case is 40 degrees. The windows used are from Rationel (Rationel AURA & AURAPLUS), which is a 4-20-4-20-4 structure with a U-value of 0.78W/m²*K. The windows are formed after a perforation in the facade, making both small and large windows, thus the U-value of the frame is affecting the temperature a lot more especially in the small windows, but as there are very few small windows, the U-value of the window is accepted as estimation. The interior heating insulation is set to 0.1 as the direction is vertical. The surface temperature is calculated:

$$t_o - t_v = (t_o - t_u) * R_i * U$$

(Stampe 2000, p. 35)

Where:

t_o – *Operative temperature*	^oC
t_v – *Indoor surface temperature*	^oC
t_u – *Outdoor temperature*	^oC
R_i – *Interior heating insulation*	m^2*C/W
U – *U value*	W/m^2*K

$$t_{window} = 40 - (40 - (-12)) * 0{,}1 * 0.78 = 35.95°C$$

The window surface temperature is thus: 35.95 degrees Celsius. The surface temperature for floor, wall and roof is further calculated. Two of the walls have different constructions and temperature these are also calculated:

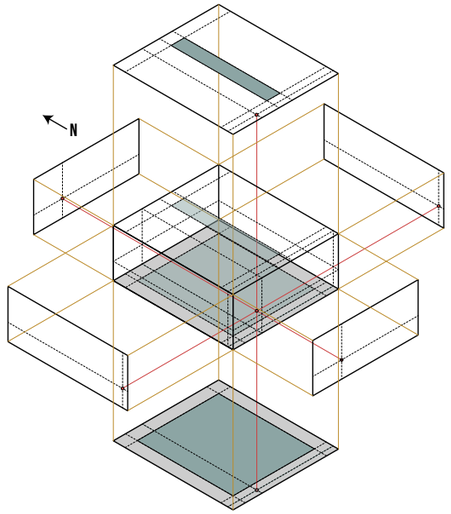
$$t_{Outerwall} = 40 - (40 - (-12)) * 0.1 * 0.11 = 39.42°C$$

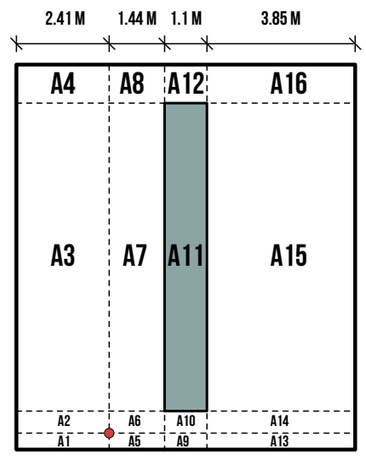
$$t_{Innerwall} = 40 - (40 - 30) * 0.1 * 0.96 = 39.04°C$$

$$t_{floor} = 40 - (40 - (-12)) * 0.1 * 0.62 = 36.77°C$$

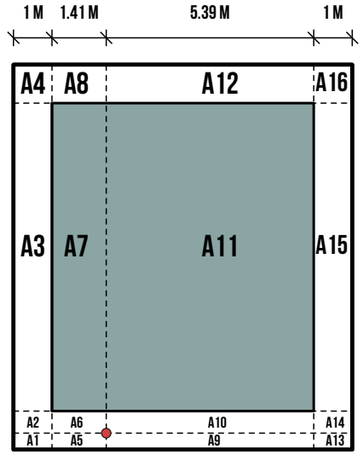
$$t_{roof} = 40 - (40 - (-12)) * 0.1 * 0.11 = 39.42°C$$

The temperature of the water is set to its respective desired temperature.
A simplified model of the pool is illustrating the placement of the person in the pool:

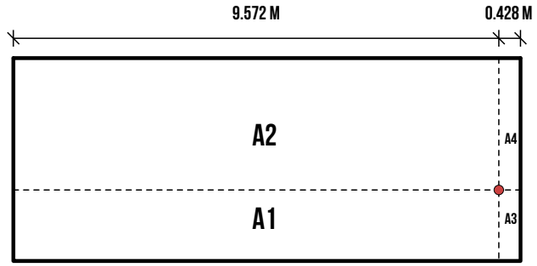




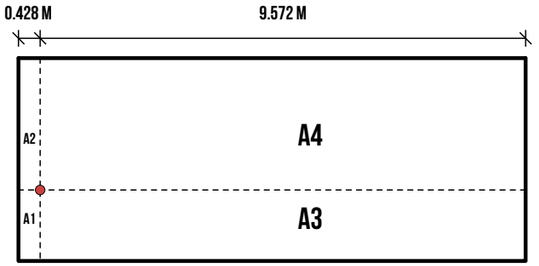
ROOF



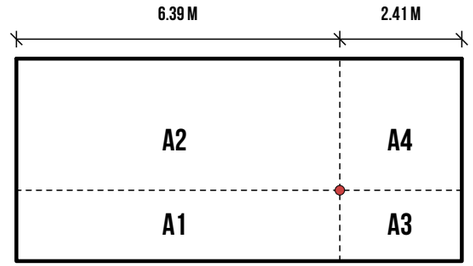
FLOOR



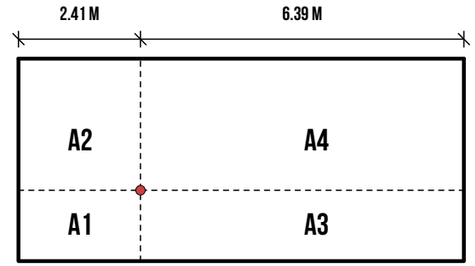
EAST WALL



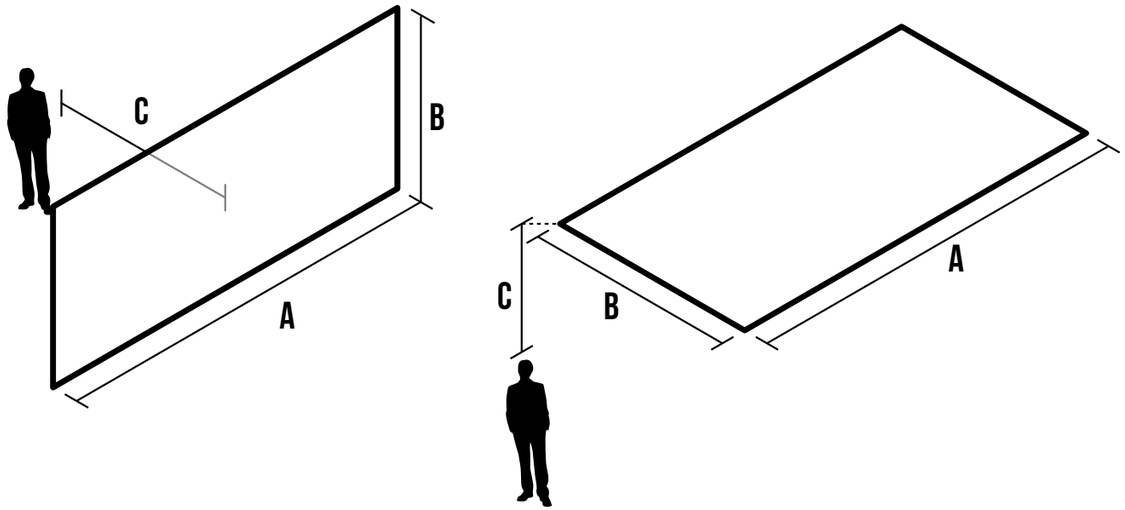
WEST WALL



SOUTH WALL



NORTH WALL



In order to find the temperature of the person, the view factor is found (Stampe 2000, p. 298-99). Starting by the roof, the notable values are the distance from the person to the surfaces and the height. The height is designated by *c* and the distance to the surface by *a.* The value *b* designate the width of the surfaces calculated. In case of the roof, the value *c* is 2.6 m:

$$\Psi_{A1} \rightarrow \frac{b}{c} = \frac{0.428\,m}{2.6\,m} \approx 0.16$$

$$\frac{a}{c} = \frac{2.41\,m}{2.6\,m} \approx 0.92$$

$$\Psi_{A1} = \mathbf{0.01}$$

$$\Psi_{A2+A3+A4} \rightarrow \frac{b}{c} = \frac{9.572\,m}{2.6\,m} \approx 3.68$$

$$\frac{a}{c} = \frac{2.41\,m}{2.6\,m} \approx 0.92$$

$$\Psi_{A2+A3+A4} = \mathbf{0.05}$$

$$\Psi_{A5+A9+A13} \rightarrow \frac{b}{c} = \frac{0.428\,m}{2.6\,m} \approx 0.16$$

$$\frac{a}{c} = \frac{6.39\,m}{2.6\,m} \approx 2.45$$

$$\Psi_{A2+A3+A4} = \mathbf{0.01}$$

$$\Psi_{A6+A10+A14} \rightarrow \frac{b}{c} = \frac{0.572\,m}{2.6\,m} \approx 0.22$$

$$\frac{a}{c} = \frac{6.39\,m}{2.6\,m} \approx 2.45$$

$$\Psi_{A6+A10+A14} = \mathbf{0.01}$$

$$\Psi_{A7+A8} \rightarrow \frac{b}{c} = \frac{9\,m}{2.6\,m} \approx 3.46$$

$$\frac{a}{c} = \frac{1.44\,m}{2.6\,m} \approx 0.55$$

$$\Psi_{A7+A8} = \mathbf{0.02}$$

$$\Psi_{A12} = \frac{b}{c} = \frac{1\,m}{2.6\,m} \approx 0.38$$

$$\frac{a}{c} = \frac{1.1\,m}{2.6\,m} \approx 0.42$$

$$\Psi_{A12} = \mathbf{0.01}$$

$$\Psi_{A11} \rightarrow \frac{b}{c} = \frac{8\,m}{2.6\,m} \approx 3.07$$

$$\frac{a}{c} = \frac{1.1\,m}{2.6\,m} \approx 0.42$$

$$\Psi_{A11} = \mathbf{0.02}$$

$$\Psi_{A15+A16} = \frac{b}{c} = \frac{9\,m}{2.6\,m} \approx 3.46$$

$$\frac{a}{c} = \frac{3.85\,m}{2.6\,m} \approx 1.48$$

$$\Psi_{A15+A16} = \mathbf{0.05}$$

In case of the floor the value *c* is 1.4 m.

$$\Psi_{A1+A5} = \frac{b}{c} = \frac{0.428\,m}{1.4\,m} \approx 0.3$$

$$\frac{a}{c} = \frac{2.41\,m}{1.4\,m} \approx 1.72$$

$$\Psi_{A1+A5} = \mathbf{0.01}$$

$$\Psi_{A2+A3+A4} = \frac{b}{c} = \frac{9.572\,m}{1.4\,m} \approx 6.83$$

$$\frac{a}{c} = \frac{1\,m}{1.4\,m} \approx 0.71$$

$$\boldsymbol{\Psi_{A2+A3+A4} = 0.02}$$

$$\Psi_{A6} = \frac{b}{c} = \frac{0.572\,m}{1.4\,m} \approx 0.4$$

$$\frac{a}{c} = \frac{1.41\,m}{1.4\,m} \approx 1$$

$$\boldsymbol{\Psi_{A6} = 0.01}$$

$$\Psi_{A8} = \frac{b}{c} = \frac{1\,m}{1.4\,m} \approx 0.71$$

$$\frac{a}{c} = \frac{1.41\,m}{1.4\,m} \approx 1$$

$$\boldsymbol{\Psi_{A8} = 0.02}$$

$$\Psi_{A9+A13} = \frac{b}{c} = \frac{0.428\,m}{1.4\,m} \approx 0.3$$

$$\frac{a}{c} = \frac{6.39\,m}{1.4\,m} \approx 4.56$$

$$\boldsymbol{\Psi_{A9+A13} = 0.01}$$

$$\Psi_{A10+A14} = \frac{b}{c} = \frac{0.572\,m}{1.4\,m} \approx 0.4$$

$$\frac{a}{c} = \frac{6.39\,m}{1.4\,m} \approx 4.56$$

$$\boldsymbol{\Psi_{A10+A14} = 0.01}$$

$$\Psi_{A7+A11} = \frac{b}{c} = \frac{8\,m}{1.4\,m} \approx 5.71$$

$$\frac{a}{c} = \frac{6.8\,m}{1.4\,m} \approx 4.85$$

$$\boldsymbol{\Psi_{A7+A11} = 0.09}$$

$$\Psi_{A12} = \frac{b}{c} = \frac{1\,m}{1.4\,m} \approx 1$$

$$\frac{a}{c} = \frac{5.39\,m}{1.4\,m} \approx 3.85$$

$$\boldsymbol{\Psi_{A12} = 0.01}$$

$$\Psi_{A15+A16} = \frac{b}{c} = \frac{9\,m}{1.4\,m} \approx 6.42$$

$$\frac{a}{c} = \frac{1\,m}{1.4\,m} \approx 1$$

$$\boldsymbol{\Psi_{A15+A16} = 0.02}$$

In case of the east wall the value *c* is 6.39 m.

$$\Psi_{A1} = \frac{b}{c} = \frac{1.4\,m}{6.39\,m} \approx 0.21$$

$$\frac{a}{c} = \frac{9.572\,m}{6.39\,m} \approx 1.5$$

$$\boldsymbol{\Psi_{A1} = 0.05}$$

$$\Psi_{A2} = \frac{b}{c} = \frac{2.6\,m}{6.39\,m} \approx 0.4$$

$$\frac{a}{c} = \frac{9.572\,m}{6.39\,m} \approx 1.5$$

$$\boldsymbol{\Psi_{A2} = 0.02}$$

$$\Psi_{A3} = \frac{b}{c} = \frac{1.4\,m}{6.39\,m} \approx 0.2$$

$$\frac{a}{c} = \frac{0.428\,m}{6.39\,m} \approx 0.06$$

$$\boldsymbol{\Psi_{A3} = 0.01}$$

$$\Psi_{A4} = \frac{b}{c} = \frac{2.6\,m}{6.39\,m} \approx 0.4$$

$$\frac{a}{c} = \frac{0.428\,m}{6.39\,m} \approx 0.06$$

$$\boldsymbol{\Psi_{A4} = 0.01}$$

In case of the west wall the value *c* is 2.41 m.

$$\Psi_{A1} = \frac{b}{c} = \frac{1.4\,m}{2.41\,m} \approx 0.6$$

$$\frac{a}{c} = \frac{0.428\,m}{2.41\,m} \approx 0.17$$

$$\boldsymbol{\Psi_{A1} = 0.01}$$

$$\Psi_{A2} = \frac{b}{c} = \frac{2.6\,m}{2.41\,m} \approx 1.07$$

$$\frac{a}{c} = \frac{0.428\,m}{2.41\,m} \approx 0.17$$

$$\boldsymbol{\Psi_{A2} = 0.01}$$

$$\Psi_{A3} = \frac{b}{c} = \frac{1.4\,m}{2.41\,m} \approx 0.58$$

$$\frac{a}{c} = \frac{9.572\,m}{2.41\,m} \approx 3.97$$

$$\boldsymbol{\Psi_{A3} = 0.03}$$

$$\Psi_{A4} = \frac{b}{c} = \frac{2.6\,m}{2.41\,m} \approx 1.07$$

$$\frac{a}{c} = \frac{9.572\,m}{2.41\,m} \approx 3.97$$

$$\boldsymbol{\Psi_{A4} = 0.05}$$

In case of the south wall the value *c* is 0.428 m.

$$\Psi_{A1} = \frac{b}{c} = \frac{1.4\,m}{0.428\,m} \approx 3.27$$

$$\frac{a}{c} = \frac{6.39\,m}{0.428\,m} \approx 14.9$$

$$\boldsymbol{\Psi_{A1} = 0.1}$$

$$\Psi_{A2} = \frac{b}{c} = \frac{2.6\,m}{0.428\,m} \approx 6$$

$$\frac{a}{c} = \frac{6.39\,m}{0.428\,m} \approx 14.9$$

$$\boldsymbol{\Psi_{A2} = 0.1}$$

$$\Psi_{A3} = \frac{b}{c} = \frac{1.4\,m}{0.428\,m} \approx 3.2$$

$$\frac{a}{c} = \frac{2.41\,m}{0.428\,m} \approx 5.6$$

$$\boldsymbol{\Psi_{A3} = 0.09}$$

$$\Psi_{A4} = \frac{b}{c} = \frac{2.6\,m}{0.428\,m} \approx 6$$

$$\frac{a}{c} = \frac{2.41\,m}{0.428\,m} \approx 5.6$$

$$\boldsymbol{\Psi_{A4} = 0.1}$$

In case of the north wall the value *c* is 9.572 m.

$$\Psi_{A1} = \frac{b}{c} = \frac{1.4\,m}{9.572\,m} \approx 0.14$$

$$\frac{a}{c} = \frac{2.41m}{9.572\,m} \approx 0.25$$

$$\boldsymbol{\Psi_{A1} = 0.01}$$

$$\Psi_{A2} = \frac{b}{c} = \frac{2.6\,m}{9.572\,m} \approx 0.27$$

$$\frac{a}{c} = \frac{2.41\,m}{9.572\,m} \approx 0.25$$

$$\boldsymbol{\Psi_{A2} = 0.01}$$

$$\Psi_{A3} = \frac{b}{c} = \frac{1.4\,m}{9.572\,m} \approx 0.14$$

$$\frac{a}{c} = \frac{6.39\,m}{9.572\,m} \approx 0.66$$

$$\boldsymbol{\Psi_{A3} = 0.01}$$

$$\Psi_{A4} = \frac{b}{c} = \frac{2.6\,m}{9.572\,m} \approx 0.27$$

$$\frac{a}{c} = \frac{6.39\,m}{9.572\,m} \approx 0.66$$

$$\boldsymbol{\Psi_{A4} = 0.01}$$

As the relation of angles from the surfaces to the person is now found, the temperature is further calculated:

$$t_m = F_{P-n} * t_n$$

(Stampe 2000, p. 30)

where;

$F_{P\text{-}n}$ – The angle relation from person to surface n
t_n – Surface temperature of surface n

$$\Psi_{roof} = 0.18\ (Window: \Psi_{A11} = 0.02)$$

$$\Psi_{floor} = 0.2(Water: \Psi_{A7+A11} = 0.09)$$

$$\Psi_{east} = 0.09$$

$$\Psi_{west} = 0.1$$

$$\Psi_{south} = 0.39$$

$$\Psi_{north} = 0.04$$

$$\sum \Psi = 1$$

$$t_{roof} + t_{floor} + t_{east+}t_{west} + t_{south} + t_{north}$$
$$= (0.02 * 35.95°C) + (0.16 * 39.42°C) + (0.09 * 40°C) + (0.11 * 36.77°C) + 0.09$$
$$* 39.42°C 0.1 * 39.42°C + 0.39 * 39.04°C + 0.04 * 39.04°C = 38.94°C$$

The operative temperature is thus:

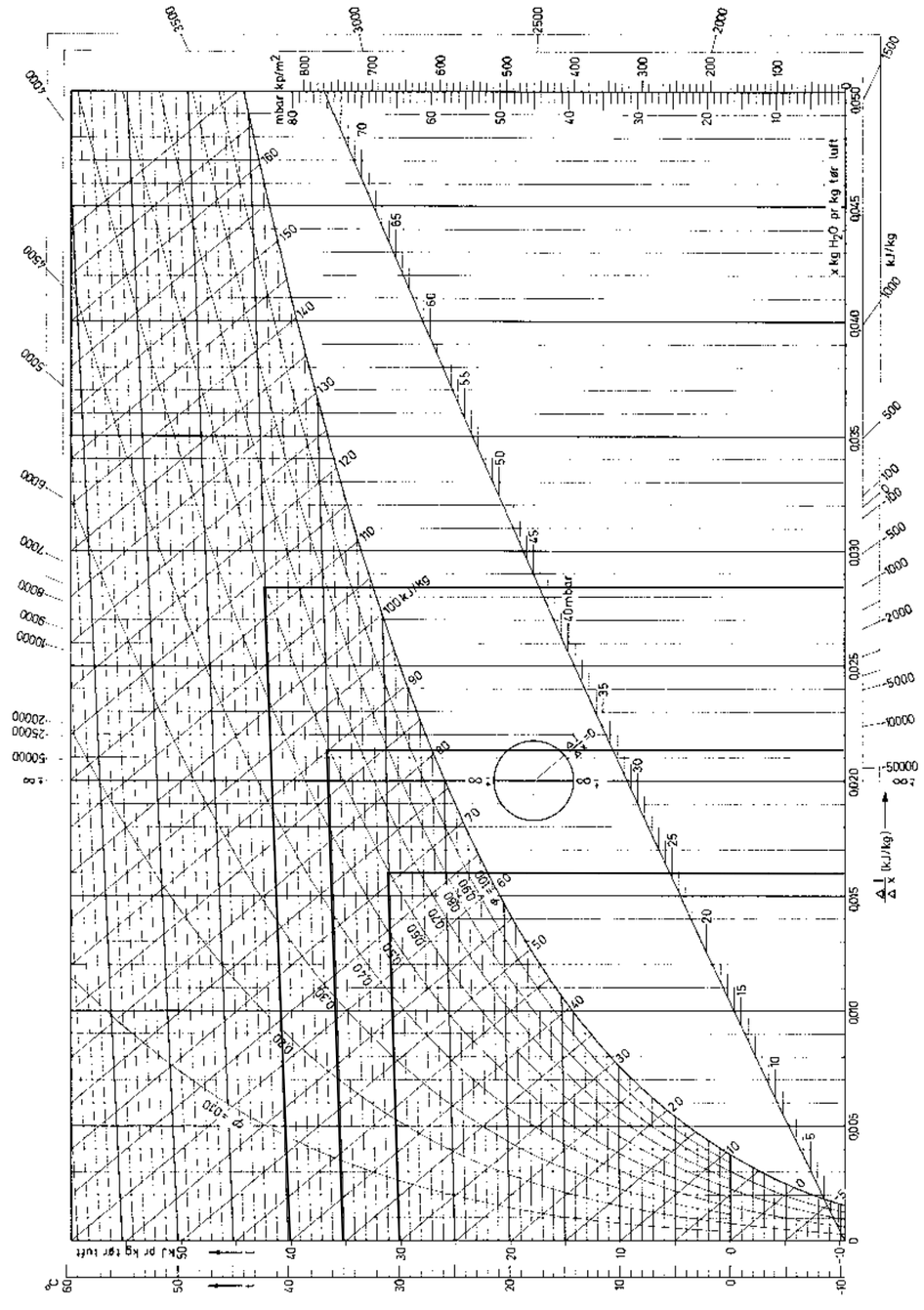
$$0.5(40 * 38.94°C) = 39.47°C$$

It can thus be concluded that although 10m² window is present, the temperature only deviates by 0.53 degrees Celsius, which is acceptable as it makes no sensational change.

References:

Stampe, Ole B. *Varme- Og Klimateknik, Ventilationsteknik.* Lyngby: Danvak, 2000. Print.

Appendix 2



Appendix 3

AirChange by Moisture

	Area [kvm]	Height [m]	Volume [m^3]	Persons [pers.]	Evaporation load [kg/h]	Moisture by people [kg/h/person]	Applied moisture [kg/h]	Total moisture [kg/h]	AirChange [n=h^-1]	Input for Bsim AirSupply [m3/s]
1st conditioning	60	4	240	8	7,8	0,06	8,3	828,00	4,31250	0,29
2nd conditioning	70	4	280	8	13,4	0,06	13,9	925,33	4,13095	0,32
3rd conditioning	100	4	400	8	24,3	0,06	24,78	1101,33	3,44167	0,38
Experience Pool	120	4	480	8	12,5	0,06	13,0	1298,00	3,38021	0,45

Water density kg/m3	60%RH Moisture inside kg/kg	10 deg C @80%RH Moisture outside kg/kg
1,25	0,016	0,006
1,25	0,021	0,006
1,25	0,0285	0,006
1,25	0,016	0,006

Activity (Stampe 2000, p.. 30)
Moisture inside (Stampe 2000, p., 331)
Air density: http://antoine.frostburg.edu/chem/senese/javascript/water-density.html

Appendix 4

Moisture load from pools

In order to find the moisture load to input in BSim, each pool needs to be calculated, as each pool has different temperature and thus different saturation pressure of water vapor, different humidity and ultimately different moisture load. In order to calculate the evaporation from the pool, following needs to be addressed (EngineeringToolBox.com – Evaporation from water surfaces):

$$g_s = \odot A(x_s - x)$$

g_s: amount of evaporated water per hour (kg/h)
$\odot$: (25+19*v) *evaporation coefficient from empiri (kg/m²h)*
v: velocity of air above water surface (m/s)
A: area of water surface (m²)
x_s: humidity ratio in saturated air (at the same temperature of the water surface) (kg/kg)
x: humidity ratio in air (kg/kg)

The first conditioning pool is set to 30 degrees Celsius and has an area of 34m². The air is anticipated to be very slow, thus 0.1m/s. The evaporation coefficient is an empirical coefficient, meaning it is a result of an experiment (EngineeringToolBox.com). The humidity ratio in saturated air is here calculated (EngineeringToolBox.com – Humidity ratio by vapor partial pressure):

$$x_s = \frac{0.62198 * P_{ws}}{(P_a - P_{ws})}$$

where;

Pa: atmospheric pressure of moist air (Pa)
P_{ws}: saturation pressure of water vapor (Pa)

The saturated pressure is calculated:

$$P_{ws} = \frac{e^{77.3450+0.0057*T-\frac{7235}{T}}}{T^{8.2}}$$

where;

T: Temperature (Kelvin)

It has been anticipated that the pool is exposed to 1 atm = 101325 Pa. The saturation pressure of water vapor at 30 degrees Celsius is calculated:

$$P_{ws} = \frac{e^{77.3450+0.0057*(273K+30°C)-\frac{7235}{(273K+30°C)}}}{(273K+30°C)^{8.2}} = 4194.81\ Pa$$

Further other two degrees:

$$P_{ws} = \frac{e^{77.3450+0.0057*(273K+35°C)-\frac{7235}{(273K+35°C)}}}{(273K+35°C)^{8.2}} = 5560.94\ Pa$$

$$P_{ws} = \frac{e^{77.3450+0.0057*(273K+40°C)-\frac{7235}{(273K+40°C)}}}{(273K+40°C)^{8.2}} = 7296.99\,Pa$$

The humidity ratio in saturated air for 30 degrees Celsius is thus:

$$x = 0.016\frac{kg}{kg}$$

Further other two ratios:

$$x = 0.021\frac{kg}{kg}$$

$$x = 0.0285\frac{kg}{kg}$$

The humidity ratio is read from psychrometric chart (see Appendix 2). With a dry bulb temperature 30 degrees Celsius and with a relative humidity of 60%:

$$x_s = \frac{0.62198 * 4194.81\,Pa}{(101325\,Pa - 4194.81\,Pa)} = 0.0268\frac{kg}{kg}$$

Further other two degrees, being 35 and 40 degrees Celsius, with 60 RH%:

$$x_s = \frac{0.62198 * 5560.94\,Pa}{(101325\,Pa - 5560.94\,Pa)} = 0.0361\frac{kg}{kg}$$

$$x_s = \frac{0.62198 * 7296.99\,Pa}{(101325\,Pa - 7296.99\,Pa)} = 0.0482\frac{kg}{kg}$$

The moisture load of a 34m² pool, with a dry bulb temperature of 30 degrees Celsius, water surface temperature equivalent to dry bulb temperature, air velocity of 0.1m/s above water surface and 50% relative humidity:

$$1C\ Pool = g_s = \odot A(x_s - x) = \left(25 + 19 * 0.1\frac{m}{s}\right) * 27m^2\left(0.0268\frac{kg}{kg} - 0.016\frac{kg}{kg}\right) = 7.8\frac{kg}{h}$$

And for further other pools that are part of the sequence:

$$2C\ Pool = g_s = \odot A(x_s - x) = \left(25 + 19 * 0.1\frac{m}{s}\right) * 33\,m^2\left(0.0361\frac{kg}{kg} - 0.021\frac{kg}{kg}\right) = 13.4\frac{kg}{h}$$

$$3C\ Pool = g_s = \odot A(x_s - x) = \left(25 + 19 * 0.1\frac{m}{s}\right) * 46m^2\left(0.0482\frac{kg}{kg} - 0.0285\frac{kg}{kg}\right) = 24.3\frac{kg}{h}$$

$$Exp\ Pool = g_s = \odot A(x_s - x) = \left(25 + 19 * 0.1\frac{m}{s}\right) * 43m^2\left(0.0268\frac{kg}{kg} - 0.016\frac{kg}{kg}\right) = 12.5\frac{kg}{h}$$

The calculated values are the input for moisture load in BSim, and are further used to calculate the air supply for BSim (See Appendix 3).