

ARCHITECTURAL INTELLIGENCE



Generative design installations

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Preface

This thesis is derived from a fascination and interest of technologies by the author that he developed throughout his academic and non-academic past.

As a person that was born in the early 90s, the authors generation - also called the millennials or gen Y - are among the last that grew up without the influence of the communication and Information technologies of the 21st Century that undoubtedly changed the way that Interact with the world and people around us.

While the people of gen z grew up with the assist of the mentioned technologies, adapting to them and seeing them as a necessity of life, the millennials are able to understand that the possibility of having a complex machinery to assist us is not a necessity but a luxury. This luxury was not obtained by us going to a shop to buy a perfectly functioning device, but the learning curve of us humans to get to the level of an all-in-one phone that does not only in-cooperate a web browser, music player and camera, but also a voice assistant that recognises ones speech and turns it into functioning code that is then translated by the internal processing unit into a task, had made us challenge our perceptions of what is possible with the low-processing power of the past and engineering skills of the past. This creativity that derived from our imagination of a realistic future directly reflects in the thesis proposal.

As artificial intelligence is becoming more advanced and part of our everyday life by in-cooperating machine learning algorithms and artificial neural networks into smart devices that track and control our behaviour patterns, the questioned opened up of imagining how his profession of an architectural design would look like in the next decade to come. The aim of the author is to establish a design, or multiple designs that support his narrative and hypothesis that he established through literature studies of the past year. The basis of the design in the interest in modern technologies, but by using a creative mindset of a millennial and not sticking to the strict defined function of the technologies used.

As this thesis works with the concept of algorithmic architecture, machine learning in architecture and Artificial Intelligence in architecture, It is of importance to understand that the interest of the author outweigh the knowledge that he has on the previously mentioned topics. Therefore, this thesis consist of some lightweight algorithmic architectural design, but mainly focuses on the metaphoric value that the new technologies of the 21st Century bring to the work of a designer. As an example, the way that a Generative Adversarial Network uses a latent space that can be manipulated to change the outcome source is not represented by a set of numbers in this thesis, but by the division of space.

Abstract

Derived by previous studies conducted at an exchange semester in Glasgow, UK, "Architectural Intelligence" explores the use of modern technologies in architectural design practice and gives an insight of how the authors vision of a design installation in the next decade looks like. A special attention is given to the introduction of algorithms and machine learning as a tool that shifts an architects role of drafters to a pure design based role where optioneering is how a project is enhanced.

Throughout the thesis, the author translates his findings to his own interpretation and forms characteristics from them that are used in the construction of the design concept. The final outcome are three Installations that help to answer the thesis question that state the following:

Using the tools and technologies that exist now and having a perspective of them for the future, how will future designs look like and function?

The thesis is divided up into five sections: Introduction, theory, introduction to the design project, design project part one and design project part two. Introduction to the design project focuses on defining the characteristics used to divide up the space of the location and other guidelines and boundaries derived from the theory. Part one of the design project develops the algorithm used for the design and concludes into three static installations. Part two focuses

on making the static installations dynamic and redeveloping the geometry and visual characteristics.

Aims

The thesis explores computational tools of the 21st century to form structures that use the authors interpretation of generative designs and generative adversarial networks and by this interpretation, makes the topic comprehensible for readers who have the knowledge prior to reading this thesis, but also for people who are not as tech-savvy as the author.

Methods

The methodology used consists of literature studies and person interest fields, the application of that formed knowledge into a working tool-set to create a design concepts, the creation of designs and analysis of their trade-offs and reformulation those designs to fit into a sustainable setting.

Results

The result is an algorithm that creates a majority of the design, which can be modified by third-party users and which forms, with the help of manual labour and creative ideas, three installation proposals that are not only generated automatically by the algorithm, but also have the ability to re-draw themselves according to the movement of visitors, identifying clusters and warning them by visual feedback.

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01

Introduction - Thesis

This thesis explores the representation of the architectural design, in connection with the concept of Generative Design tools, Generative Adversarial networks, smart architecture and interactive architecture, all of them being emerging to offer the authors perception of how designs of the next decades might look like but also, to make it possible for anybody who is interested in these topics to use this thesis and the tools created with it to create individualised designs of their own and place them in their own environments.

Figure 1.01 show a mind-map that was used to create a focal point of interest for the design study.

Theory on computational architectural design, generative design, generative adversarial networks, interactive architecture, virtual and augmented reality, social issues regarding the use of surveillance and fictional and artistic interpretations of design and scaling are used as a base understanding, however the driving force behind this research is the authors Interest into technology that grew over the past decade, it's use in architectural design and how it changed the way architects work which climaxed in a study that the author concluded at an exchange semester at the University of Strathclyde in the fall of 2019 where he developed his understanding of the importance of autonomous designs in architecture for the new future.

The project outcome is a set of three installation in the faculty of architecture at Chalmers University of Technology that is digitally presented with the use of virtual environments.

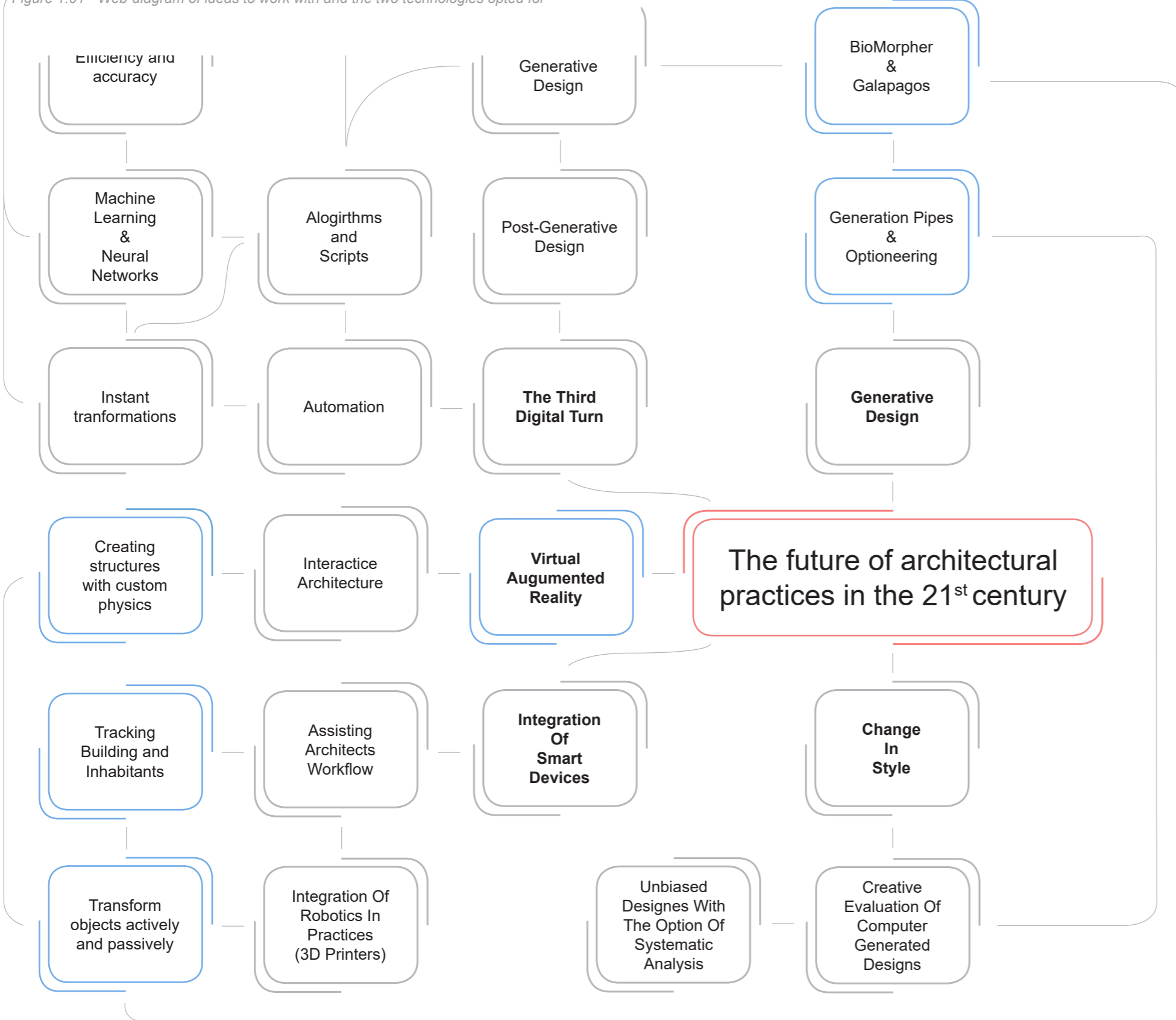
The following project objectives have been derived before the start of the research :

1. Explore the characteristics of generative design systems and generative adversarial networks.
2. Figure out a tool-set that the author can use to translate these characteristics into a working model of its own.
3. Derive a tool and materiality that enables to represent what the design that
4. Create a structure using those tools and materials that gives an insight on how future design proposals in the next decades will look like.
5. Adjust the structure that it follows a form of sustainable analysis, such as the analysis of movement of people.

These objectives answer the thesis question that started off the research idea:

Using the tools and technologies that exist now and having a perspective of them for the future, how will future designs look like and function?

Figure 1.01 - Web-diagram of ideas to work with and the two technologies opted for



Generative Design, Generation Pipes, BioMorpher & Galapagos



Created by David Rutten at Robert McNeel & Associates, Grasshopper is a visual programming language and algorithm solving plug-in for Rhinoceros 3D. By applying and connecting scripts, one can transform a simple point into an array of points that form a closed mesh, without having to model it manually in the Rhinoceros 3D interface.

Virtual Reality, Tracking behaviour, Generating structure with alternative physics



Created by David Rutten at Robert McNeel & Associates, Grasshopper is a visual programming language and algorithm solving plug-in for Rhinoceros 3D. By applying and connecting scripts, one can transform a simple point into an array of points that form a closed mesh, without having to model it manually in the Rhinoceros 3D interface.

02 Theory

A historical recap of computational design in architecture

Computational design in architecture can undoubtedly be seen as a revolution that has changed the way architects have worked in the last century. It has shifted the work-flow from desk and pen to a computerised environment that managed to increase the efficiency and possibility for large and small scale.

While in theory the art of computerised architectural design has been around since the early-20th century, by Walter Gropius introduction of systematic simplified architecture in form of the Baukasten concept that would make rational decision making possible, It wasn't until the 1950s that P. Hanratty, a PhD graduate at the University of California and American computer scientist published the first prototype of a CAD (Computer Assisted Drawing) software called PRONTO (Programme for Numerical Tooling Operations), which was a geometry encoder for a milling device used by General Electrics. Hanratty was also the founder of the first CAD program that used an Interactive graphics interface called DAC (Design Automated by Computer) which later translated to another program called ADAM (Automated Drafting and Machining), the first commercially available integrated, interactive graphics design and drafting tool.

By publishing their first program in 1979 called Interact CAD, which later became MicroCAD. Autodesk, the common market leader in 2020 in CAD software, set new parameters to the com-

mercialisation of computer aided architectural design. It was in fact the first CAD software to run on mainstream microcomputer hardware, hence the name given. Meanwhile, during the same period, French aircraft manufacturer Avions Marcel Dassault created one of the first 3D surface modelling program which also hosted NC commands for milling and named this "CATIA" (Computer-aided Three-dimensional Interactive Application) which was used to develop fighter jets and later found use in the military with companies like Boeing. However, it took 30 years until Canadian born American architect Frank Gehry created his own company called Gehry Technologies in 2002 that served to innovate the way architects use software in their everyday practice. In 2005, Gehry partnered up with Avions Marcel Dassault to use their CATIA program and adapt it to the needs of architects, engineers and contractors. This led to Digital Project, a CAD software based on CATIA V5, which Gehry then went on to use for his famous Guggenheim Museum Bilbao. Mario Capro, architectural historian, describes this time period as the First-Digital Turn in architectural design.

However, Digital Project was not a simple CAD software with 3D-modelling capabilities. It was among the first attempts to introduce BIM (Building Information Modelling) into AEC (Architecture, Engineering and Construction) by being able to send information directly to the manufacturer, rather than having to adapt it to software's

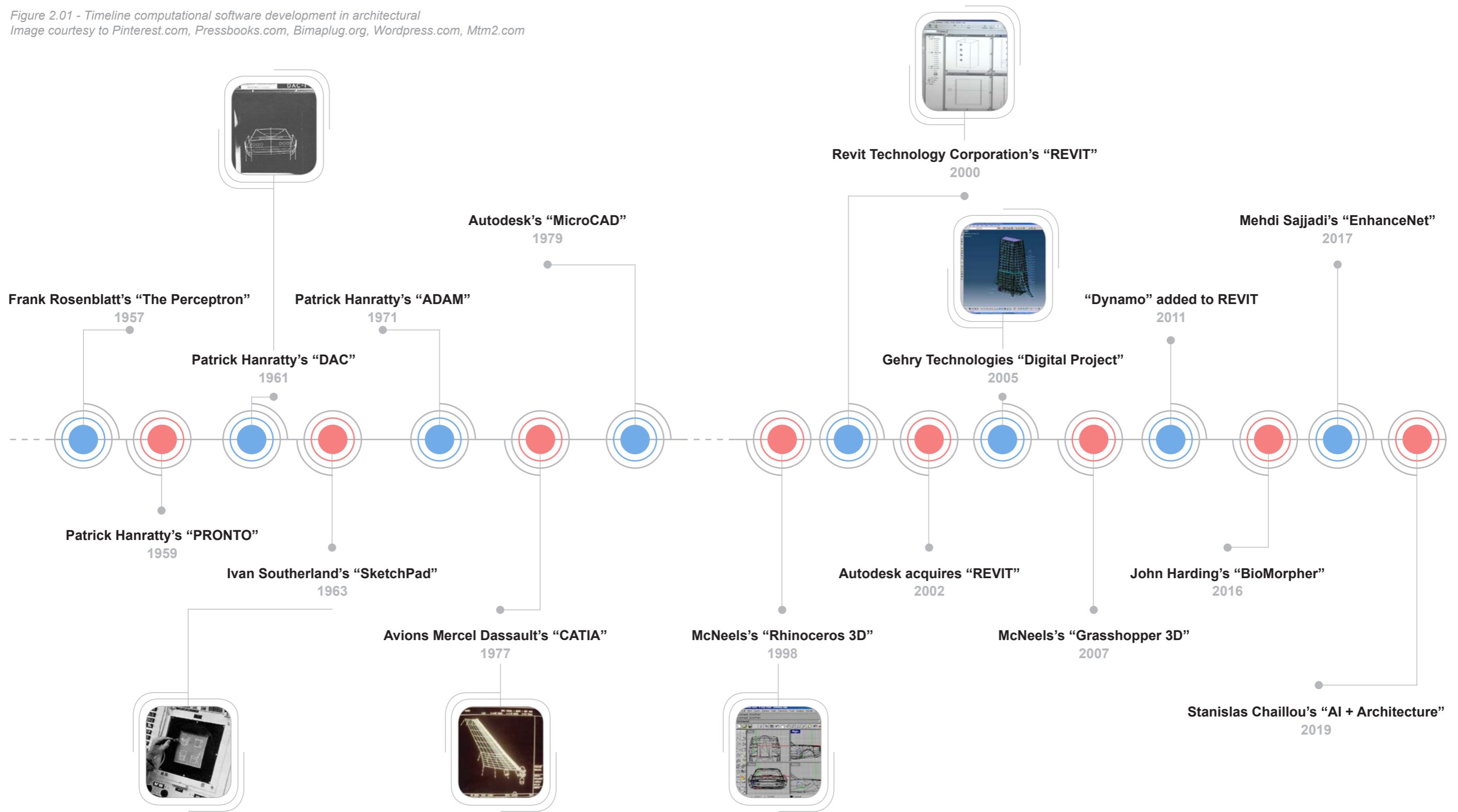
of project participants before sending it to them. Meanwhile, under the advisory of Phil Bernstein, Autodesk simultaneously acquired REVIT from Carles River Software in 2002, which became the know market leader for BIM in the first decades of the 21st century. The newly discovered parametric design allowed users to now only draft and model in a digital environment, but also let users manipulate form and dimensions of a object in real-time.

The availability and interest of consumer based machines that could handle complex 3D-Modelling by using computer algorithms climaxed with the release of Grasshopper 3D for Rhinoceros 3D in 2007 and DYNAMO for Autodesk REVIT in 2011 which offered a visual programming language that made it possible for users to create their own scripts and algorithms to suit their needs of design.

Furthermore, Grasshopper 3D allowed users to import customized interactive evolutionary algorithm plug-ins that third-party users created using the integrated programming language. This led to the craft of BioMorpher by John Harding and Cecille Brandt Olsen. BioMorpher is a generative design tool that lets users use a generation pipeline to design, rather than having to independently design and analyse thousands of objects separately. This new period of design is defined as the Second Digital Turn by Carpo.

The prospect of algorithmic design and generative design begs the question of how involved architects will be in future design and which tools will be needed for the "Third-Digital Turn" to be established. While the past century has represented architectural design in technological advancements, one has to question the limitations that these technologies have brought to the creative aspect of design. This technological illiteracy lead to the need of translations of difficult to understand computational assistants, into a working tool that everybody can use.

Figure 2.01 - Timeline computational software development in architectural
 Image courtesy to Pinterest.com, Pressbooks.com, Bimaplug.org, Wordpress.com, Mtm2.com



Generative design in architecture

Generative synthesis systems, which are the function behind generative designs are systems of mechanism that work together to create many alterations of designs that address problems and give solutions by a framed concept.

While generative architecture is a commonly used phrase in the 21st century, due to the new computational technologies and power, the core idea of the systematic approach towards architecture in the last four centuries can be traced back to Andrea Palladio's interpretation of Greek design rules to form spaces in the 16th century and Jean-Nicolas-Louis Durand's rules on how to build neoclassical architecture. Modern approaches can be found in Christopher Alexander's rules that give solutions to urban design problems in the 1960s and Peter Eisenman's "Transformational diagrams" that define the process of architectural design, shown in figure 2.02. Slawomir Wojtkiewicz from the technical University of Bialystok in Bialystok, Poland further interpreted his notion of generative synthesis systems with a design process and came up with different criterias that have to be fulfilled for a successful generative design system of the 21st century:

1. Conclusion of a design concept that that is influenced by determining factors such as a the building program and cost, but also the visual appearance.

2. Listings of hierarchies and levels that define the weight of the previously mentioned design concept factors.

3. Start of generating a structure to try and see if any modification is needed to the previous steps.

4. Creation of the final generative system.

5. Setting the correct parameters as constraints of the design

6. Creation a rule set that define how each other designs in the project are replaced by another.

7. Creation of a computer algorithm that automatizes the system and act as a blueprint for the design.

8. Creation of a Analysis system that figures out how well a proposed design solutions suits the objectives.

Figure 2.03 shows Wojtkiewicz's suggestion for the mentioned system.

For this thesis, the generative synthesis system defined by Wojtkiewicz acts as a framework for design steps that have to be taken to form a working generative design.

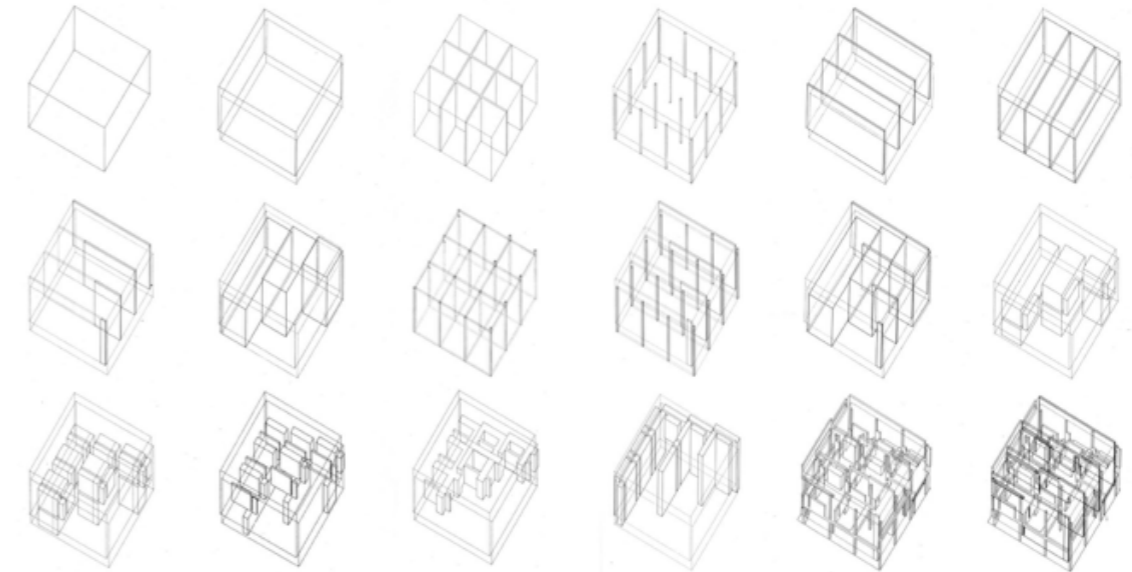


Figure 2.02 - Peter Eisenman's "Transformational diagrams"
Image courtesy of Ttu.edu

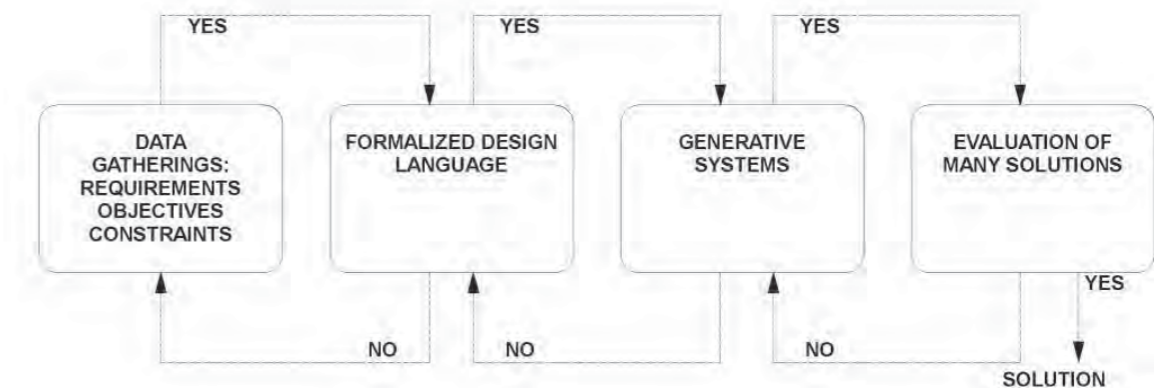


Figure 2.03 - Wojtkiewicz's system of a functioning generative design system
Image courtesy to Slawomir Wojtkiewicz

Generative adversarial networks

Generative Adversarial Networks (GANs) are an offspring of the evolution that Artificial Intelligence (AI), Machine Learning (ML) and Neural Networks (ANNs) have been processing through in the last century. ML, being a subtopic of AI, was a defined invention by Arthur Samuel, a data scientist from IBM, who developed a function for a chess game that indicated the probability of each side winning according to the positioning of the chess figures. Later on, he further configured this algorithm to track all positions which have already been played on and combined this value with the probability of winning the game. He published his algorithms as ML in 1952.

Half of a century later and further developments in the field have emerged, Mehdi Sajjadi, a data scientist at the Max Planck Institute for Intelligent Systems published his work, together with his colleagues Bernhard Schölkopf and Michael Hirsch, called "EnhanceNet". This program used GANs to create an automated texture synthesis algorithm that upscaled the resolution of any given picture. It was the first GAN model to be applicable in a scientific paper in 2017.

GANs typically feature two neural networks working simultaneously while being connected: One with a discriminative algorithm (DA) and the other one with a generative algorithm (GA). The DA simply analyses a set of data on existing contents while the GA rather tries to figure out

how to generate new content. The GA generates a random picture by defined pixels according to binary numbering, then feeds that to the DA which, using a set of data - in this case, pictures that it knows is "true", analyses if the value of the picture is true or false. If false, the GA will then redo the steps until the picture turns out as a true value. This all in a matter of seconds.

In his Master Thesis at the University of Harvard, Stanislas Chaillou, Architect & Data Scientist at Spacemaker AI, presented his interpretation of how generative design can help us architects drafting and designing a floor plan for a given area.

While Chaillou's model has more aspects to it than just the GANs, proving that ML can not only be used to produce designs, but also analyse architectural styles and develop these styles into a contemporary version, one can sum up that the GAN algorithm analyses the given dataset - in this case, floor plans with a similar typology as the project that one works on - and applies the result to an empty floor plan from which the user wants to generate. Figure 1.6 shows a diagrammatic representation of how Chaillou's model work.

While generating, these sets of algorithms can incorporate all features needed for a functioning floor plan, but also include all building regulation codes and structural calculation when the formula would be expanded. All of this in a matter of seconds.

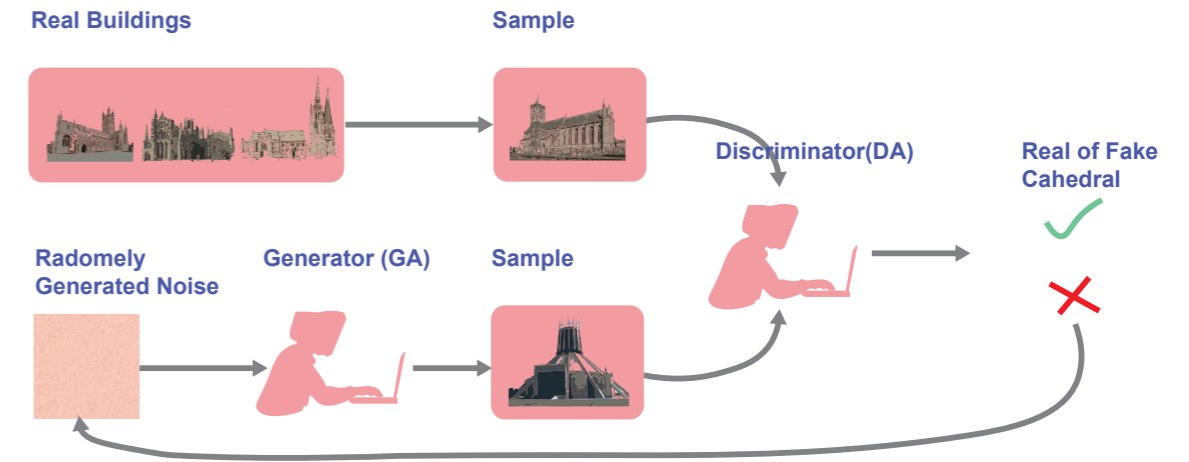


Figure 2.04 - A diagram on how GANs work

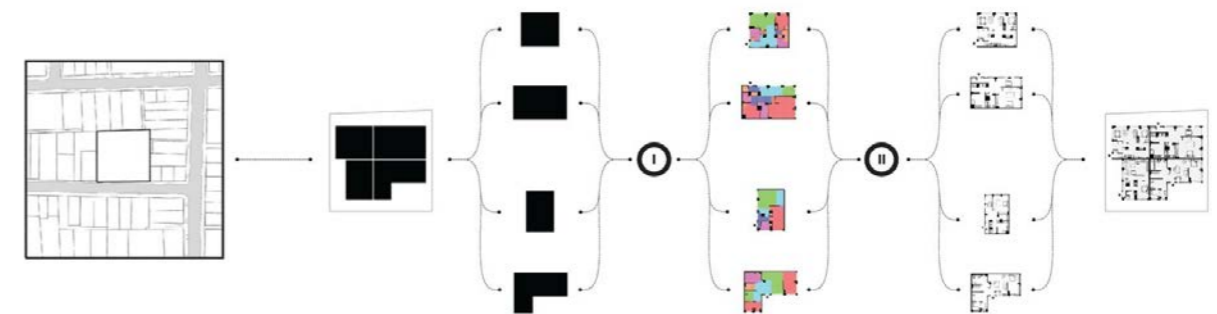


Figure 2.05 - A diagram of a floor plan generator using GANs
Image courtesy to Stanislas Chaillou

Interactive architecture: A non-intrusive design methodology

Interactive Architecture (IA), architecture that exhibits autonomous behaviour, in which that behaviour evolves through interactions with its users and environment (Jaskiewicz, 2010), has gained in popularity in the last decade with projects such as Amore Pacific by Levin and Lieberman from 2003 which uses motion-tracking systems and displays as a medium of presentation or the Prada Changing Room by AMO and OMA which uses RFID technology to create a harmonious connection between the user, the item and the changing rooms.

While the technologies of the 21st century have dramatically improved the way that users can interact with designs, the concept of participants having a creative productive role on a design using technology can be traced back to the Fun Palace, a project by Gordon Pask and Cedric Price from the 1960s that aimed to come up with design tools that make it possible for the visitors to form the space surrounding them. Later on, in 2009, REX and OMA went on to realise their version of a fun palace by designing the Dee and Charles Wyly Theatre which is able to adjust its interior structure to the design that the scenes of the theatre performance needs.

This thesis focuses on Smart Architecture (Senagala, 2006) in connection with IA. That is, using technologies to create a systemic mechanism by which Dynamic Architecture is envisioned to operate. The aim is to unite the digital with the

physical, forming new urban settings, an action called Urban Computing (Kindberg, Chalmers et al. 2008).

Reference projects of such are commonly found in settings where interaction is needed. Interior spaces that need to highlight the movement of people in order to define motion behaviour. All of these projects use so called Multi-Agent Interactive Architecture systems (xMAIAs). Those are systems that are a construct of software, hardware and interactions that build up the layers for a functioning piece of interactive design.

Dune 4.0 by Studio Roosegaarde created a network of illuminated fibres along the Maastunnel in Rotterdam which brightened according to the intensity of sound by bypassing visitors. Figure 2.06 shows the installation in action.

Lumen by Electroland is an installation located in the Cooper-Hewitt, National Design Museum in New York that uses an additional layer of technology by incorporating sound feedback to every visitor that enters the staircase seen in Figure 2.07. Light arrays then follow the paths of people. If a person stays at a spot for a few seconds, the light in that area gets brighter.

What all these projects share is that they rely on a physical medium to project IA. This thesis focuses on the use of virtual and augmented reality to further emerge the users.



Figure 2.06 - A picture of Dune 4.0
Image courtesy of Nathanjohn.works



Figure 2.07 - A picture of Lumen
Image courtesy to Electroland.net

HSB Living Lab

The HSB Living Lab is a residential building that is occupied by students and guest teachers, located at the Joannesberg Science Park in Gothenburg, Sweden. It is, in fact, a research project that is a collaborative project between the host university of the author of this thesis, Chalmers University of Technology and HSB, a Swedish housing association who aim is to research more sustainable living methods and create sustainable housing for the future.

The building is made out of pre-fabricated housing units that are composed together to inhabit 33 people that reside in the building continuously.

To research construction technologies of future use, the building features interior facades that can be swapped out and upgraded.

To achieve the goal of researching sustainable living methods, the project uses smart technologies and therefore also relates to the term of Smart Architecture. These technologies track the students behaviour and indoor qualities such as the emissions of each user, the concentration of carbon dioxide in each space unit but also detects the social behaviour of the inhabitants

This thesis takes acknowledgement to the project as a possible tool of experimentation and client, were the year 2020 shows how important tracking behavioral patterns are for the wellbeing of the users.

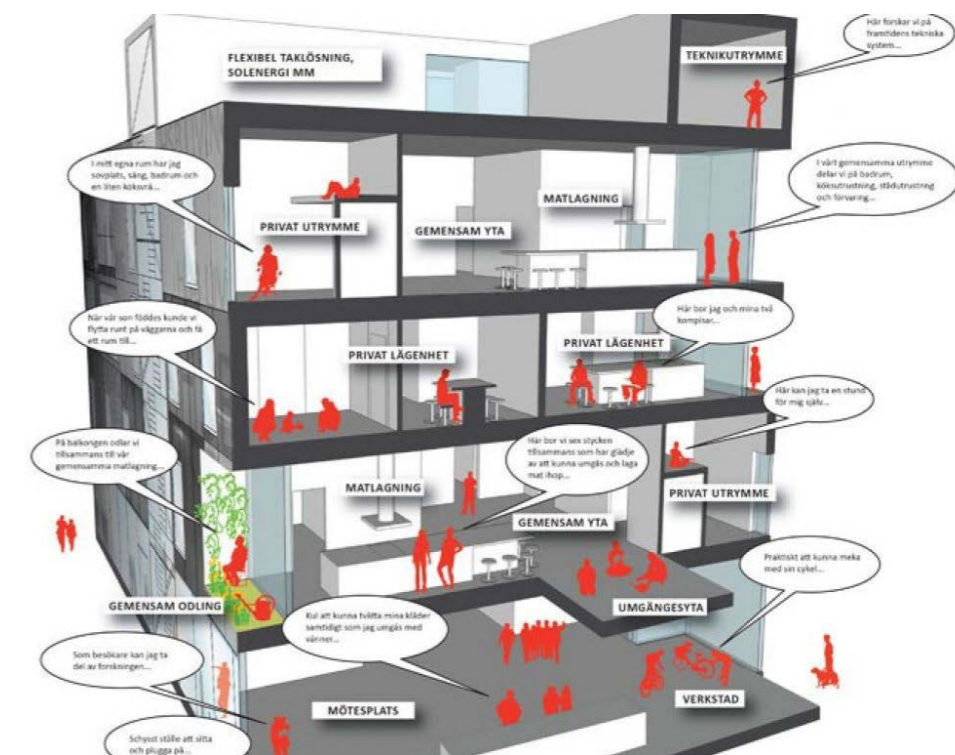


Figure 2.08 - Picture and diagram of HSB Living Lab
Image courtesy of Erik Abel & HSB

2020 Surveillance for safety

This thesis is an ongoing project that takes into consideration the changing perception of data protection laws in Europe as a consequence to the ongoing pandemic that showed the need of smart technologies as a tool to combat health risks.

The use of visual and digital tracking, to analyse the movement of people in public spaces has been a topic of the past two decades that did not have high popularity ratings in Europe and the Western society, while in Asia it has been a norm in order to give governments a better control mechanisms over their citizens. However, with the uncovering of NSA files by Edward Snowden in 2013 proved that the surveillance was not excluded in the Western society, but was hidden away from the public. While Snowden highlighted the importance of the public knowledge about the surveillance actions by governments, it also showed the acceptance of these actions by the public due to the lack of public outcry.³²³²³ This acceptance led to projects such as the facial detection camera system, stationed and trialed at the train-station Südkreuz in Berlin Germany, where the Germany's ministry of the interior worked together with the federal police for a six month trial facial recognition at designated entrance areas, as seen in figure 2.09.

This thesis does not embrace this change, but accepts it as a future tool to be used in architecture and design and interactive architecture.

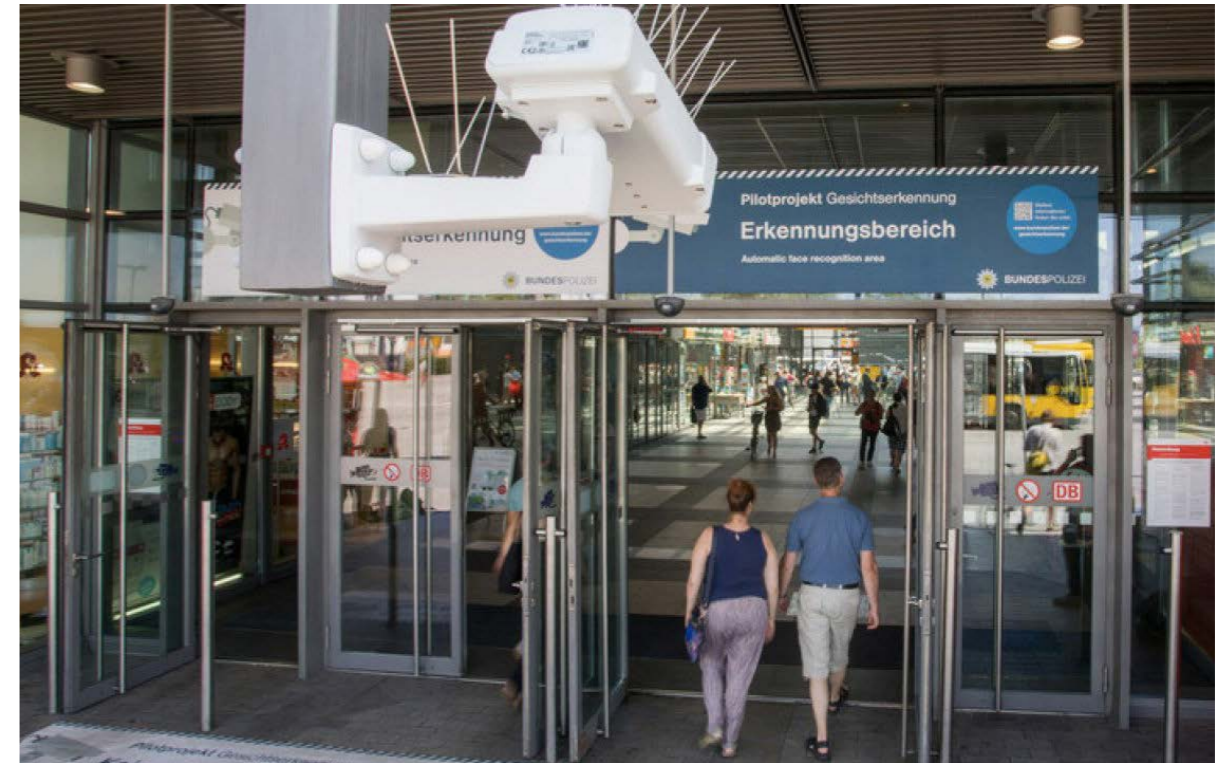


Figure 2.09 - A picture of the entrance at train station Südkreuz in Berlin
Image courtesy of heise.de



Figure 2.10 - A picture of a thermal camera, measuring body temperatures of people in 2020
Image courtesy to fpf.org

“
*I can access all points of my
three dimensional space. Yet,
I'm a prisoner in the present .*
”

(Neil deGrasse Tyson, 2014)

Representation of virtual space in science-fiction

Visualising unimaginable places using advanced future technologies is something that is being done in film industries around the globe. When defining the technologies of the future, the science fiction movie 2001: A Space Odyssey by Stanley Kubrick not only prophesied the use of a virtual assistant that uses artificial intelligence and machine learning to adapt to the user needs but also a mere exact replica of the Apple iPad, which was set to launch in 2010. While 2001: A Space Odyssey followed the design paths of a reality that has not been explored yet, a follow-up called Interstellar by Christopher Nolan took it to the next level by trying to render the fourth dimension. Humans can comprehend the next spatial dimensions with ease, while the first three are also representable in a physical form. The first dimension represents a line, the second a plane, the third space and the fourth time. The fourth dimension then - as for Interstellar - is a view on all those other dimensions from an external source, in this case, the main antagonist who is using the tesseract as a tool to do so. This external source, as Neil Tyson explained in an interview in 2014, can access all points of the three-dimensional space, but is still a prisoner of the present. This type of interactivity is an aspect that one can also find in generative design. While one can optioneer the result to the desired design, the key aspect of generative design lies in leaving the algorithm to its job to come up with designs without us having to draft or draw anything.



Figure 2.11 - A tablet in the movie "2001: A Space Odyssey"
Image courtesy of Metro-Goldwyn-Mayer

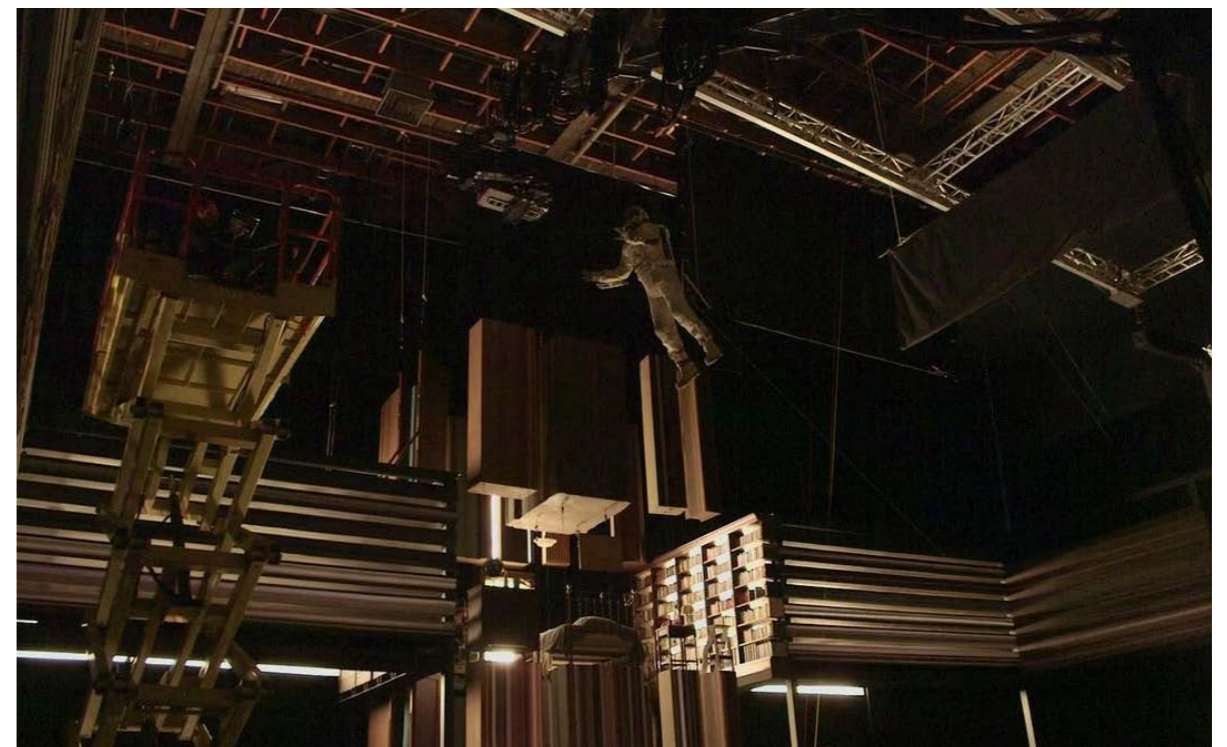


Figure 2.12 - Representation of the 5th dimension in the movie "Interstellar"
Image courtesy of Paramount Pictures

Scale and illusion in space

The ability to vary in scale and representation is of essential importance when creating the illusion of a never-ending process of design that generative design has to offer.

While algorithms in a design environment have much more to offer than just adjusting the size and shape of an object in a given place, scale and representation is something that is tangible for the human mind to comprehend and easier to understand for those who are new to the world of artificial designs. It is not by chance that one of the first things one gets taught at an architecture school is the relevancy of scale in design.

During the design Biennale 2014 in Venice, Italy, Doug Wheeler, an American artist and experimental architect, redesigned the atrium space of the Palazzo Grassi, a residence that dates back to the 18th century. The author filled the space with a textile structure and illuminated it to a brightness level where all visual senses of the surrounding space was illuminated.

The final outcome left people in question of what could be placed here if the space was endless as the endless white space that they were in.



Figure 2.13 - Doug Wheeler illusion of infinite white space inside Palazzo Grassi
Image courtesy of Dezeen.com

Virtual and Augmented Reality

This thesis discusses the potential in technologies that exist today to represent generative designs in an ever-changing identity. Since one is limited by the material and constructibility of the early 21st century, It is important to look at virtual media as a bridge to fill a physical space. In the last decade, a tool called Virtual Reality and became widely known through the gaming industry. Virtual reality defines as follows:

“A computer simulation of a real or imaginary system that enables a user to perform operations on the simulated system and shows the effects in real-time.”
(The American Heritage Dictionary, 2020.)

Examples of this technology are the virtual reality glass HTC Vive and the Oculus Rift. Google has made an cheaper alternative called Google Cardboard where, unlike the Vive and the Rift that rely on an external processing unit, the phone becomes the processing unit that projects the virtual world surrounding the user.

The aim is then to merge the simulation with the in a real space. A virtual-physical-space, or also called Augmented Reality. This optimum tool-set has the potential for the user to interact with virtual objects surrounding him. Examples of this technology is the Microsoft HoloLens, which is already capable of rendering objects in real time, as shown in Figure 2.17.



Figure 2.14 - A picture of HTC Vive
Image courtesy of Ventrebeat.com



Figure 2.15 - Picture of what people see in VR
Image courtesy of Wikipedia.com



Figure 2.16 - Picture of Microsofts HoloLens
Image courtesy of Microsoft



Figure 2.17 - Picture of what people see in AR
Image courtesy of Skift.com

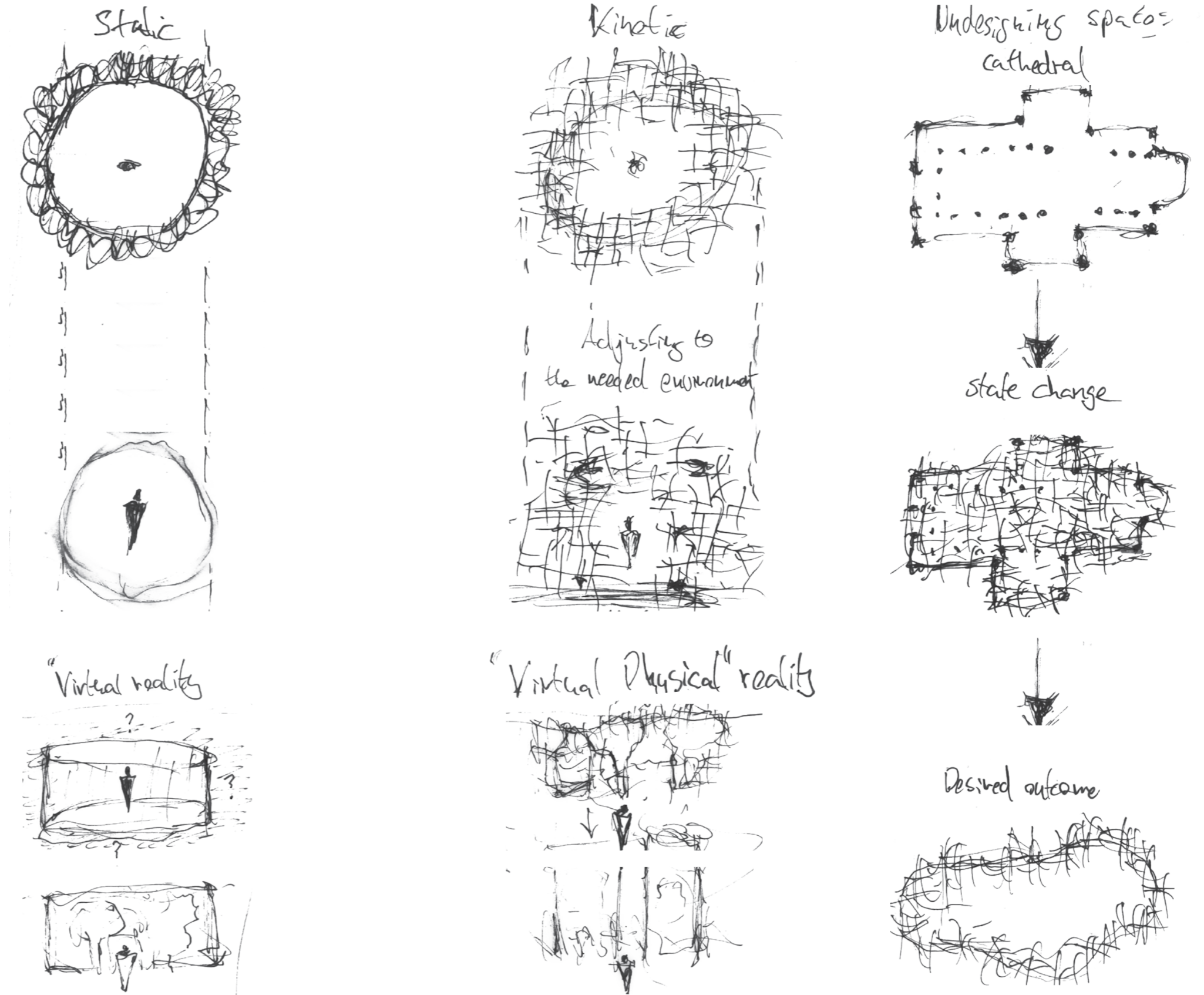
Figure 2.18 - Sketches of the first trial to put generative design to a physical form

Generative design and state changes

For the development stages of the Installations, experimentations with state changes of shapes and sizes are undertaken by free-hand sketches that show the potential of unknown materiality in connection with the re-use of existing and non-existent spaces, represented in figure 2.18. As one can see, the levels of designs are divided into static and kinetic, where the static representation is something that is already existent and understandable by humans. An example of this would be a 360 degrees panoramic screen that displays the surrounding in a similar way to the previously mentioned virtual reality or augmented reality if one works with a transparent screen. The kinetic state change, however, is what this Installation aims for - to immerse the viewers into the augmented space that they create.

The section called "Un-designing spaces" shows the potential of the kinetic state change if one thing about materiality not as a static form, but as a kinetic form. One would then be able to transform any space into a new desired space - the core essentials of generative design.

The Installation makes it possible for us to emerge into the kinetic state and show us the state change of objects in real-time, adjusted by the viewer.



03

Introduction - Project

An interpretation of the GANs and Generative Synthesis Systems in architecture design

In order to translate the theory from chapter 1 of this thesis into a working design that let's the reader understand the application of GANs and Generative Synthesis Systems in an architectural design, this project is using a metaphorical translation of features from both systems, and implements these by using concepts and technologies, such as the representation of digital space with the use of virtual reality or augmented reality glasses instead of staying in the creative realm of the 20th century that insisted on physical based designs. The aim of the design is then categorised into these steps:

1. To have a design that has a visual appearance that suit the space it is put in and follows other determining factors such as scale and randomness.
2. To use a crude version of a generative deign tool, by the use of an algorithm written in Grasshopper for Rhino 3D so that any person who has the ability to use these programs can replicate the idea in any other location.
3. Having the ability to be adjusted according to user Input to represent the flexibility that IA and GANs offer.
4. To be a tool that helps with a societal issue such as overcrowding spaces.

The design project is divided up into three parts:

Introduction to the design methodology:

This chapter introduces the chosen location of the design Installation, the methodology used to separate the space for the design creation, initial concept sketches derived from that methodology and the criteria needed to create the algorithm for part one of the design project.

Design project part one:

Part one of the design project focuses on the creation of the algorithm and gives a detailed understanding of how characteristics of GANs and and Generative Synthesis Systems are used, such as the randomness in shape creation, in a result of three Installations that are proposed at the end.

Design project part two:

Part two of the design project focuses on developing the idea of an Installation that uses smart racking devices to track visitors movement and forwards that information to the computer processing the algorithm, in order to move the objects to the location where clusters build up. For that, restrictions are created on where the Installation is allowed to expand to.

Figure 3.01 - Plan of Chalmers University of Technology's campus and surrounding area
Image courtesy to Google.com & Openstreetmap.org

Location of project

As the kinetic state changes and generative designs can vary in scale and shape, one has to account the need for space for the design to expand or to minimize. Therefore the installations alterations are placed in a large volume with no intruding structures.

The atrium space of the architecture faculty at Chalmers University of Technology offers a box-like space with the dimensions of 26 x 26 x 17 meters without any intrusions, other than the balconies on the upper floors which are worked around with the design. It is an architecture faculty, also means that the action of presenting a new sphere in designing with the use of generating design is influencing the student and tutors creativity and technological understanding.

The total volume of use is 11492m³.

The different entrances of the to the elevators, workshop and library also mean that the constant flow of circulation is used as a design influence when the scale and position of the installation is generated.

Finally, the aim of the user-influenced Installation is to emerge the viewers of the exhibition into their own generated space.



Figure 3.04 - Representation of space division for the proposed Installations

Pre-design step one: Representation of space

The guideline of generating the user-defined Installation is given in the next three pages to come.

Step one is to define the volume to work with and gives it the right dimensions accordingly. In this case, one can see the entire volume of the atrium.

Then this space is divided up into fragments which, in this case, are squares for simplification of the algorithm.

The squares are then adjusted in scale by Bio-Morpher and the final choice of scaling is then chosen by the user, in this case the author.

The flexibility in scale offers the Installation to not be dependent on the space that it is put in and can adjust to any narrowness or limitations on height.

The different alterations can be seen in figure 3.04

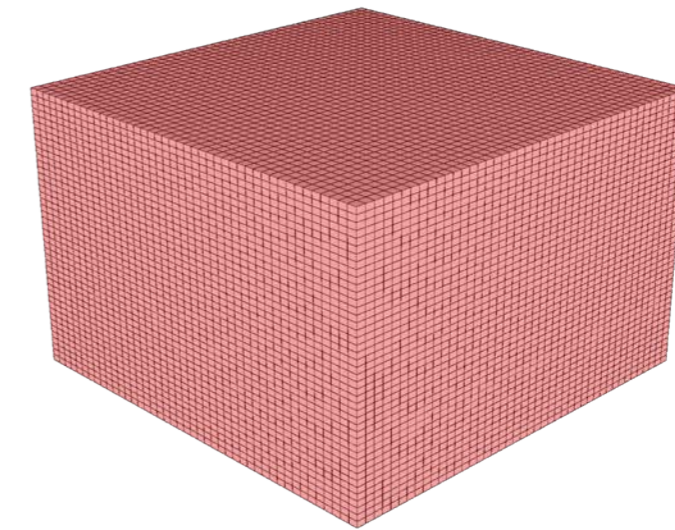
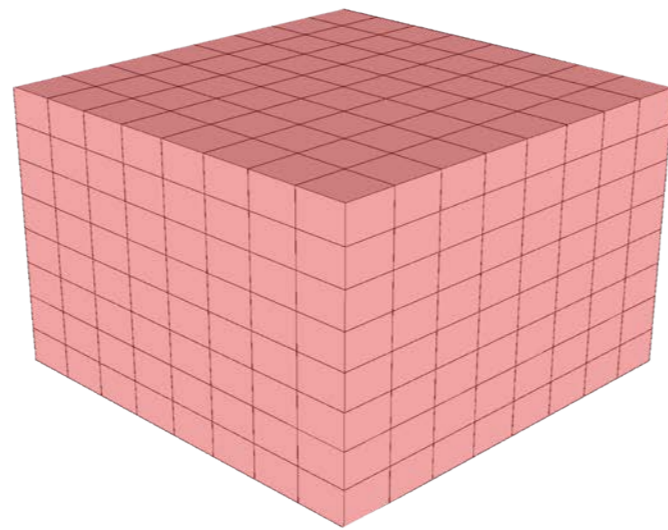
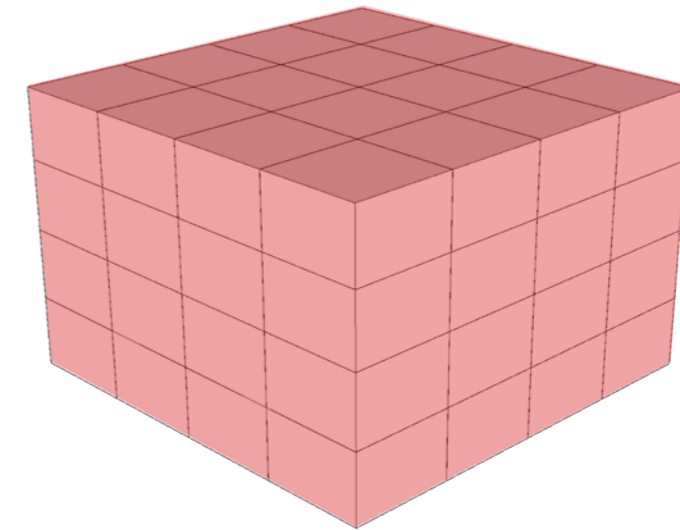
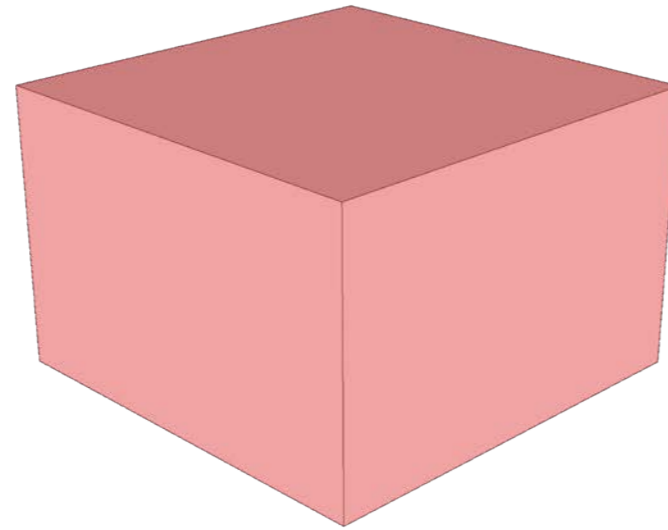


Figure 3.06 - Composition of space for the proposed Installations

Pre-design step two: Composing elements

Step one is repeated for a minimum of two times to generate a counter-Installation that interacts with the first one. The following alterations, however, differ from the previous in scale and randomness to offer a more interesting interaction with each other. This step is also done by the generative design plug-in BioMorpher.

By running BioMorpher several time for each alteration, one will be left with new forms of designs.

Figure 3.06 shows example structures that were manually designed rapidly and shows the potential this design aspiration has.

The top left and bottom right figure show a random array of cubes in size and/or randomness that on don't have any function on the first glance, but when seen from above one can see what effect the structure has to the shading of the atrium.

The top right figure shows fewer alterations of the sizes but the randomness of the cubes formed an encapsulation of the viewer by a circular wall in the middle of the atrium.

The last on the bottom left shows an array of cubes in a tower shape that would function as a standard architecture object with different elevations.

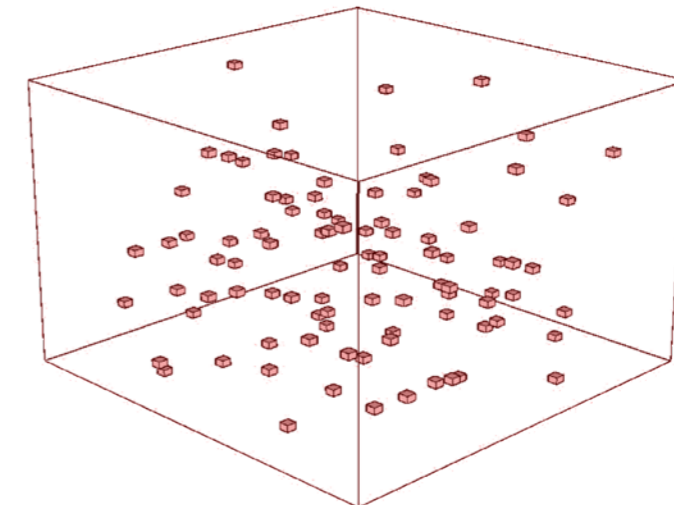
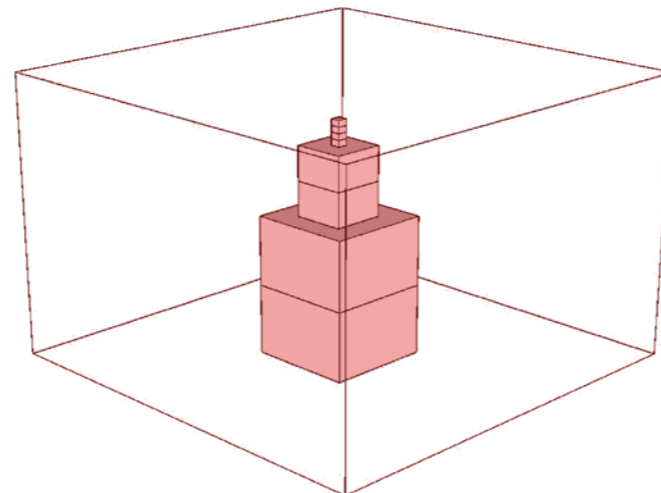
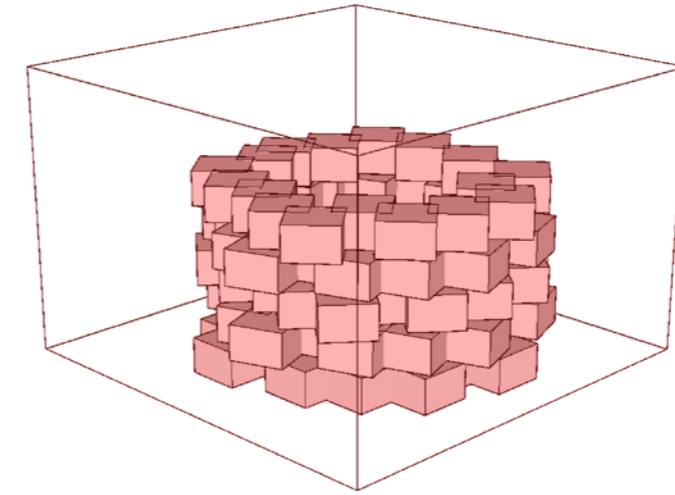
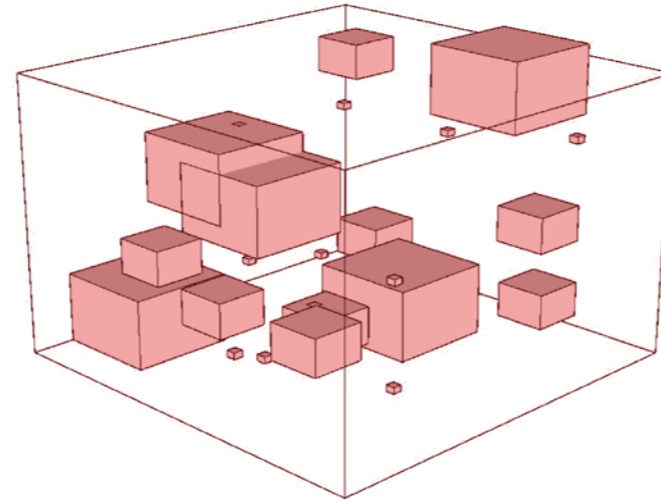


Figure 3.07 - Transformation to a new shape/medium for the proposed Installation

Pre-design step three: Transformation of form

The final design step of the Installation's design concentrates on the translation of the cubes into any desired object that the user defines it to be.

For the preliminary designed, the Installation was adjusted manually with the help of a graphics software tool, representing an unknown type of material.

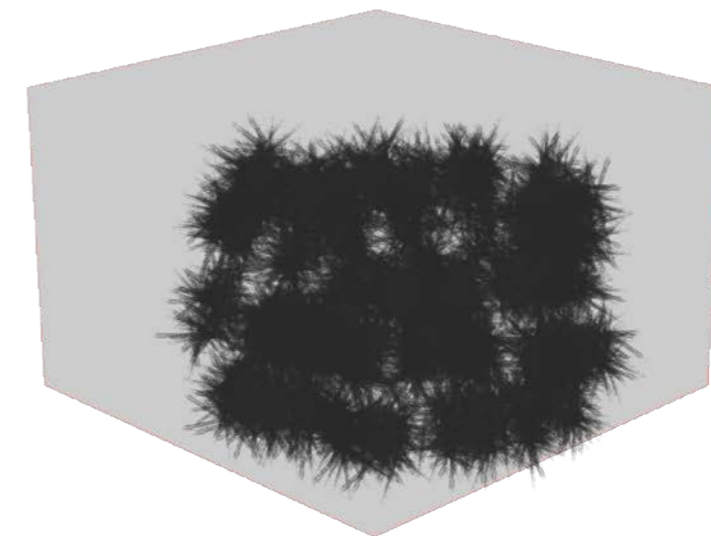
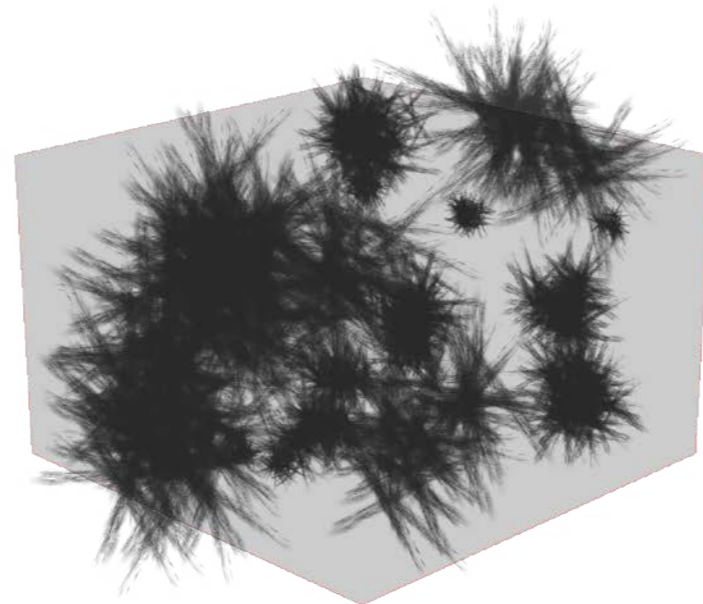
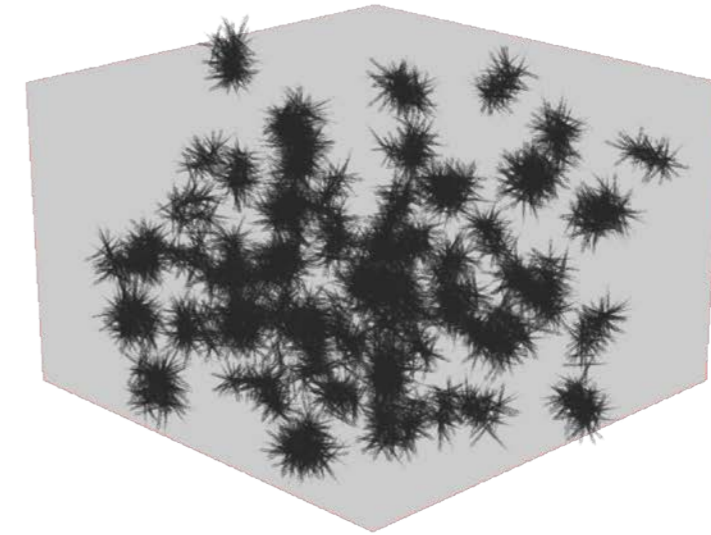
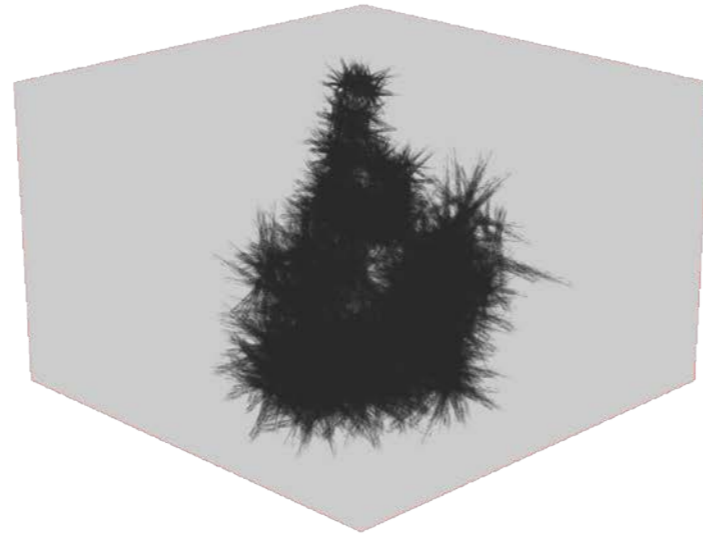


Figure 3.08 - Visualisation of generating the unknown according to first initial sketches part one

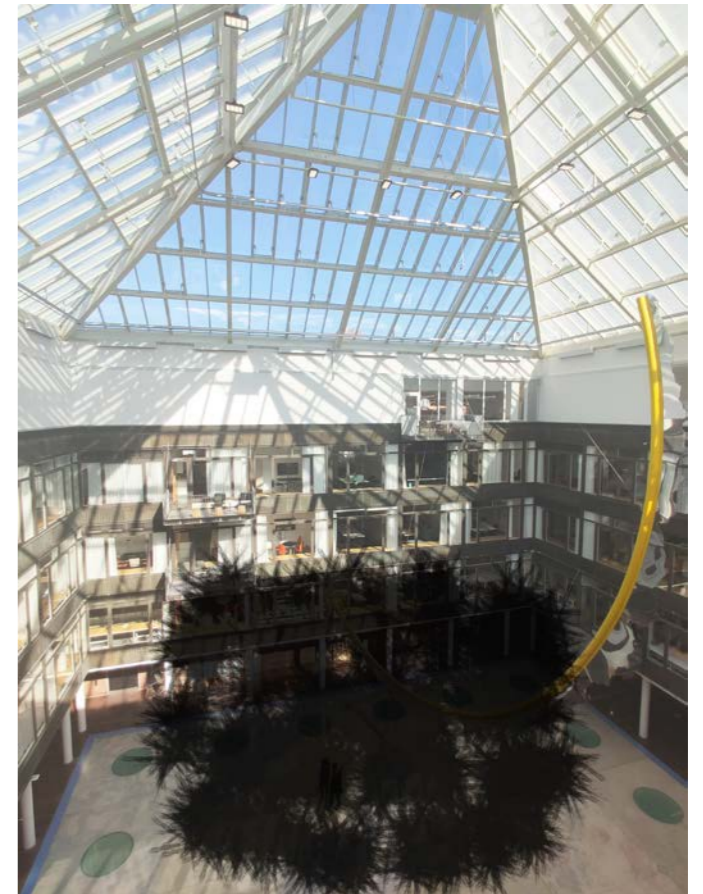
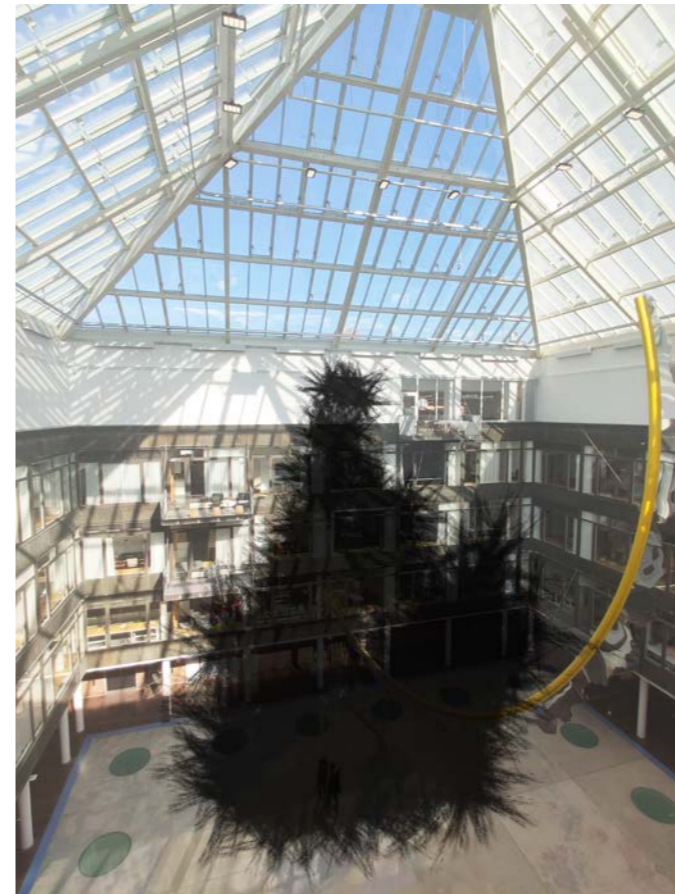




Figure 3.09 - Visualisation of generating the unknown according to first initial sketches part two

Re-evaluation of objectives

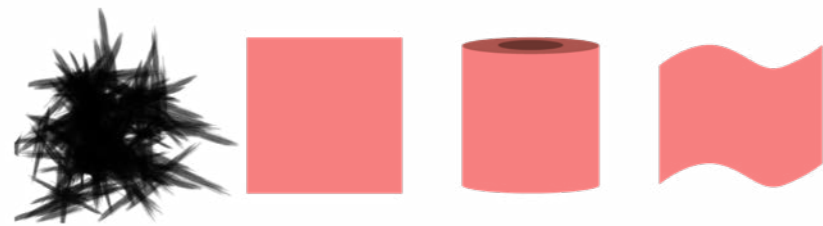


Figure 3.10 - Illustration of transformation from a unknown medium/object to a user defined geometrical form

Now that the thesis has established the preliminary design steps, the objectivity of the installation itself becomes more concrete. The three steps symbolise the equation of physical representation of generative design and GANs.

However, step three shows certain delimitations and flaws which are addressed before making the step towards a physical realm. If the installation is trying to symbolise an unknown object - something that humans are unable to comprehend - then how do represent that in a finished design? With this in mind, the characteristics of the transformation into the unknown is re-evaluated and concludes into the following: To transform the installation into the unknown, one does not have to design the unknown, but

let third-party users design the shapes, making it the unknown to the original author. The transformed shapes will then have a physical-virtual augmented substance that one need to alter.

Volumetric state changes

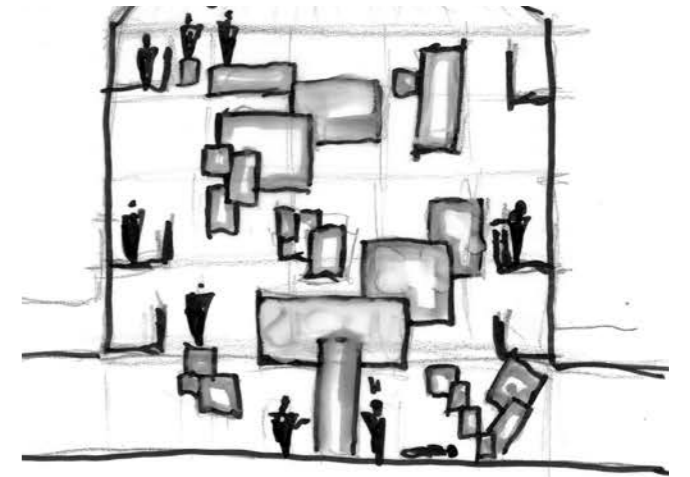
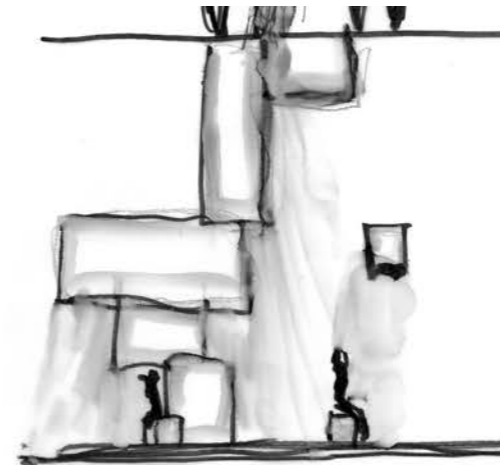
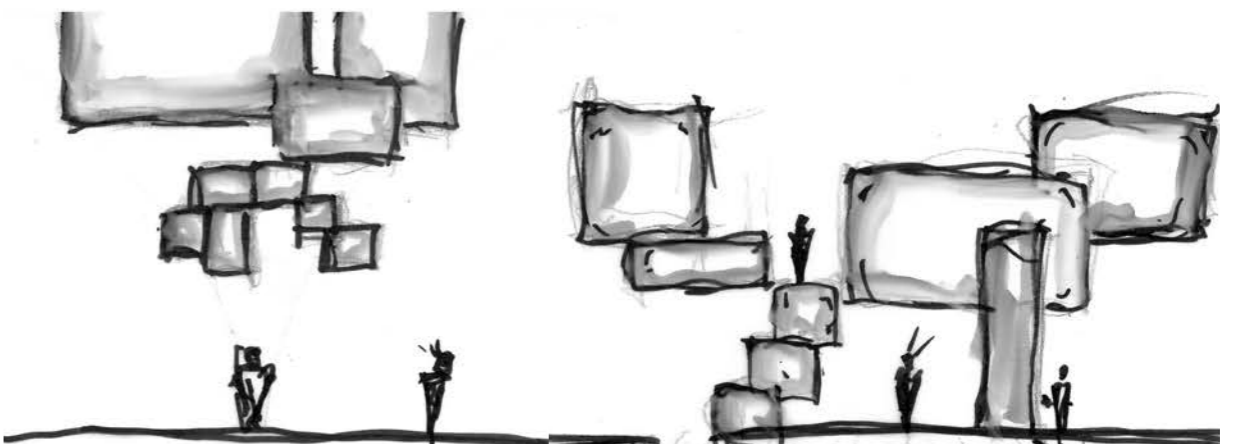
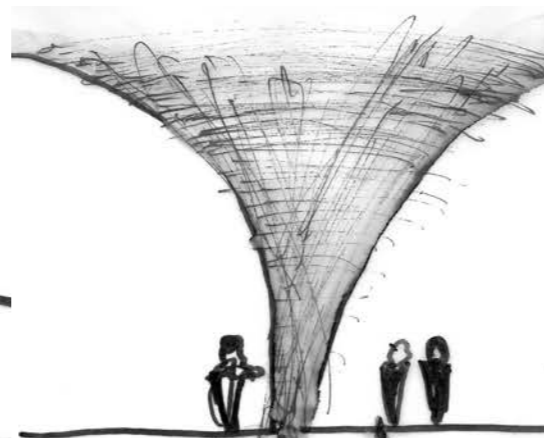
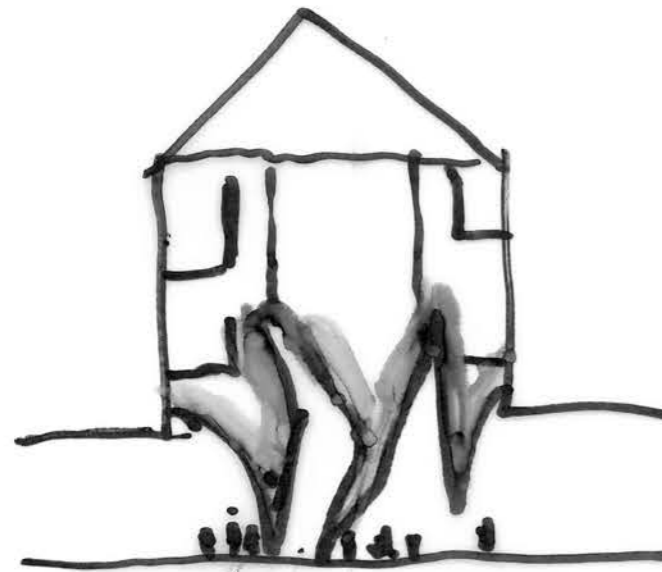
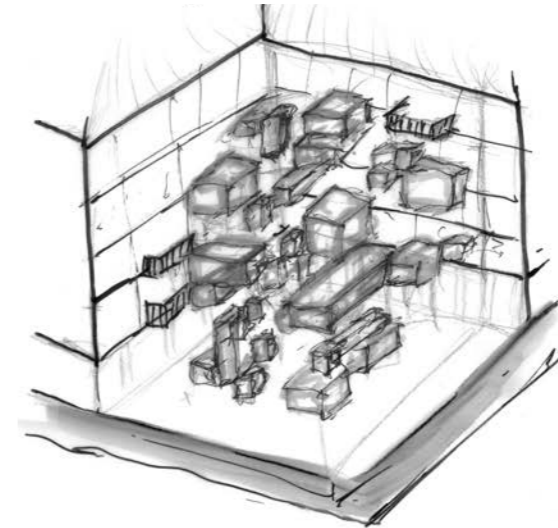
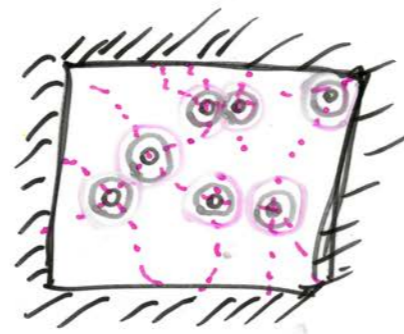
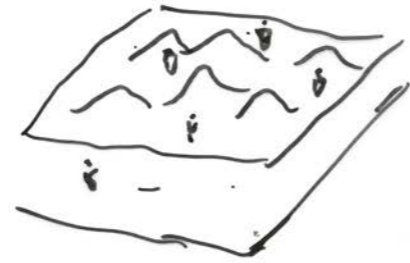
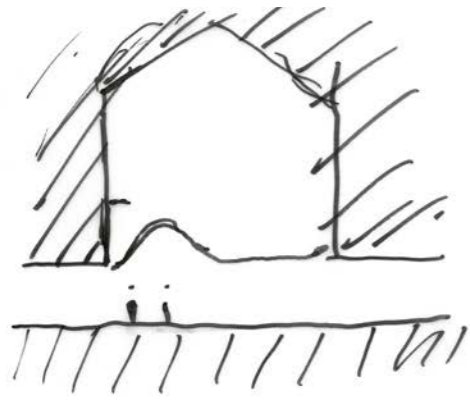
The re-evaluation of the objective concludes in using shapes that are easy to comprehend for the creators and visitors of the Installation. A new analysis concludes in a depiction of the characteristics that generative designs and my Installation will feature - instant state changes.

Figure 3.11 shows the theoretical mechanism behind the Installation.

On the left hand side, one can see the first trial, where tensile structures in addition to weights and magnets would have created the possibility for instant state changes, however, neglecting the aspect of various shapes that we previously determined is of great importance when working with generative design. The structure would react to peoples movement and expand in size according to how many people stand below it.

On the right hand side, the tensile structure is translated into the previous concept of independent shapes - in this case cubes. Using the potential of virtual architecture and different technology types one could achieve the flexibility of movement and size as the tensile structures had.

Figure 3.11 - Sketches of finding a form for the proposed installations



Design boundaries: Scale, randomness, shape

The further design alliterations, certain design boundaries are set that keep the project in the scope of generative design and to keep the project in the scope of reality to what is possible due to computer, project time and creative limitations.

Therefore, the three core concept ideas previously determined for generative designs have been put as these very limitations:

Scale:

1. Human scale
2. Monolithic scale
3. Full scale

Randomness:

1. Level 1 - low dilution
2. Level 2 - medium dilution
3. Level 3 - high dilution

Shape:

Pages 60-61 shows the types of shapes that will be used.

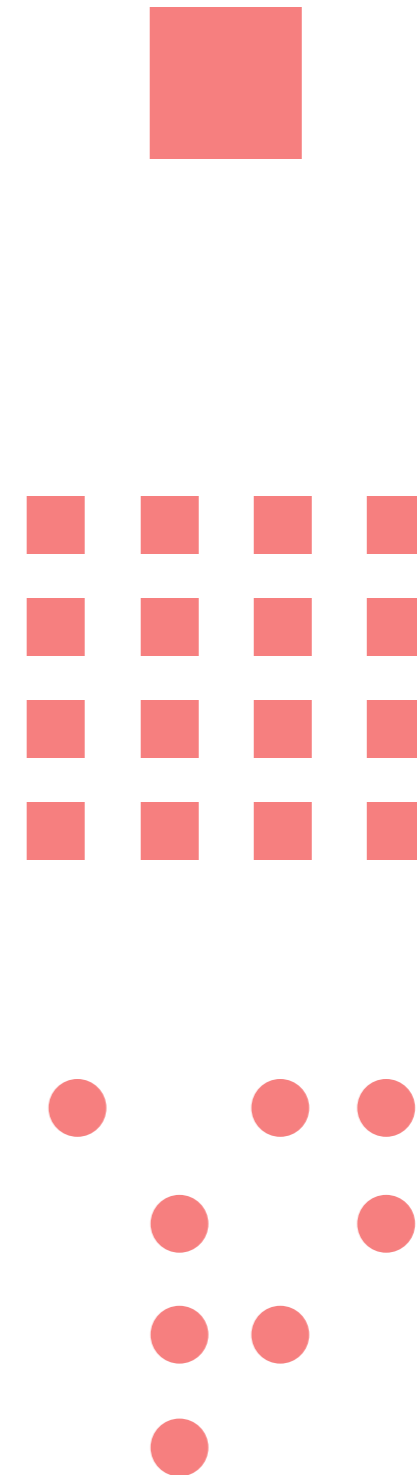


Figure 3.12 - Characteristics of a generative design; Defining the boundaries

04

Design project part one

A optioneered installation of radomeness

With the help of the investigative analysis of Generative Adversarial Networks and virtual reality and the pre-design steps: Representation of space, Composing elements and transformation of form, in addition to the three design methodologies: Scale, randomness and shape, the design in part one of this thesis establishes a experimental study on generative designs and their possible impact on our built environment in the near future. The three Installations, placed in the architecture department of Chalmers University of Technology a design proposals. However, this design project is not meant to be taken as an architectural proposal that must be realised in the given space, but is a concept design project that can, in future, be modified to suit any location and can be manipulated by any new author with new input data that transforms the composition of their own shape.

The design phase includes a computer algorithm that has been created in Grasshopper for Rhino 3D. This algorithm defines the metaphoric value of the GA in GANs. It is composed of five main elements: The creation of basic squares and volumes in the given space, adjusting the randomness of these squares, using BioMorpher to generate designs and designing two pairs of Installations, the solid subtraction of the two sets for more variation in the design objects and the transformation of the squares into different object types.

For the transformation of the squares into different object types, the algorithm uses a database of shapes fed into Rhino 3D and into Grasshopper. This database is a metaphoric translation of the database that DAs use in GANs in order to proof-read the generated material, created by the GA. While the database is an essential role to a GANs structure, this design project uses it as a tool to create more diverse designs. More on the objects selected for the algorithm is shown on pages 60-61.

The final Installations created using the software are translated into a virtual reality environment. There are two display-option scenarios. The first scenario uses virtual reality glasses and a own modelled physical space, which in the case of this thesis is the atrium area of the architecture faculty at Chalmers. The user submerges him/herself into an all digital environment and therefore, does not have to physically attend the atrium area in order to see the Installations. The second scenario uses augmented reality glasses which project the generated Installations onto the eyes of the user, tracking the movement of the person through the atrium area, adjusting the viewing angle on the Installations.

The Installations of part one of this thesis are static virtual objects that do not have the capability of interaction with the user other than feeding information into the algorithm.

Figure 4.01 - Participatory projects, their authors and descriptions of the project

Participating of architects around the globe

Participatory models from friends and colleagues, who are all in working or studying architects, are used to transform the cubes into the provided shape. This participatory action is needed to ensure that the design process done by the author himself is minimized and the autonomous generative design concept of this thesis stays cohesive.

As one can see in Figure 4.01, the participants are divided up into three rows. Each row is the equivalent of one design proposal. The models from each row have their own generated Installation and were then merged to create alternative compositions due to the subtraction of intrusions in the merging process.

The finished Installations are sent to the participants for their personal use at home to feed into their digital environments.

In future alterations with further research done on the algorithm used in Grasshopper, the participants are exchanges with a large database of finished projects that automatically feed into the algorithm. However, with the availability of chosen the right shape for this level of a design project, one ensures that the computer processing power available can handle the shapes fed into the algorithm.



Author: Anton A.
Nationality: Sweden
Description: A digital sculpture based on the shape and deconstruction of wind turbine towers.



Author: Frans H.
Nationality: Sweden
Description: A foot for a public light post. One surface was supposed to be unique for every time it was printed.



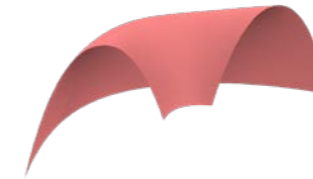
Author: Goda V.
Nationality: Lithuania
Description: Facade brick 315x120x60mm. These clay bricks suspended by steel cables form a facade shading system in my project.



Author: Toni G.
Nationality: Romania
Description: I used this kind of shaped made out of wood for a footway in a garden.



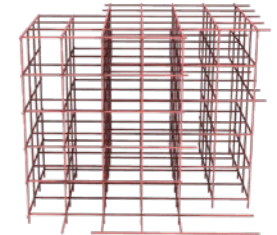
Author: Beatrice D.
Nationality: Romania
Description: A wind shelter placed on Tidan's river bank, in Mariestad, Sweden, which will protect against wind, rain, snow and noise from the industry.



Author: Olga H.
Nationality: Ukraine
Description: A Installation (...) for interaction and expression (...) to exploring movement as a form of communication.



Author: Matteo B.
Nationality: Italy
Description: The result of a workshop to learn how to make a survey by using photogrammetry, in order to make earthquake proof project for museum.



Author: Pattaraporn T.
Nationality: Thailand
Description: A scaffolding that holds units, representing cells in the nature.



Author: Khaled H.
Nationality: Syria/UK
Description: This is a model of previous Grasshopper works



Author: Emanuele T.
Nationality: Italy
Description: A pac-man model, created for Lars to use.



Author: Aleksej B.
Nationality: Sweden
Description: This is a donut, with strawberry filling on the inside. The ingredients are jam and donut dough, that were farmed and made sustainably.



Author: Eda S.
Nationality: Turkey
Description: This structure is part of the timber production and boat-building workshop in Govan Transforming communities through craftsmanship.



Figure 4.02 - Visualisation of Installation one



Figure 4.03 - Visualisation of Installation two

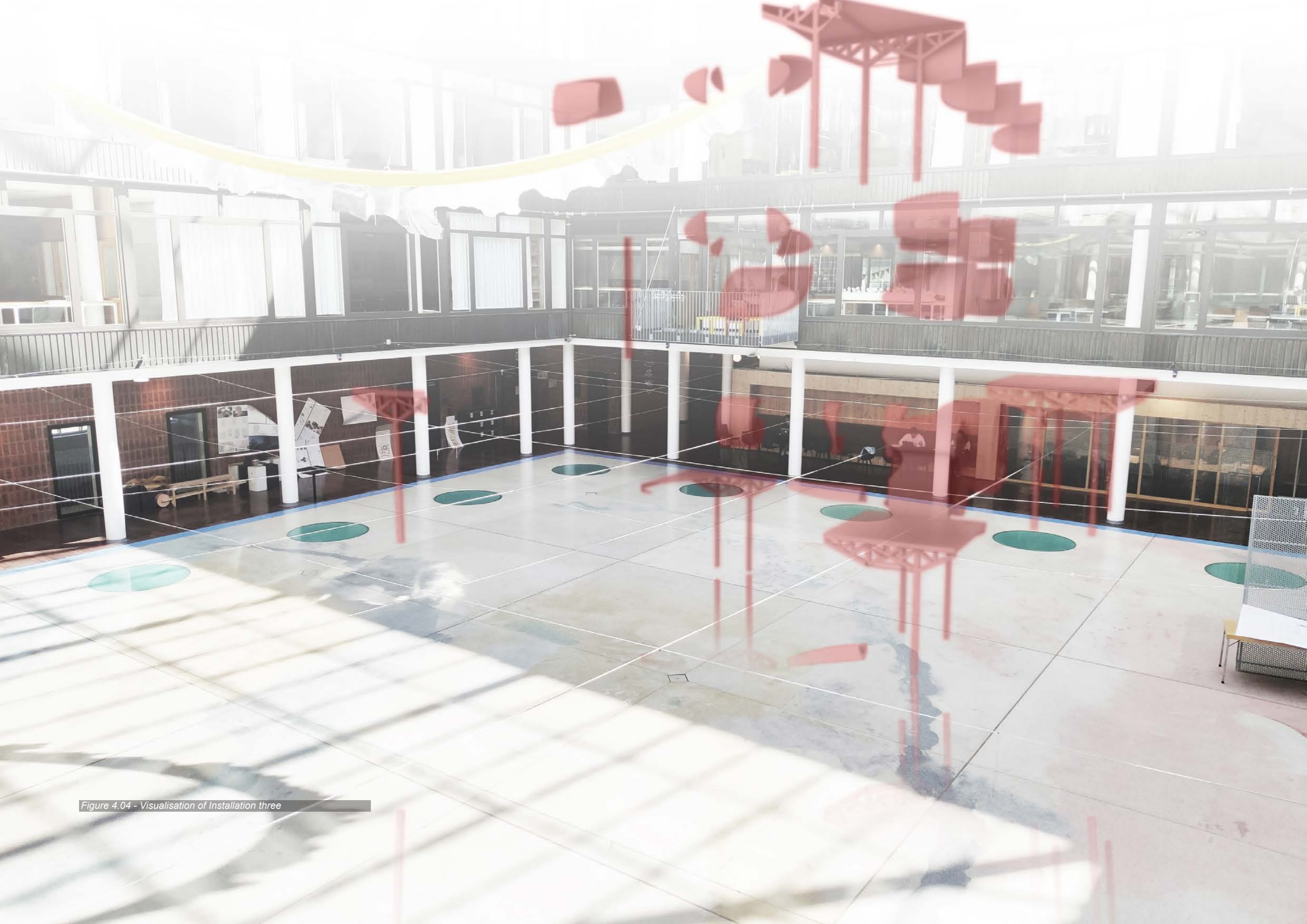


Figure 4.04 - Visualisation of Installation three

Figure 4.05 - Participatory projects, their authors for the first proposed Installation and Isometric views of the merged Installation one

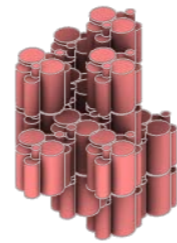
Installation one

The first Installation is made up by contributed models of Anton A. from Sweden, Frans H. from Sweden, Toni G. from Romania and Goda V. from Lithuania. Figure 4.05 shows the used shapes, the individual generated Installations for each shape and the isometric view of the final merged Installation. For part one of the design proposal of this thesis, each shape starts off with a individually generated Installation, where the shape gets copied, distributed in random orders to a fixed dimension and then all of the copied are scaled up to the same scale factor. However, every participants shape gets an own scale factor. This results in a shape like a brick being larger than the food of a light post. When merged and subtracted from each other by the algorithm, the final Installation created offers newly defined geometries. Due to the use of a box-like structure as a scaling limited geometry, shapes such as the brick structure from Goda V. has been scaled up unproportionally, resulting in a geometry that does not resembles the original shape.

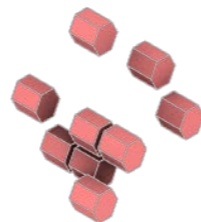
This installation has the human-scaled option, therefore having a fixed maximum dimensions of 3 x 3 x 3 meters.

Anton A.'s shape has a dimension of 1 x 1 x 1 meters. Frans H's shape has a dimension of 0.6 x 0.6 x 0.6 meters. Toni G's shape has a dimension of 0.7 x 0.7 x 0.7 meters. Goda V.'s shape has a dimension of 0.5 x 0.5 x 0.5 meters.

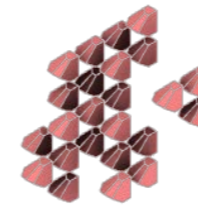
Anton A.



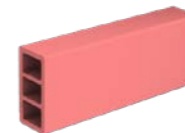
Toni G.



Frans H



Goda V.



Isometric view

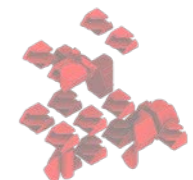
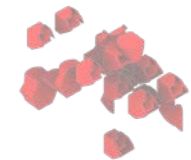
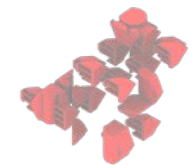
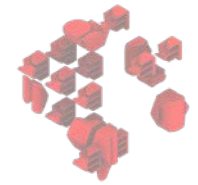
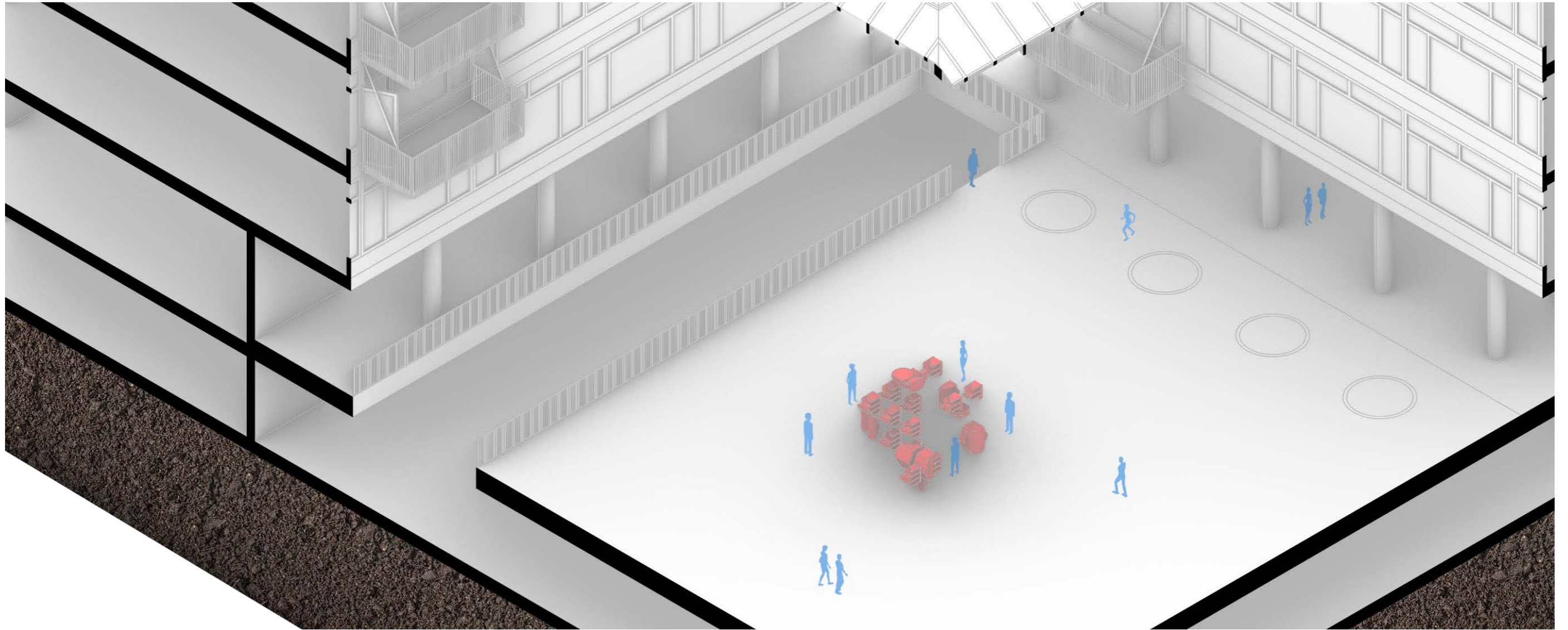


Figure 4.06 - Isometric view on installation one



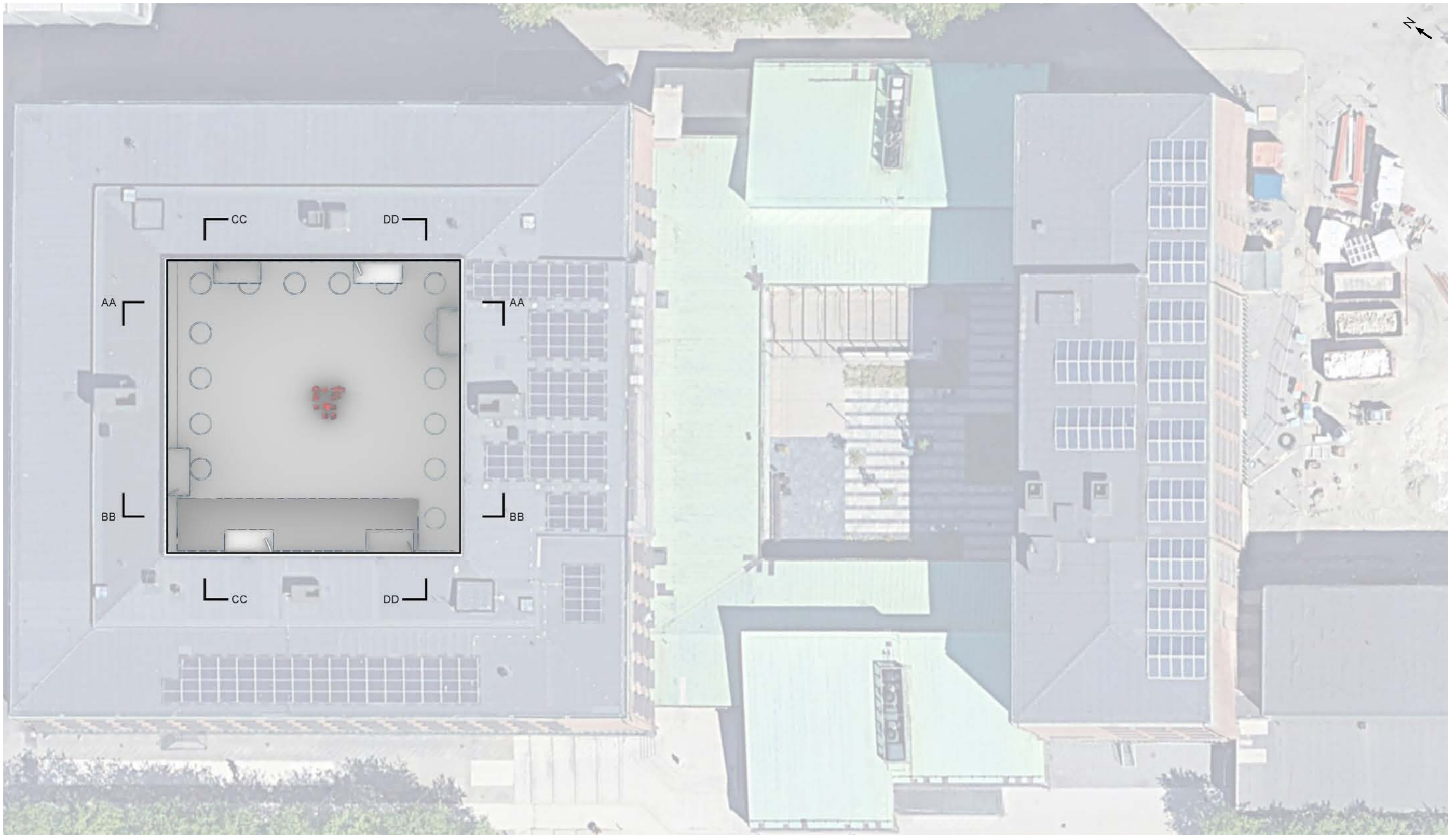


Figure 4.07 - Site plan of the university campus with a visualisation of Installation one place into the atrium
 Image courtesy to Google.com

1:350 0 4 8 12 16 20m

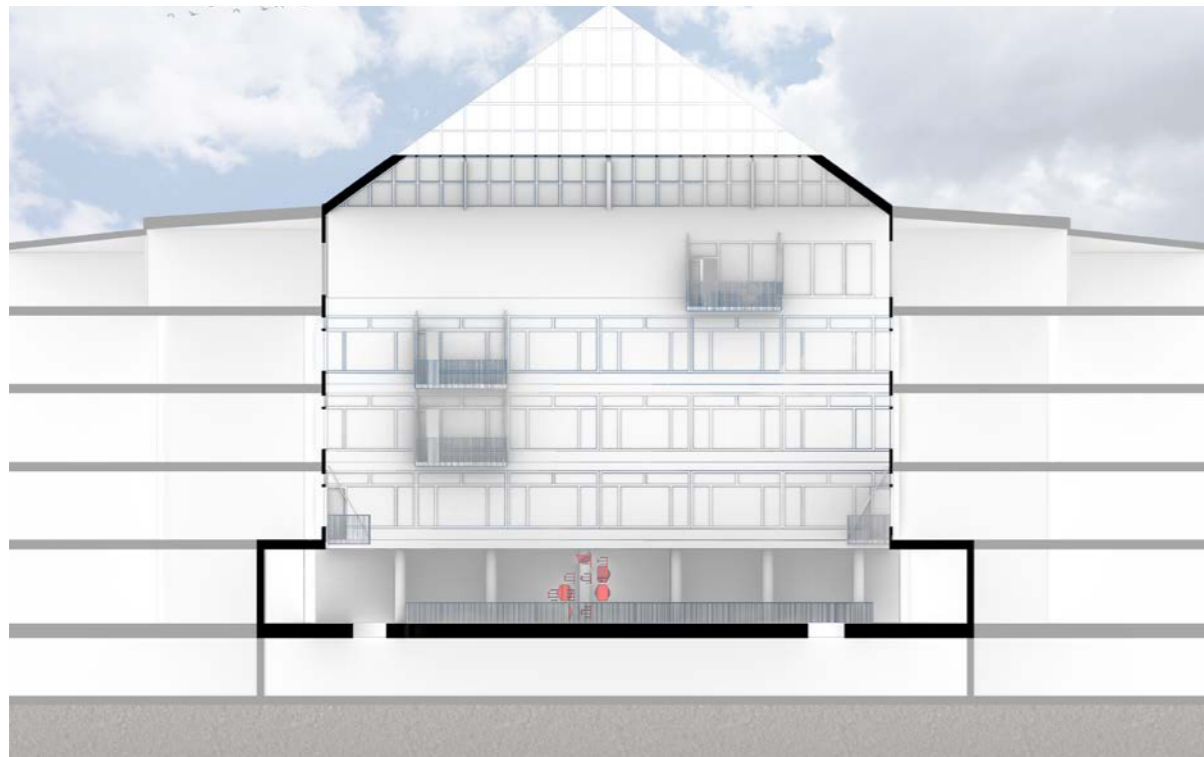


Figure 4.08 - East elevation AA of Installation one and the atrium 1:350 0 4 8 12 16 20m

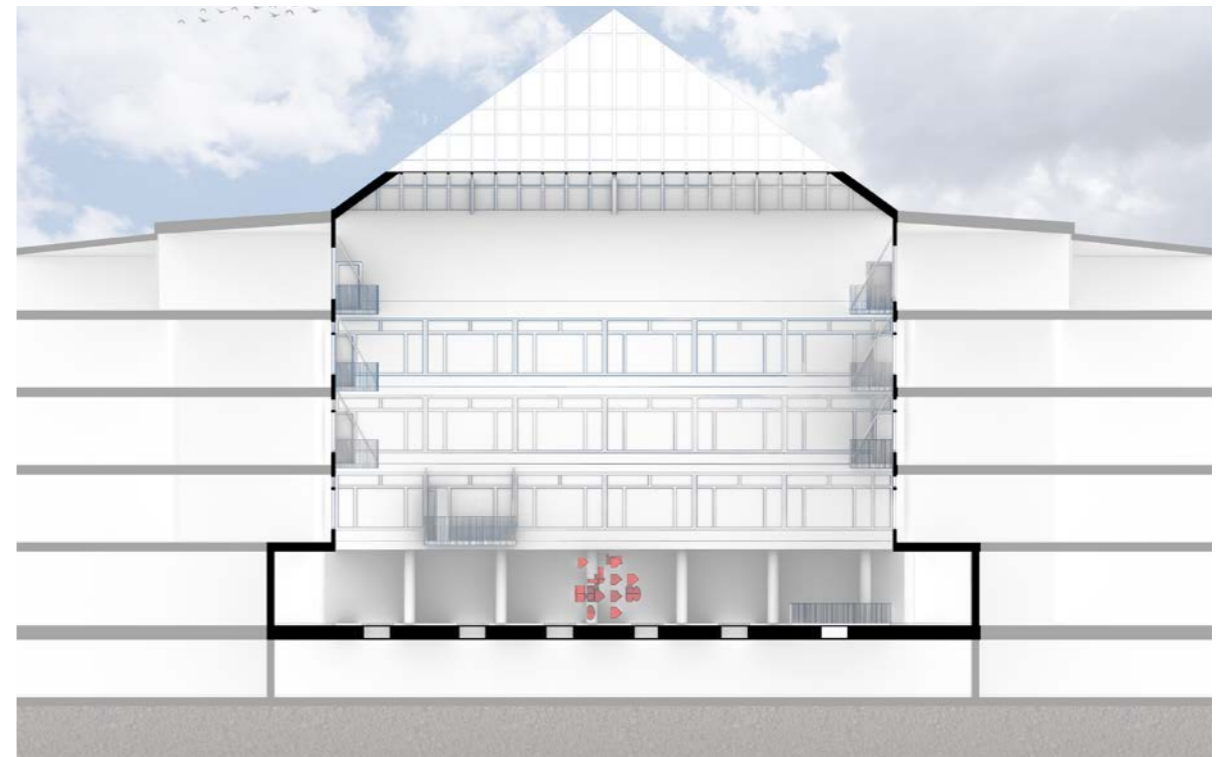


Figure 4.10 - West elevation CC of Installation one and the atrium 1:350 0 4 8 12 16 20m



Figure 3.09 - South elevation BB of Installation one and the atrium 1:350 0 4 8 12 16 20m

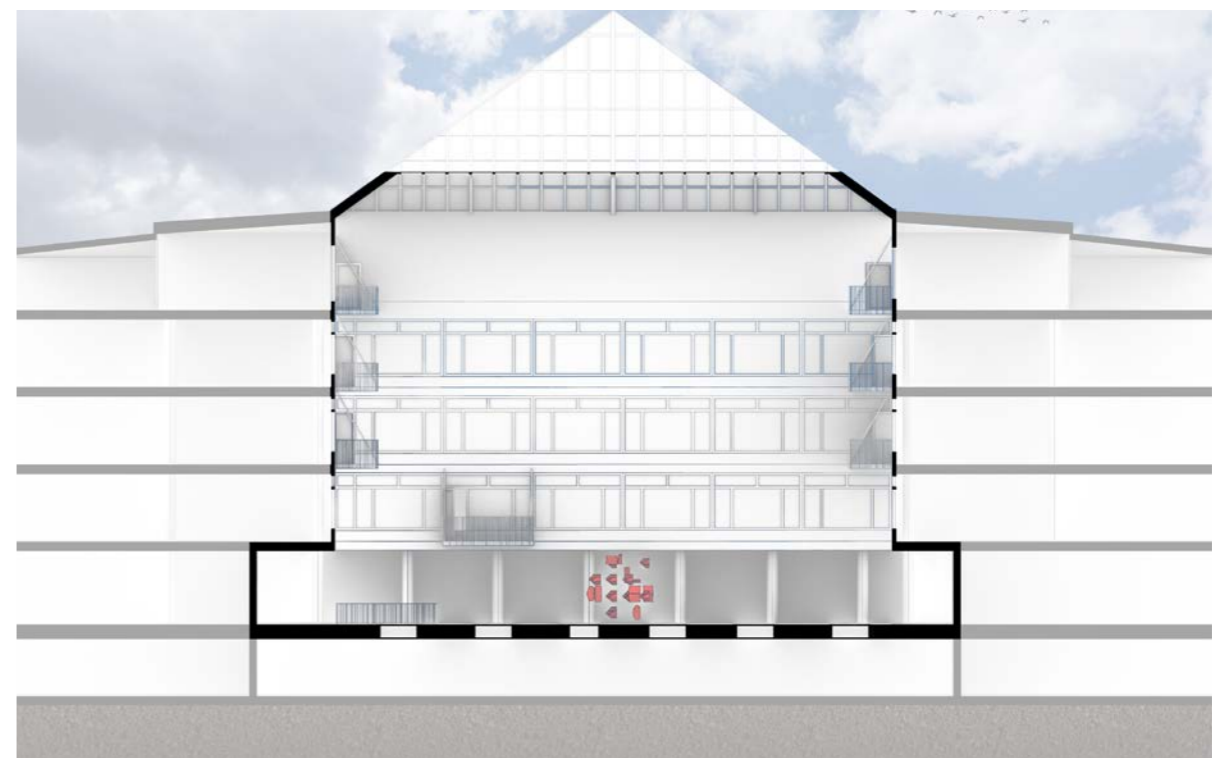


Figure 4.11 - North elevation DD of Installation one and the atrium 1:350 0 4 8 12 16 20m

Figure 4.12 - Participatory projects, their authors for the first proposed Installation and Isometric views of the merged Installation two

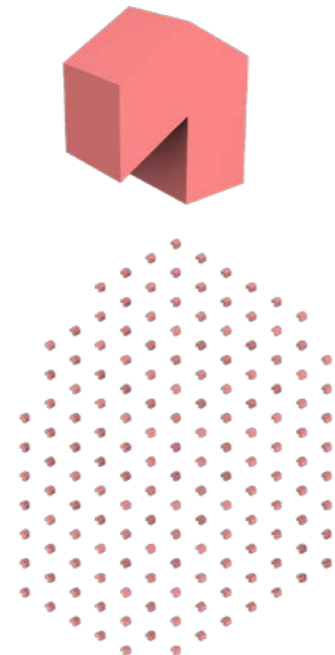
Installation two

The first Installation is made up by contributed models of Beatrice D. from Romania, Olga H. from Ukraine, Matteo B. from Italy and Pattaraporn T. from Thailand. Figure 4.12 shows the used shapes, the individual generated Installations for each shape and the isometric view of the final merged Installation.

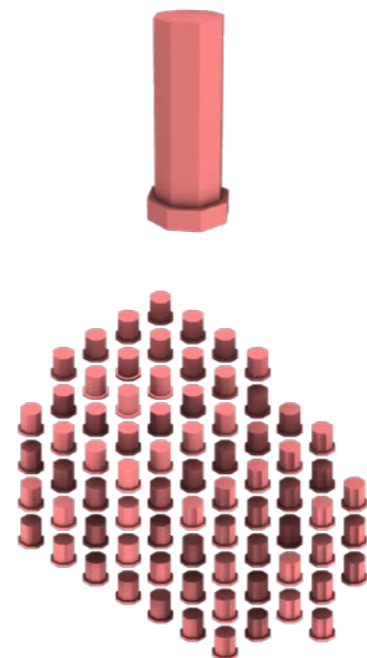
This installation has the full-scaled option, therefore having a fixed maximum dimensions of 12 x 12 x 15 meters.

Beatrice D.'s shape has a dimension of 0.3 x 0.3 x 0.3 meters. Olga H.'s shape has a dimension of 1.5 x 1.5 x 1.5 meters. Matteo B.'s shape has a dimension of 1.1 x 1.1 x 1.1 meters. Pattaraporn T.'s shape has a dimension of 3.2 x 3.2 x 3.2 meters.

Beatrice D.



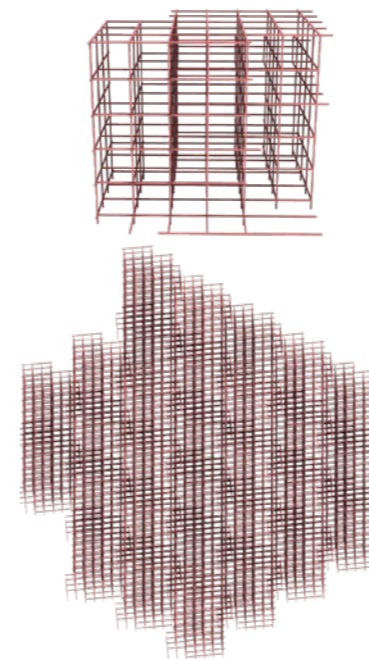
Matteo B.



Olga H.



Pattaraporn T.



Isometric view

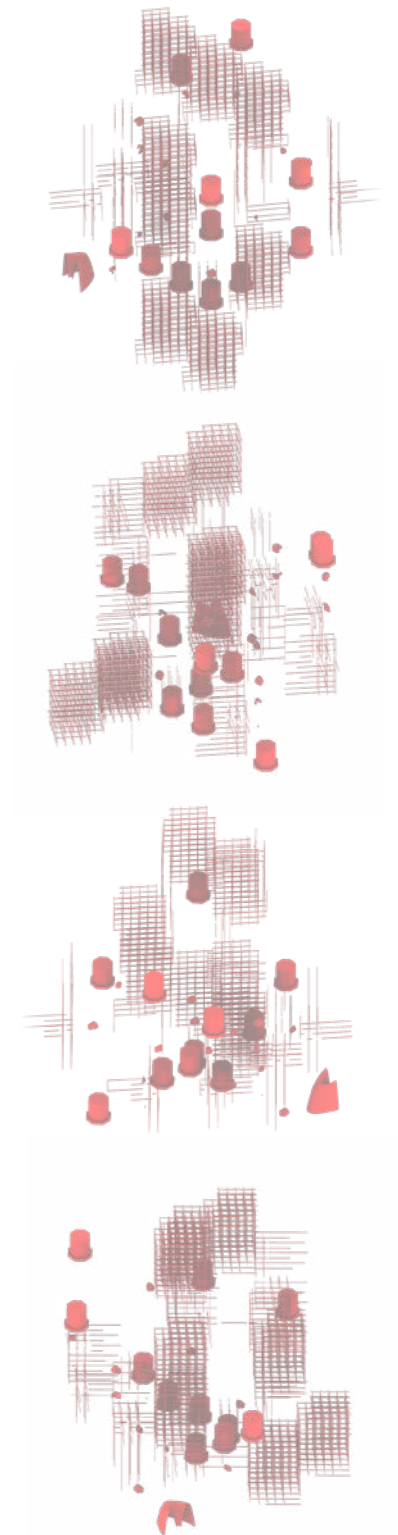
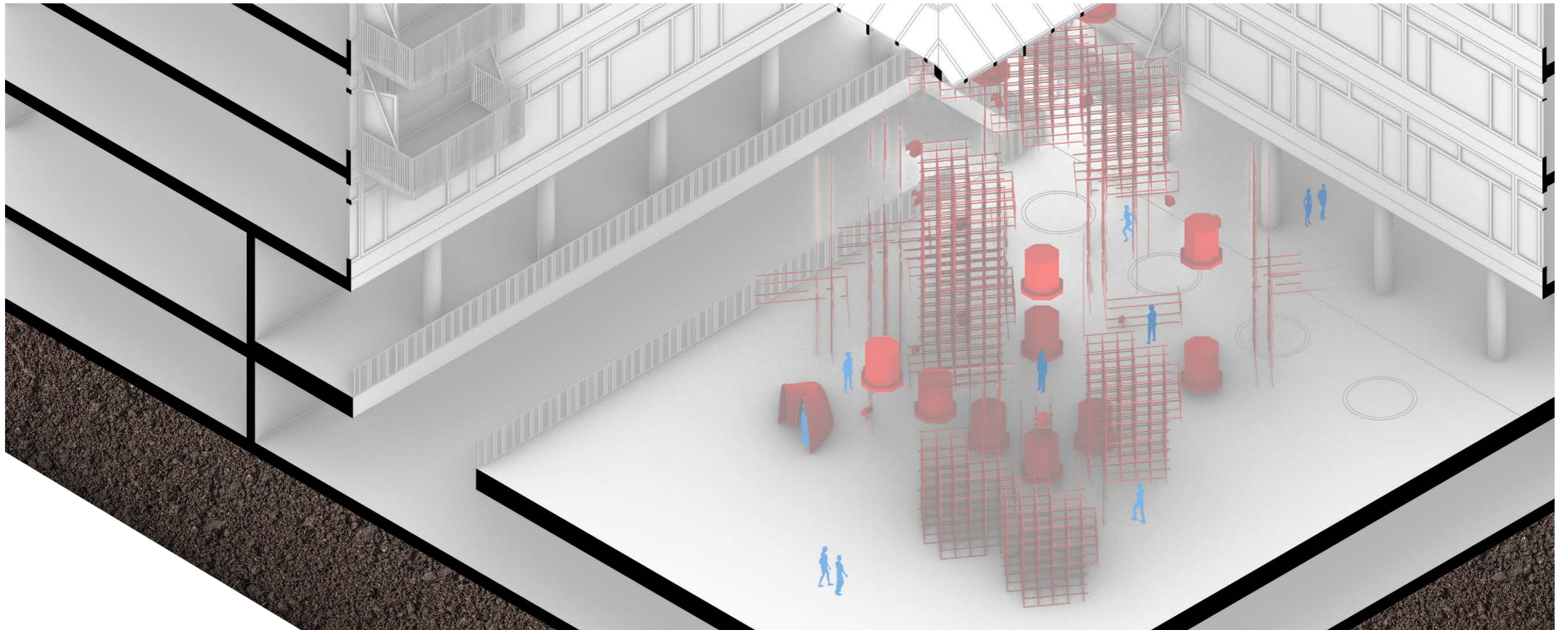


Figure 4.13 - Isometric view of installation two



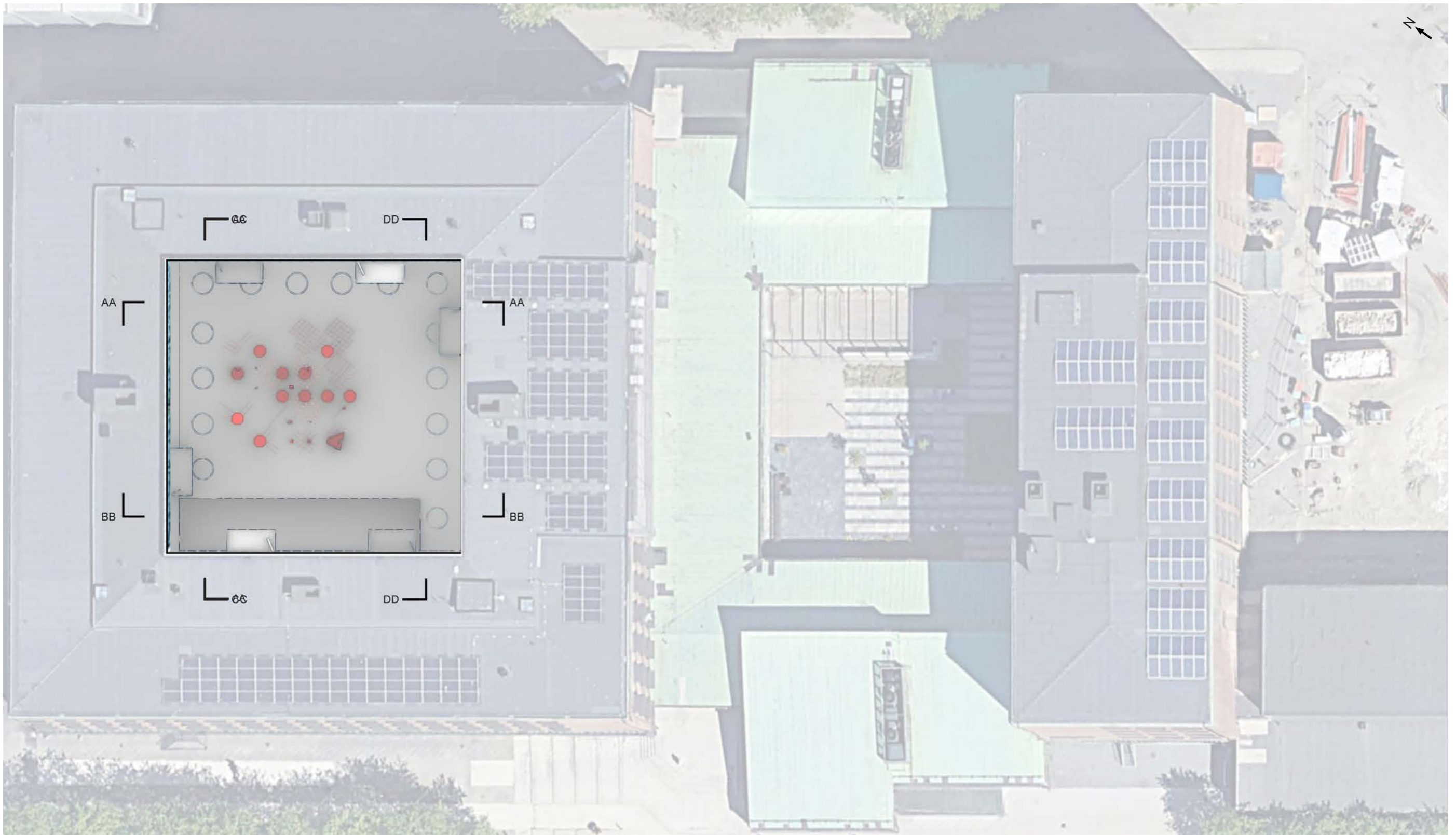


Figure 4.14 - Site plan of the university campus with a visualisation of Installation two place into the atrium
 Image courtesy to Google.com

1:350 0 4 8 12 16 20m

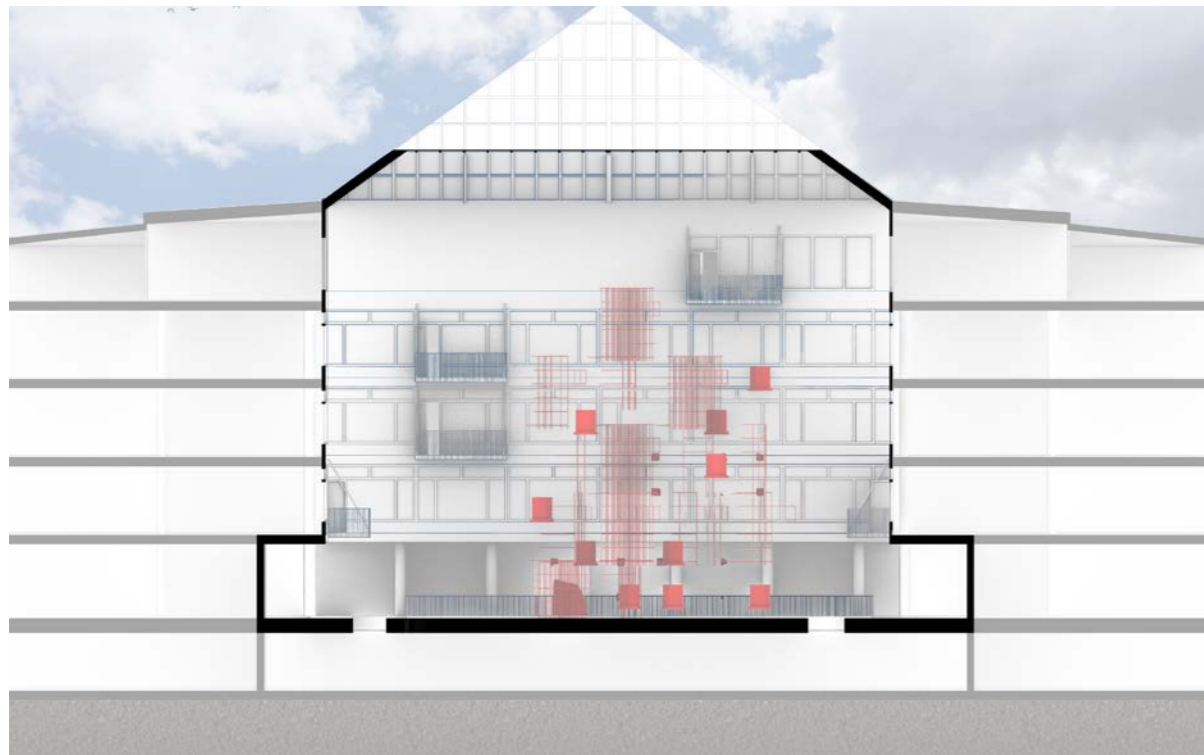


Figure 4.15 - East elevation AA of Installation two and the atrium 1:350 0 4 8 12 16 20m

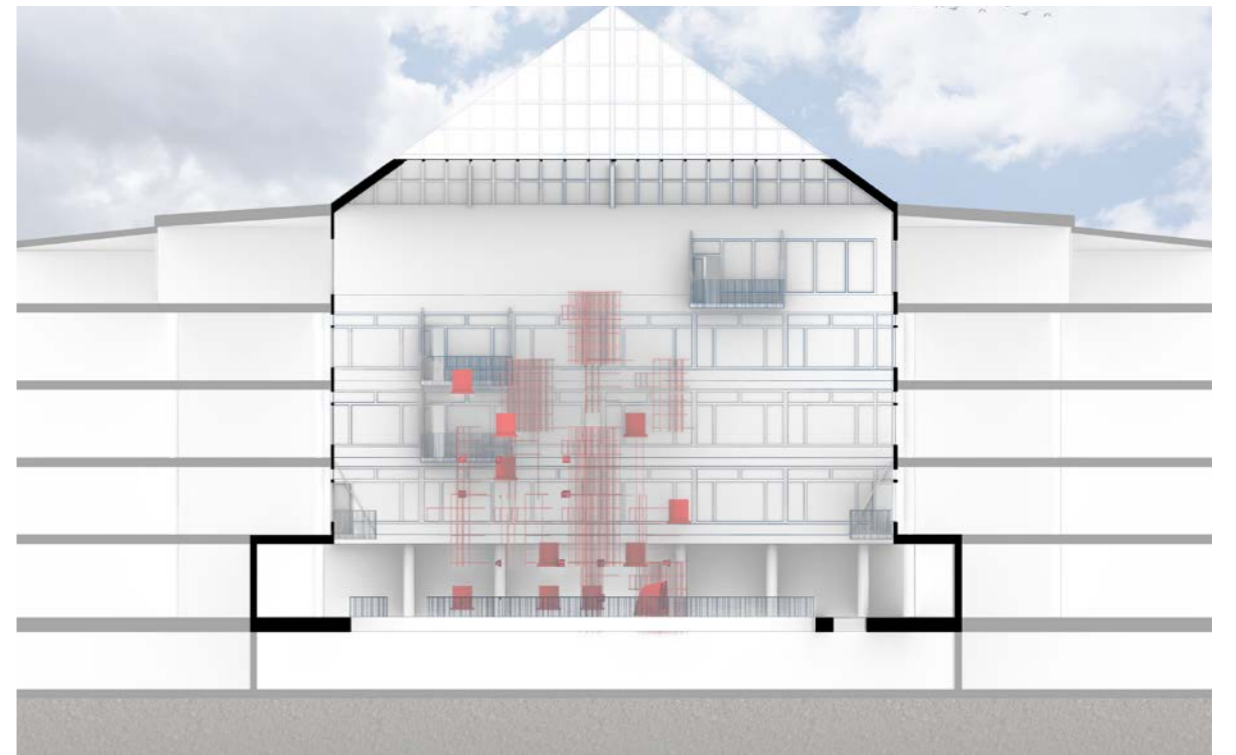


Figure 4.17 - West elevation CC of Installation two and the atrium 1:350 0 4 8 12 16 20m

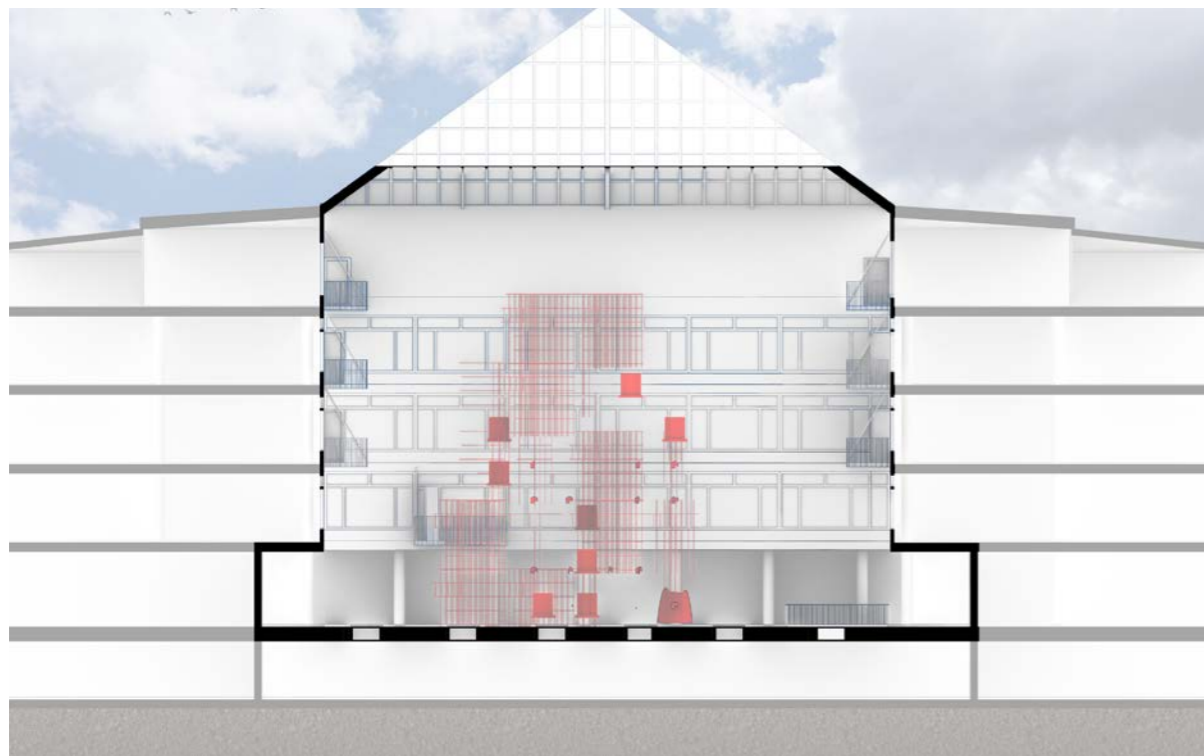


Figure 4.16 - South elevation BB of Installation two and the atrium 1:350 0 4 8 12 16 20m

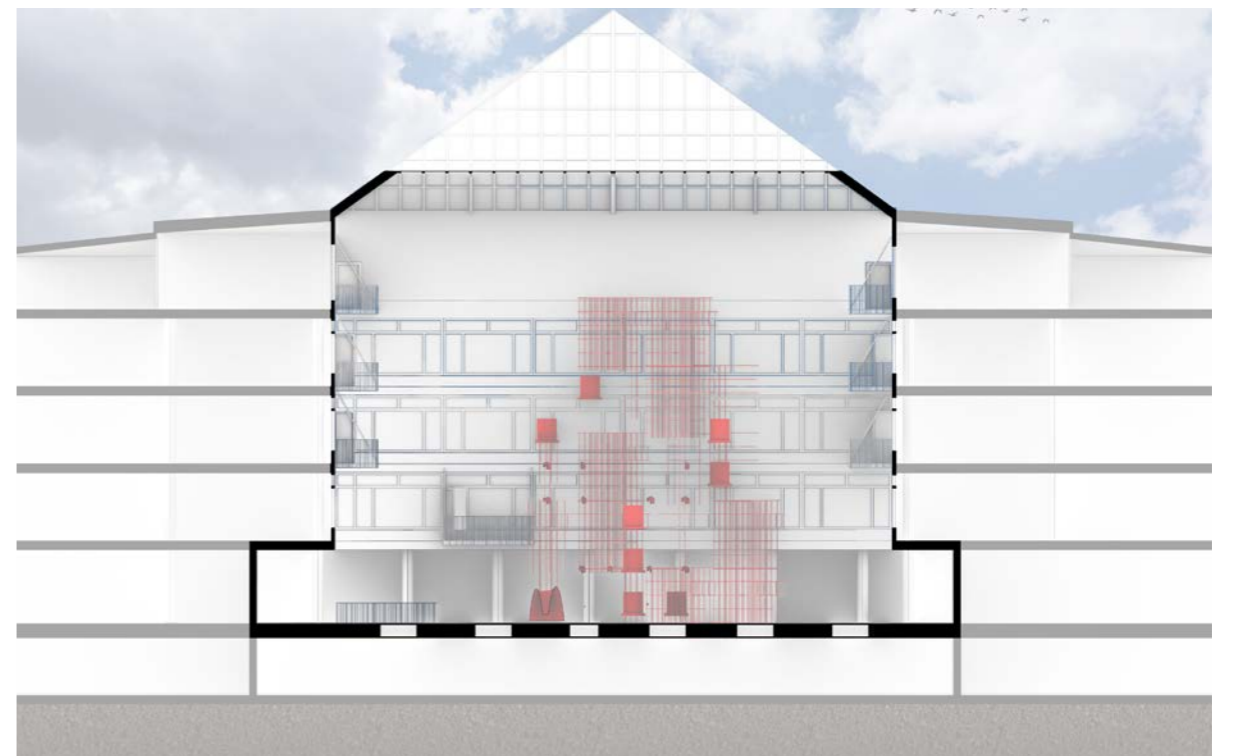


Figure 4.18 - North elevation DD of Installation two and the atrium 1:350 0 4 8 12 16 20m

Figure 4.19 - Participatory projects, their authors for the first proposed Installation and Isometric views of the merged Installations three

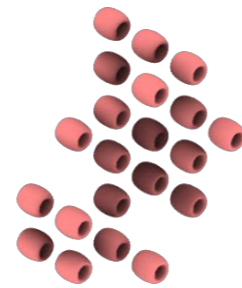
Installation three

The third Installation is made up by contributed models of Aleksej B. from Sweden, Emanuele T. from Italy, Eda S. from Turkey and Khaled H. from Syria/UK. Figure 4.19 shows the used shapes, the individual generated Installations for each shape and the isometric view of the final merged Installation.

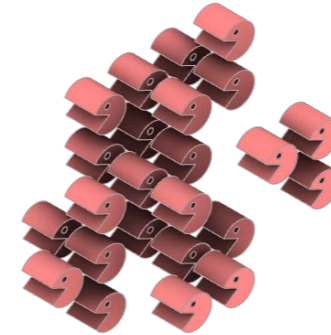
This installation has the monolithic-scaled option, therefore having a fixed maximum dimensions of 10 x 10 x 12 meters.

Aleksej B.'s shape has a dimension of 0.9 x 0.9 x 0.9 meters. Emanuele T.'s shape has a dimension of 1.2 x 1.2 x 1.2 meters. Eda S.'s shape has a dimension of 1.6 x 1.6 x 1.6 meters. Khaled H.'s shape has a dimension of 0.9 x 0.9 x 0.9 meters.

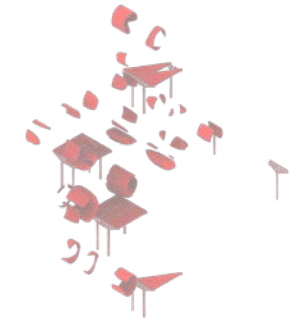
Aleksej B.



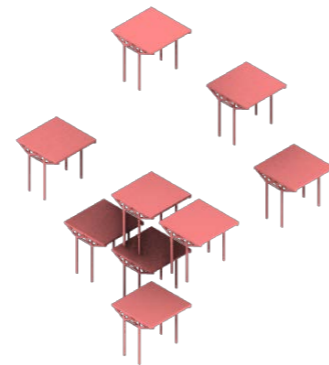
Emanuele T.



Isometric view 1



Eda S.



Khaled H

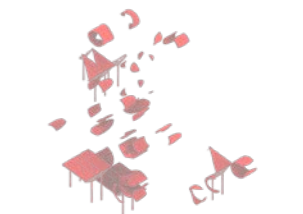
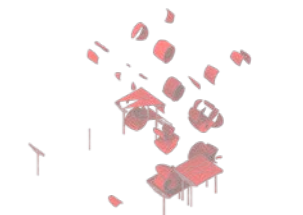
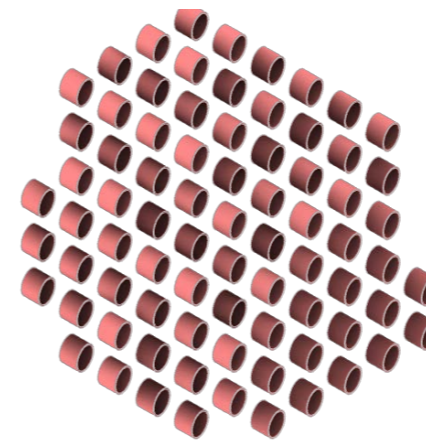
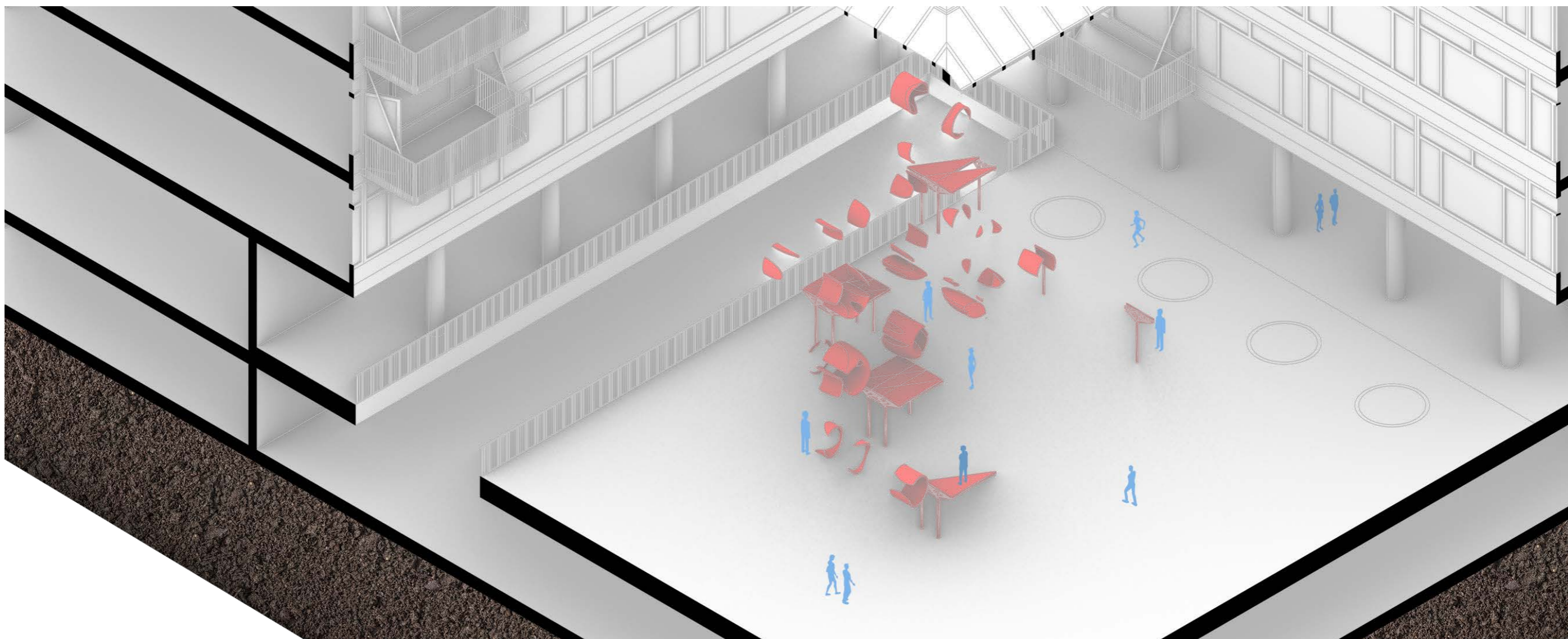


Figure 4.20 - Isometric visualisation of installation three



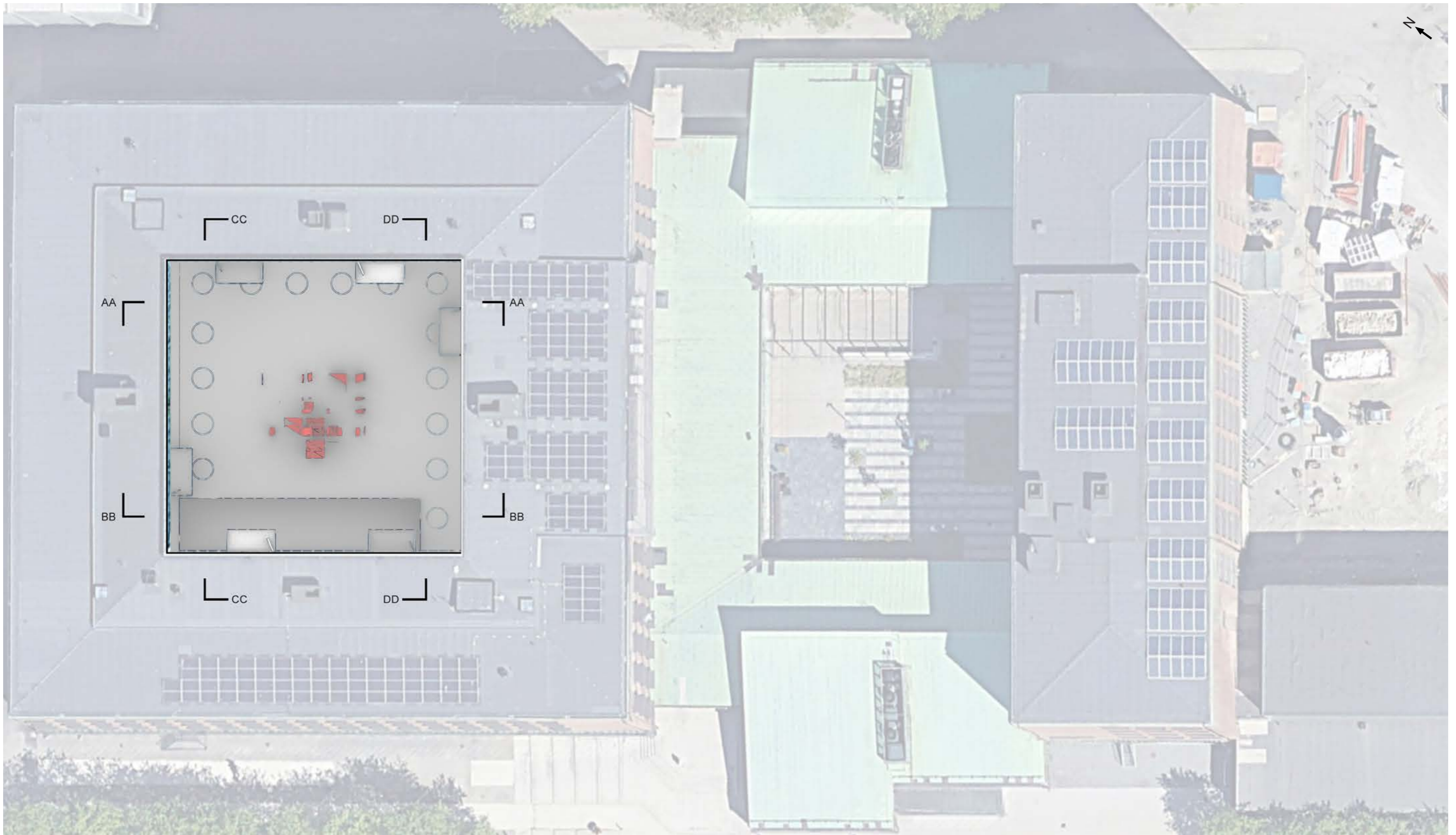


Figure 4.21 - Site plan of the university campus with a visualisation of Installation three place into the atrium
 Image courtesy to Google.com

1:350 0 4 8 12 16 20m

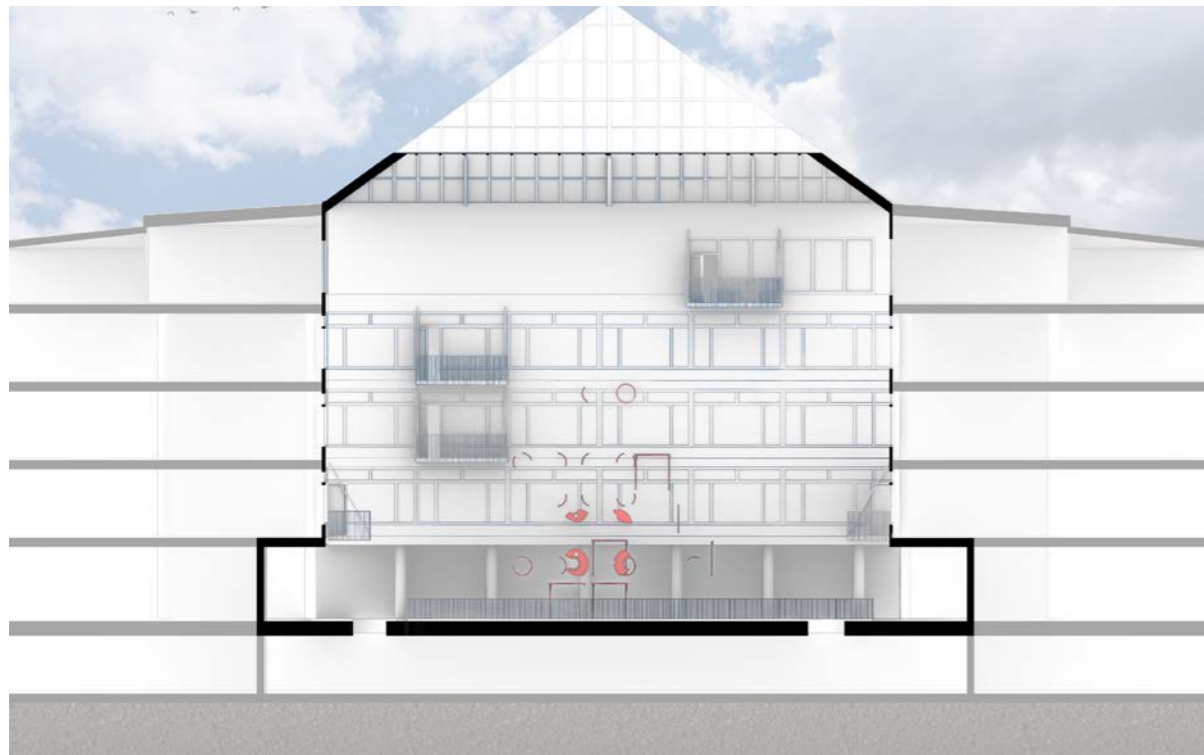


Figure 4.22 - East elevation AA of Installation three and the atrium 1:350 0 4 8 12 16 20m



Figure 4.24 - West elevation CC of Installation three and the atrium 1:350 0 4 8 12 16 20m

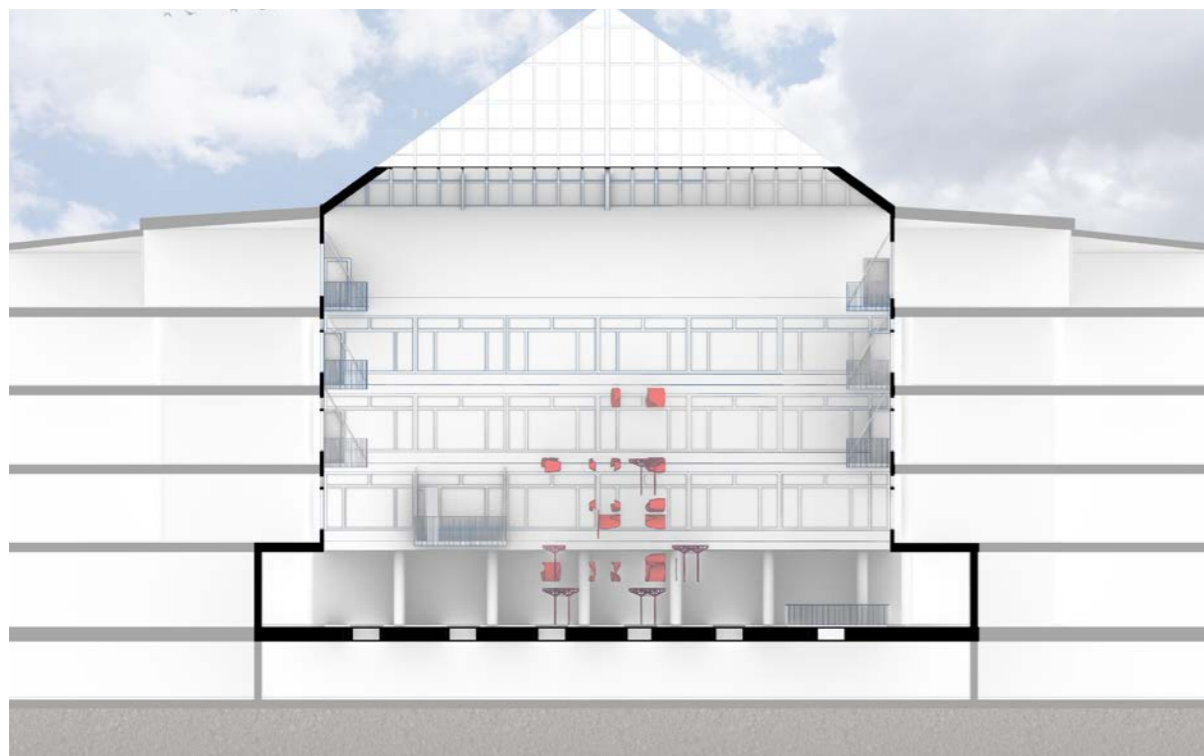


Figure 4.23 - South elevation BB of Installation three and the atrium 1:350 0 4 8 12 16 20m

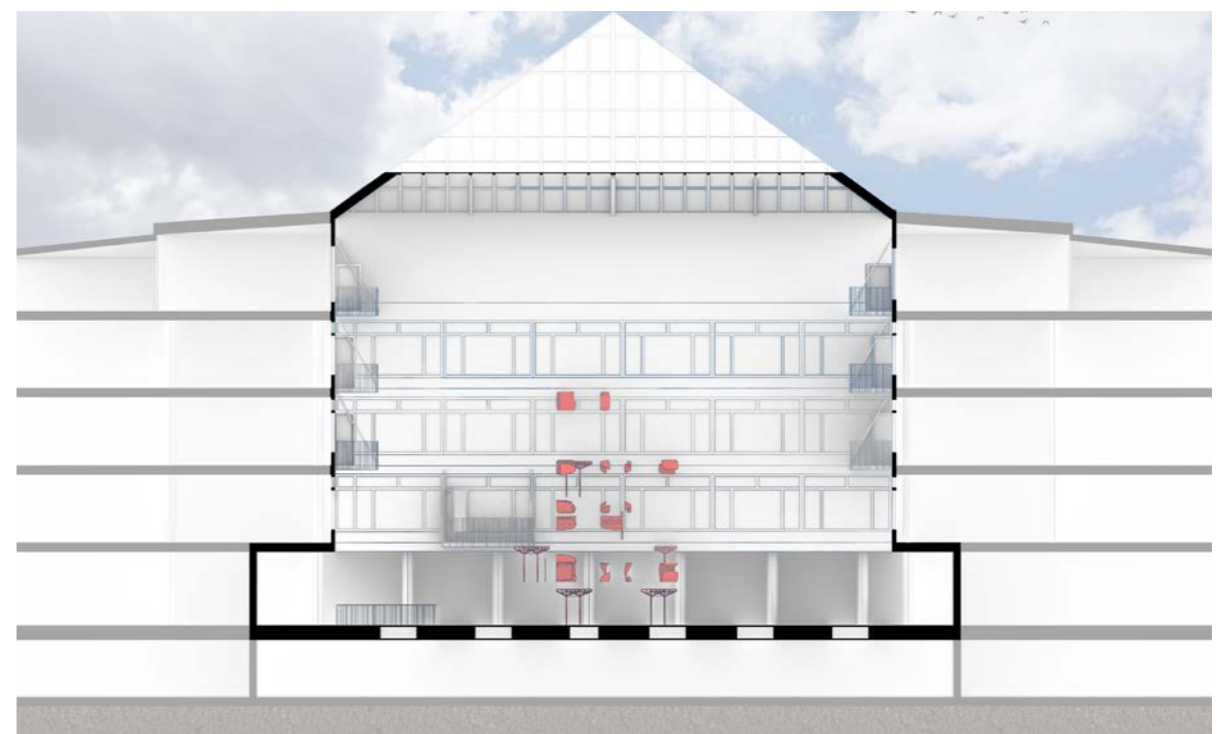
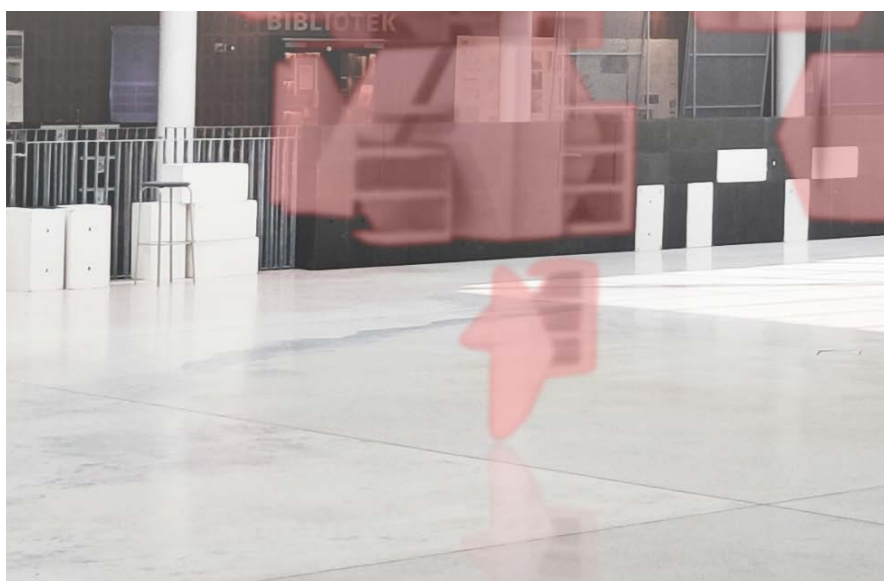


Figure 4.25 - North elevation DD of Installation three and the atrium 1:350 0 4 8 12 16 20m

Figure 4.26 - Zoom-In visualisations of the three proposed Installations



05 Design Project Part Two

Dynamizing the Installations

The establishment of a working generative design installation has been realised in the first part of the design project. A set of three installations has been generated, which will function as a introduction to the second step of the design project. Those three installations fulfill the function of the first metaphoric value of the use of Machine Learning and GAN's in architecture and design : The ability to create autonomously designs by supplying the system with a large enough database to work with.

The second metaphoric notion that this thesis works with is the concept of altering these generations of designs by a non-intrusive interactions. This resembles the concept of the latent space that GAN's use that define visual outcome of the finished design. Further on the latent space design can be read on pages 94-95.

Kas Oosterhuis, a Dutch architect and one of the visionaries that saw the potential of IA as a tool of future design proposals, acknowledged that fact that the future of our built environment will be programmable, in form and substance and that the interaction between users and designs will become more important in near future, without intruding our everyday lives with the help of smart devices. What many of the architects of his generation didn't fully know back in the early 1990s and 2000s was how to turn the theoretical thought into a working practice, i.e. how can materials change their substance.

“
Let's image that buildings could move with changes in use, more so that was considered possible before now, that they could move with changing conditions.
”

(Kas Oosterhuis, 2001)

With the development of virtual reality, augmented reality and hyper-connected smart devices, the ideas of Oosterhuis are now becoming reality.¹²

By including the concept of a Self-Regulating-System, the installations of part one of this thesis are turned into installations which don't remain static, fixed in one position, but they will function as a visual representation of movement that highlight clusters of people moving through the atrium of the architecture department to identify spaces that are overfilled. Figure 5.01 represents the Multi-Agent Interactive system used in the theoretical project and Figure 5.02 shows the precision and data recorded by the camera tracking system. The system detects the amount of people in relation to their distance.

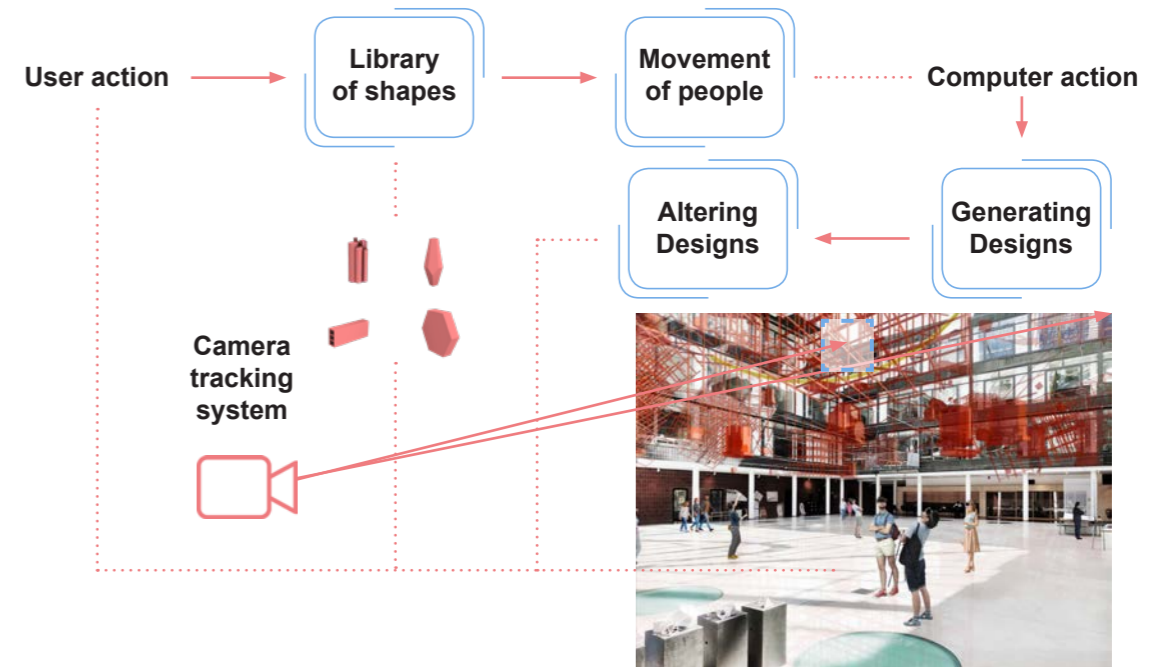


Figure 5.01 - Diagram of working tracking system in the atrium

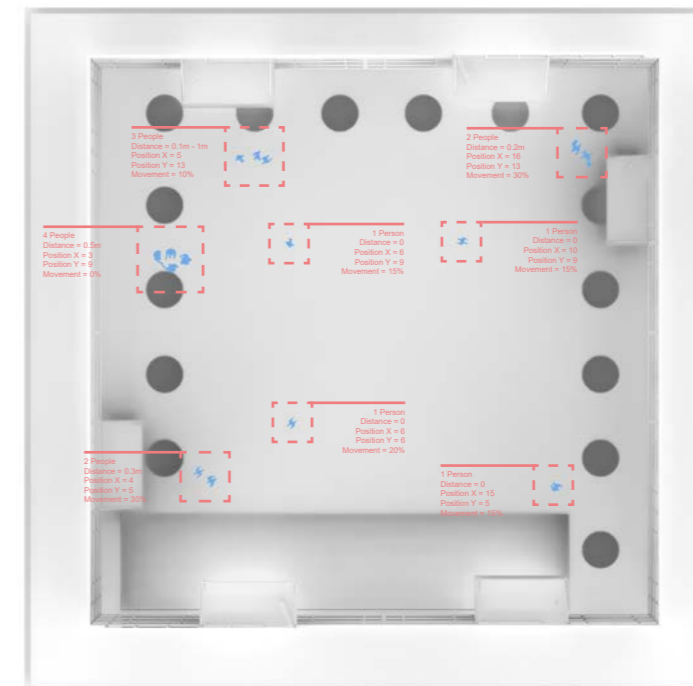


Figure 5.02 - How the tracking system records data

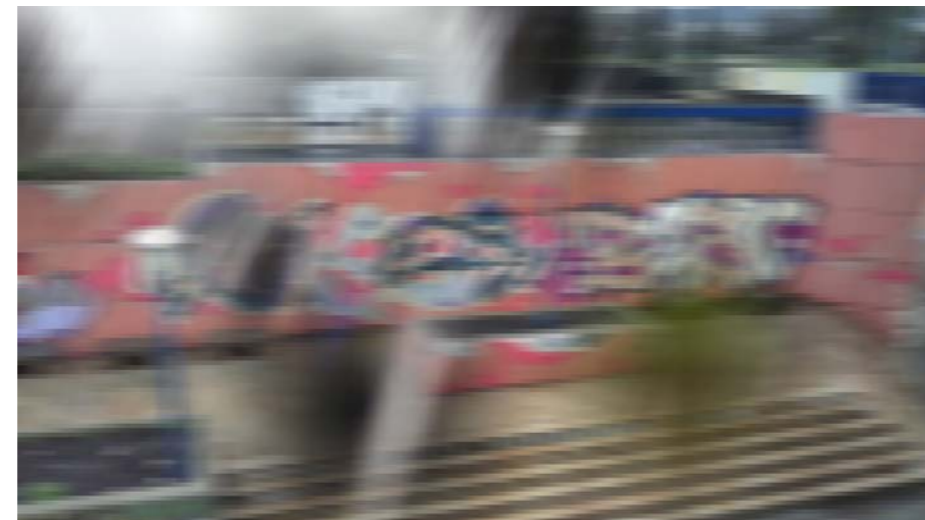
Figure 5.03 - Explanation of the latent space

The latent space in design

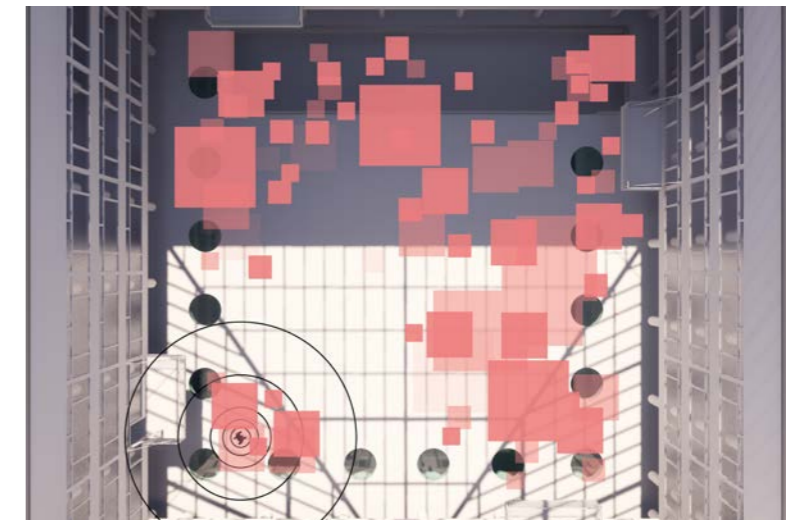
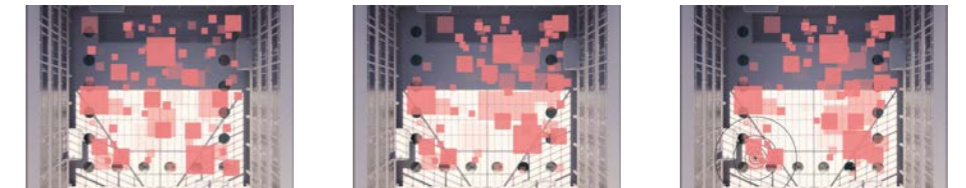
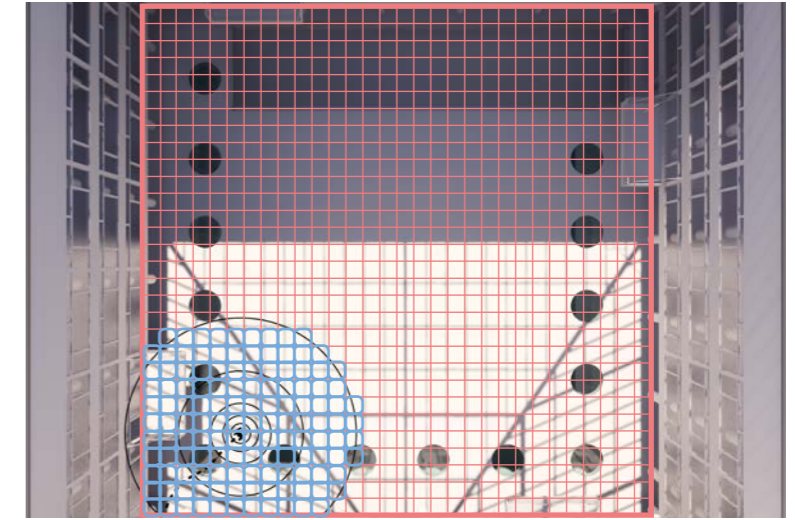
The latent space, in use with GANs is the representation of compressed data generated by the model using the fed library of media. The latent space has a latent vector, which is the set of numbers represented in figure 5.03. Each of these values represent a different characteristic to form a unique illustration, i.e. a unique set of pixels that alter the output of the GA. This set of data is what defines how “realistic” a picture becomes that the GA generated. The closer the numbers are that are taken, the smoother the transition is. The further apart they are, the more abrupt and chaotic the outcome will be. While the intended use of a latent space is for the algorithm to decide what numbers to take, it can also be altered by a human interaction to create a outcome that the user wants. One can represent this in a still or animations, where the animation can change it’s visual outcome smoothly and slowly to have a homogeneous animation, or change rapidly with large differences in the numbers selected to make more chaotic abrupt changes. This characteristic is metaphorically translated into the interactive installation. The latent vector is represented by a visual grid which divides up the space of the architecture department’s atrium in 2 dimensions. The people walking through the space imitate the choice made by the GA or human of what numbers are taken as a outcome. Figure 5.03 is a visual comparison of the original latent space and the adapted one.

GANs latent space

0.4285789176023467	-0.7209949864638014	0.6868897488745346	0.3992917078543881
0.6944315767355409	-0.2995410921515622	0.4163589595893207	0.1809181129471017
-0.2266448304181195	-0.2212610827857912	0.2197121583017112	0.2816413674883737
-0.3849733888101639	-0.2604718223495742	0.9028715872684827	0.1073870468453444
-0.2967830753404567	0.3159181910175449	-0.2448657142207331	-0.1503769835226130
0.5240805174801874	0.2640463808849669	-0.2830046262978597	0.8988316645374669
0.7665838858888410	-0.5592038601446914	-0.0596439526694099	-0.0381196648991292
-0.5225947720569533	0.2167802793983278	0.7094882883641349	0.7550776897720423
0.7093519585716314	0.9035736750362317	-0.1988087786356027	0.6733977849005711
0.0470634536105504	-0.8470143339815615	-0.6648148073185303	0.2919259524400932
-0.1224548887100325	0.1687229495349913	0.1734268382067917	0.2108272263830654
0.0297555928257087	-0.1178938090418901	0.4691820551963438	0.0772313359553140
0.6580272529544435	0.3984883350313121	-0.0587265161139547	0.6232914382700303
-0.1613536696701094	0.5501428337535554	-0.6962678058521206	0.3572376712026250
0.2639897490218233	0.3221182298483878	0.8030338863856317	0.8668928173682153
-0.0908866688101024	-0.1924960572237595	0.9814057471144039	0.3011803213978095
0.3672351554814889	-0.6752648072667721	-0.7711806147225110	0.9569030282818261
0.6488133751083228	-0.1387457070586949	-0.0814651945053902	-0.2375095511029984
-0.0112117347359711	0.1046166127103457	-0.9583162935256567	-0.4492473599730279
0.9632897851817728	-0.3275578372774448	0.1801715200674587	-0.0766417556799210
-0.1945205355037564	0.7737683773849943	-0.2151645856048746	-0.6478289224430121
-0.6324943665566361	0.1274709818546991	-0.8666506921251540	0.5431158074844237
0.2972629318466703	-0.5503241007916275	0.6597042016963028	0.0996287563348322



Installations latent space



Setting up the virtual space for pedestrians



Figure 5.04 - Giving limits to the installations

The positioning of the static installation generated in part one of this design project were simply determined by the randomness of the algorithm used. This result showed three different scaling options: Human, monolithic and full scale. All three versions shared the characteristics that they were visually obstrusive for the people observing them, i.e. they did not give a clear overview from all angles of how the installation altered the void.

In order to achieve a sensation of visual analysis of the space by the users, the Installations from part two of the design project have been elevated above the pedestrians on the ground floor of the space. used. It has been lifted by 3.4 meters, which is in correlation with the beginning of the

floorslab of the first floor. In order to make it observable from the the following three floors, the installations have been limited to a total height of 7.5 meters which leaves a possible dimensions of the installation height at at 4.1 meters.

To be able to track the movement of people across the entire space, the algorithm was also set to generated a visual outcome that would fill up the required space.

Further adjustments such as the rotation and scaling individual objects in the installation were made to create a more diverse design.

The differences in positioning of the Installation is shown in Figure 5.04

Physical & visual behaviour of objects with pedestrians



Figure 5.05 - Defining visual change of the installations

The concept of an interactive Installation resulted in dynamizing the newly generated options. With the use of the Multi-Agent Interactive system, that incooperated the camera tracking devices and the algorithm that defined the positioning of the objects after the information of the visual latent has been analysed, the Installation now features the possibility of moving objects towards people walking through the given space. The larger the group of people would be, the larger the attraction field of the objects would be. In total, there are four attraction zones for each party that shape themselves in a circular geometry. The virtual circles, which will not be visible for the users, have different spacing according to the amount of people that group together. Figure 5.05 represents one person

moving through the space. One can see that the radius of the zones goes as follows: 0.75, 1.55, 2.95 and 6.1 meters. With every person added to the group, the diameter difference of the the attraction zones increase by 0.4, 0.8, 1.6 meters , depending on the zone. Thus, a group of two people would have radii of 0.95, 1.95, 3.75 and 6.77 meters. Any objects outside of these zones will not be attracted to the group. Each attraction zone has different percentage levels, which define the intensity of transparency and the intensity of attraction of the objects. To be counted as a group, people are not further than 2 meters apart. The red colour was used as it's alarming and warns the users of clusters. Figure 5.05 shows combinations of different numbered groupings in interaction with eachother.



Figure 5.06 - Gravitation behaviour and correlation between people and objects

Dynamizing installation one

For the continuation of Installation one, the original Installation has been redeveloped to cover the entire atrium area. Due to the high-density of the individual objects, the resulting virtual structure offers a large precise visual change with people moving throughout the space.

Figure 5.07, representing Installation one, Scene zero, shows the installation with no movement. Scenarios like this one represent the night time, weekend and holiday days.

Figure 5.08, representing Installation one, Scene one, show a single person in a stationary position. The objects reshape to hover above the head of the person, forming a new composition and turning bright red in addition to decreasing the transparency. The other object sin the space keep the transparency of 30% and the positions.

Figure 5.09, representing Installation one, Scene two, shows a single group of five people in movement, reshaping one quarter of the entire space available.

Figure 5.10, representing Installation one, Scene three, shows a mixture of groupings made up of five, four and one perons.

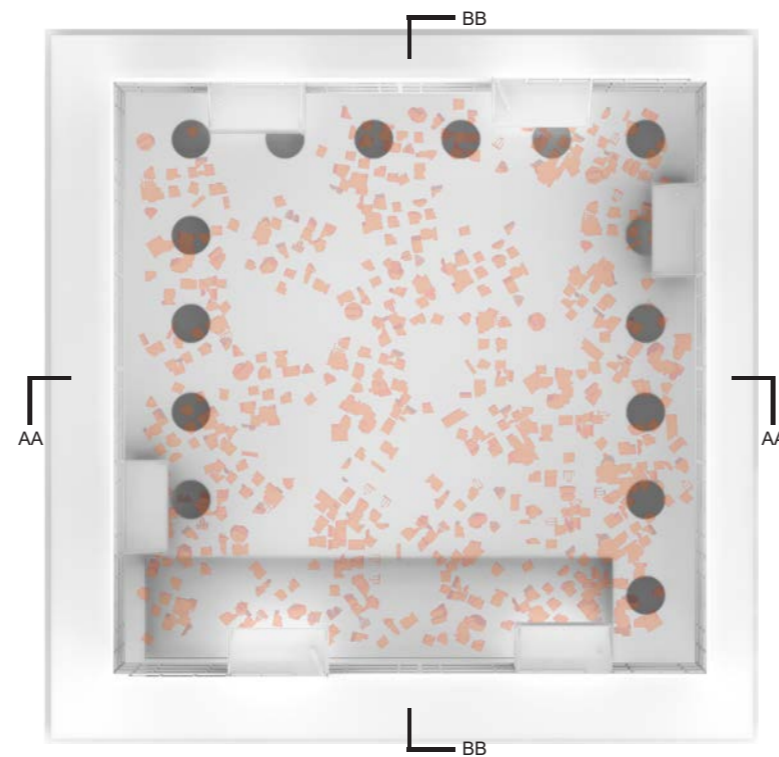


Figure 5.07 - Installation 1 Scene 0

1:350 0 4 8 12 16 20m

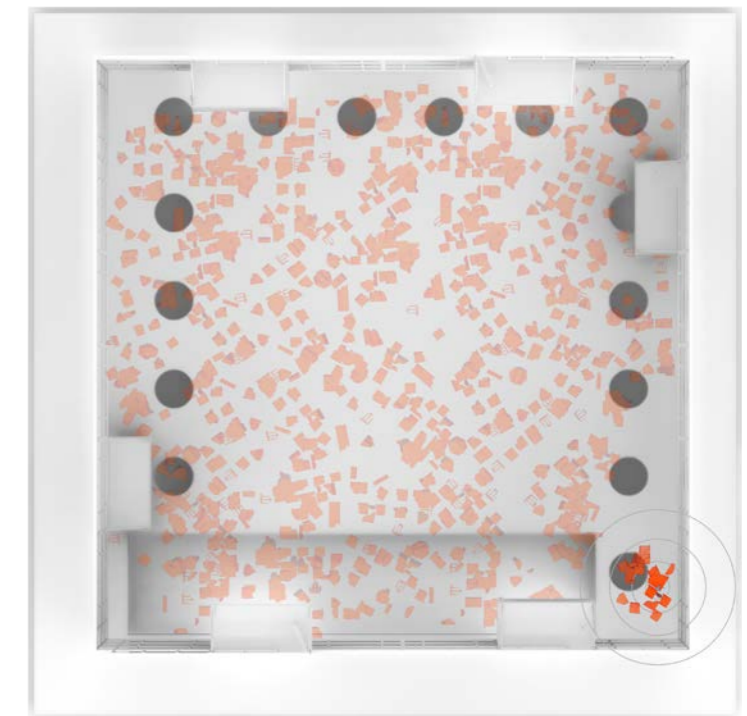


Figure 5.08 - Installation 1 Scene 1

1:350 0 4 8 12 16 20m

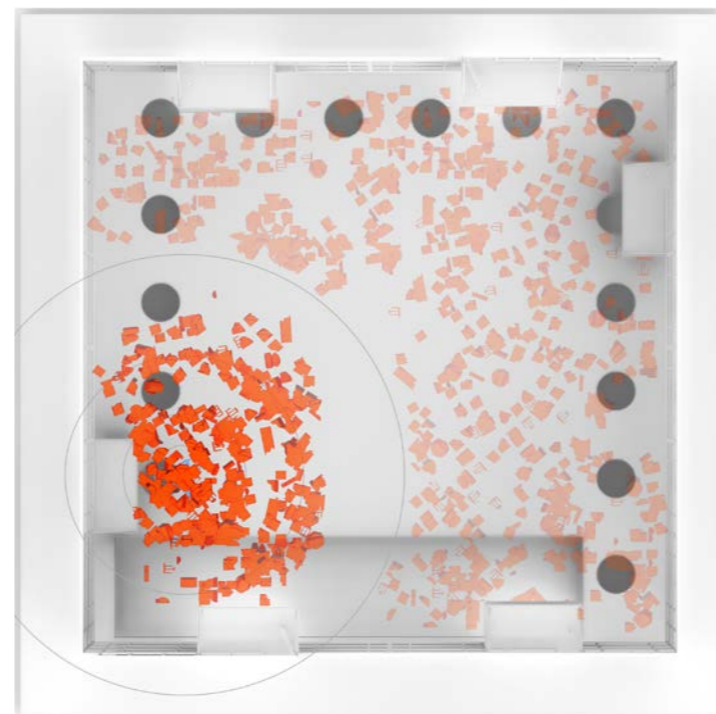


Figure 5.09 - Installation 1 Scene 2

1:350 0 4 8 12 16 20m

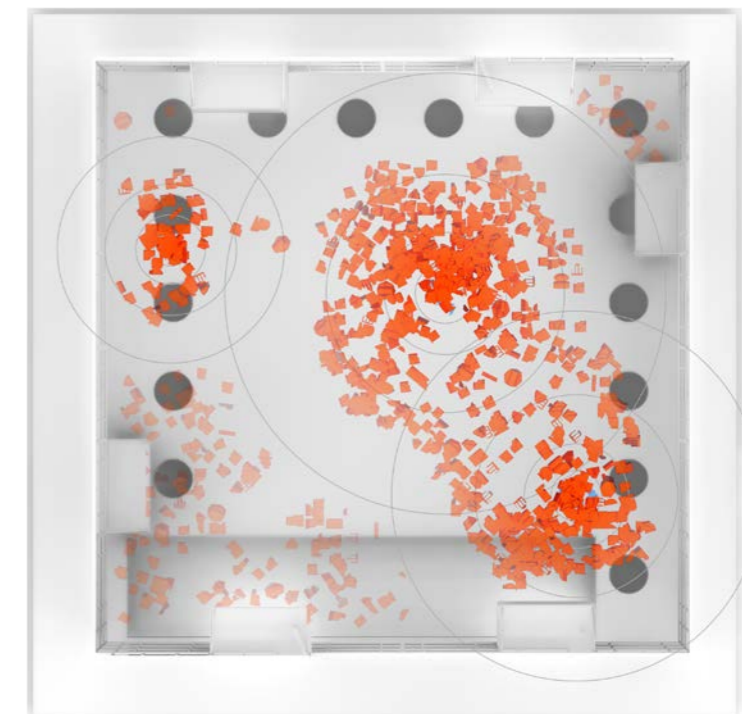


Figure 5.10 - Installation 1 Scene 3

1:350 0 4 8 12 16 20m



Figure 5.11 - Visualisation of installation 1 scene 0

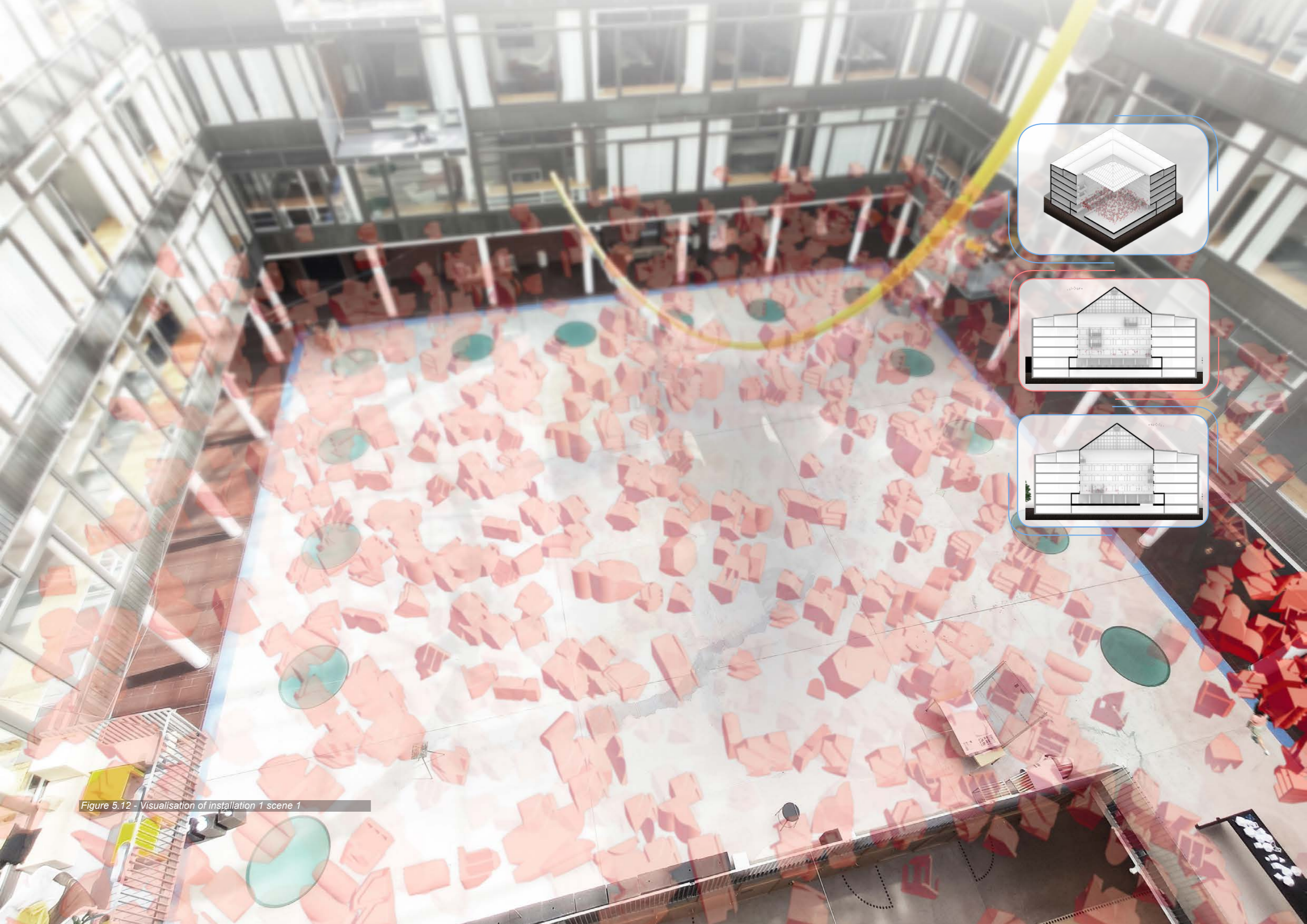


Figure 5.12 - Visualisation of installation 1 scene 1

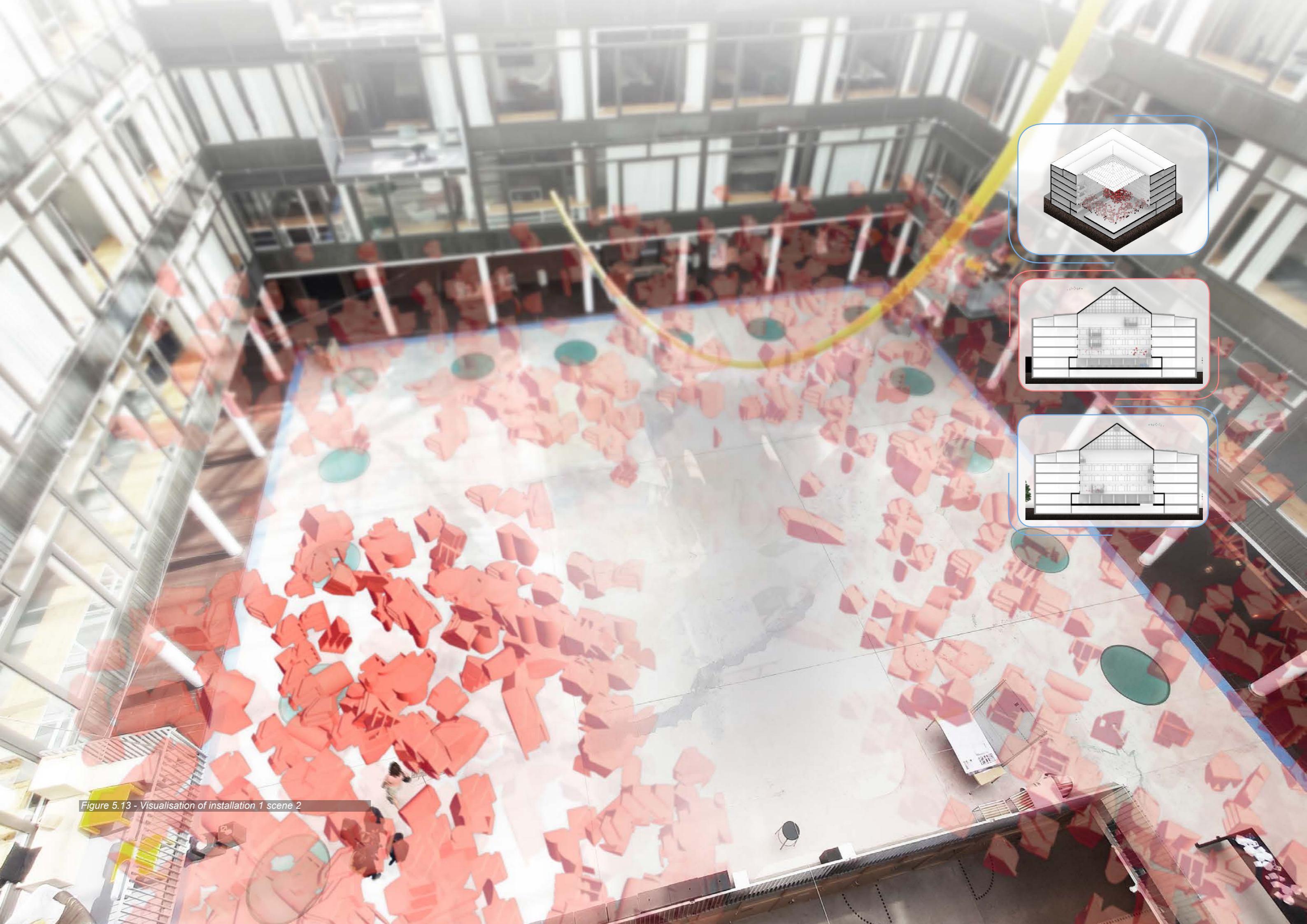


Figure 5.13 - Visualisation of installation 1 scene 2

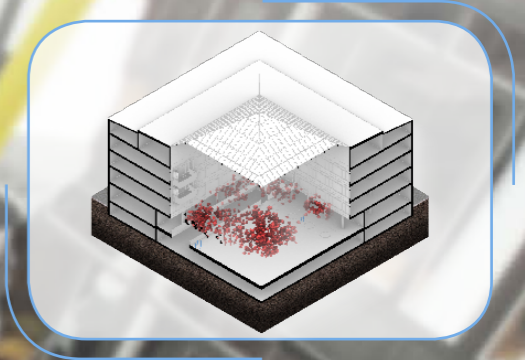


Figure 5.14 - Visualisation of installation 1 scene 3

Dynamizing installation two

The Dynamization of Installation two also included the new added feature/value of the algorithm to remodel objects by rotation and scaling. The full scaled Installation from part one of the thesis has also been regenerated to fit the entire space of the atrium. The result is an Installation that features objects so large that one person is enough to manipulate the visual outcome of the space.

Figure 5.15, representing Installation two, Scene zero has no movement.

Figure 5.16, representing Installation two, Scene one features two group of six and three people. The magnitude create by the group of six remodels the entire space, leaving a large space in the center of the atrium. While the group of three people does attract a large span of objects, the group of six has a larger attraction field, made up by the zones, resulting in a shift of objects from the group of three to the group of six.

Figure 5.17, representing Installation two, Scene two, features the same groupings as Scene one, but in different locations.

Figure 5.18, representing Installation two, Scene three, has four groups and four individual people walking through the space. The groups have sets of two pairs, four people and three people. The result is a space where the objects have shine red and have a low transparency throughout the atrium.

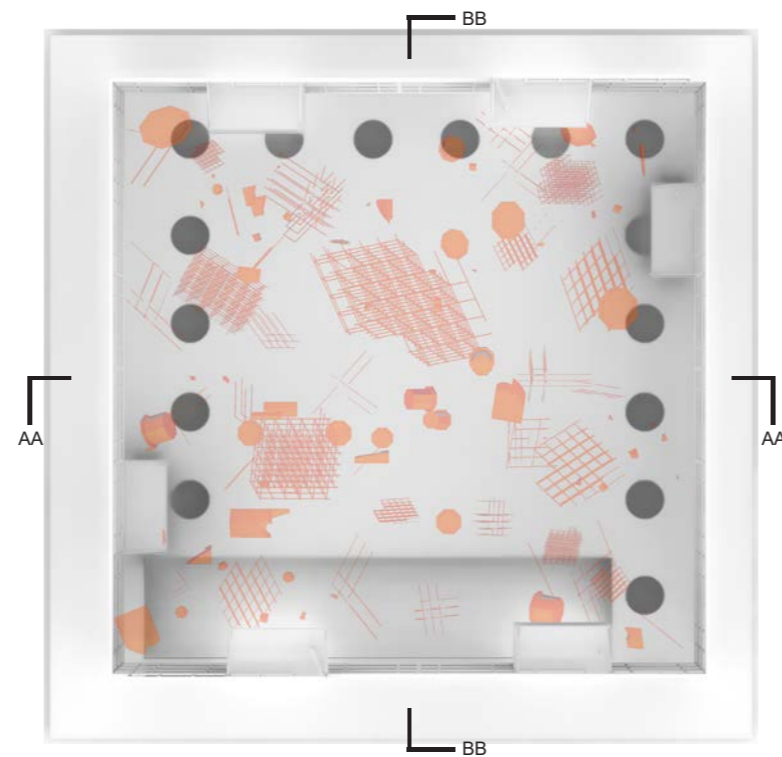


Figure 5.15 - Installation 2 scene 0

1:350 0 4 8 12 16 20m

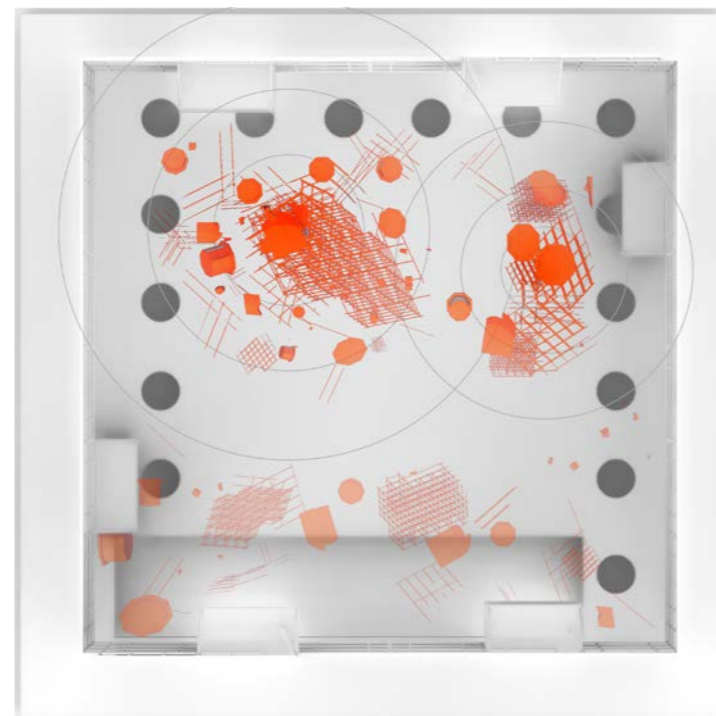


Figure 5.17 - Installation 2 scene 2

1:350 0 4 8 12 16 20m

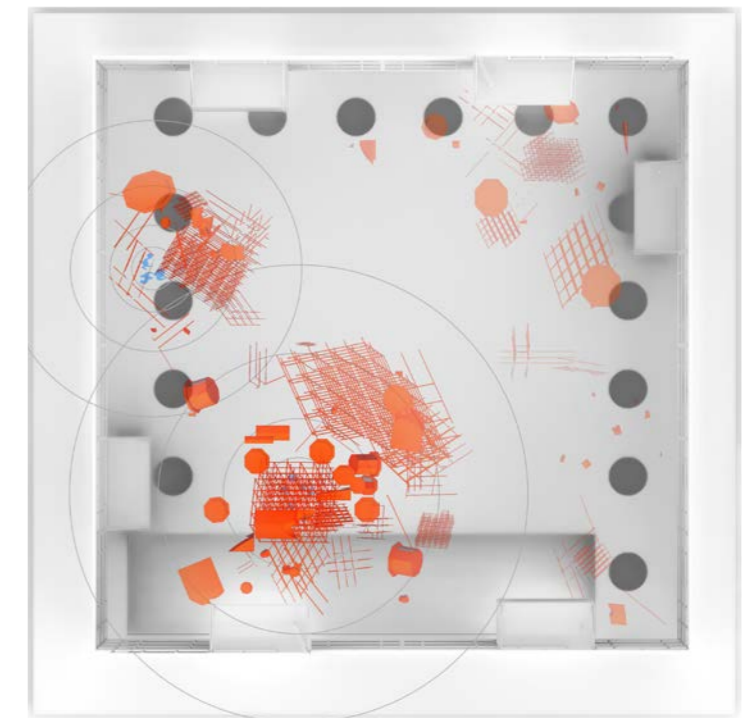


Figure 5.16 - Installation 2 scene 1

1:350 0 4 8 12 16 20m

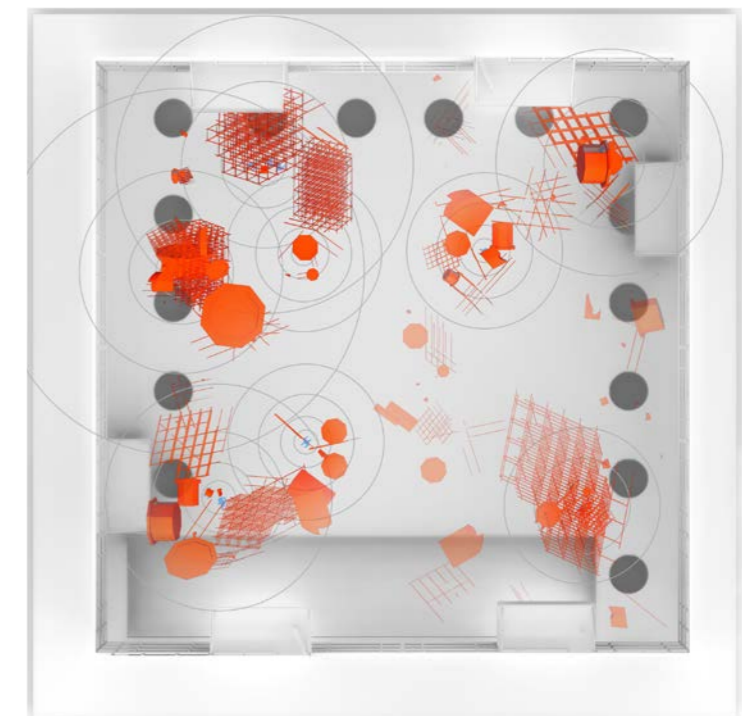


Figure 5.18 - Installation 2 scene 3

1:350 0 4 8 12 16 20m



Figure 5.19 - Visualisation of installation 2 scene 0



Figure 5.20 - Visualisation of installation 2 scene 1



Figure 5.21 - Visualisation of installation 2 scene 2



Figure 5.22 - Visualisation of installation 2 scene 3

Dynamizing installation three

The dynamization of the Installation three features similar characteristics to Installation one: A high density of objects which are rather small in comparison to Installation two. For the following scenes, the aim is to analyse the behaviour of objects if a smaller group of people would walk through a set of two larger groups.

Figure 5.23, representing Installation three, Scene zero, has the original generated Installation with no moving participants added.

Figure 5.24, representing Installation three, Scene one, features two groups of six people. The magnitude of those two large groups result in a shift of objects to the center of the atrium, leaving the objects in the space change their colour to bright red and a low transparency level, while objects near the edges of the atrium aren't attracted.

Figure 5.25, representing Installation three, Scene two, features the same groups as Scene one, which an addition of a pair in the top left corner.

Figure 5.26, representing Installation three, Scene three, features the same groups as Scene two, however the pair moved from the top left corner through the two groups, approximating to leave the space in the bottom right corner. The result is multiple of new generative patterns as one can see when comparing the scenes.

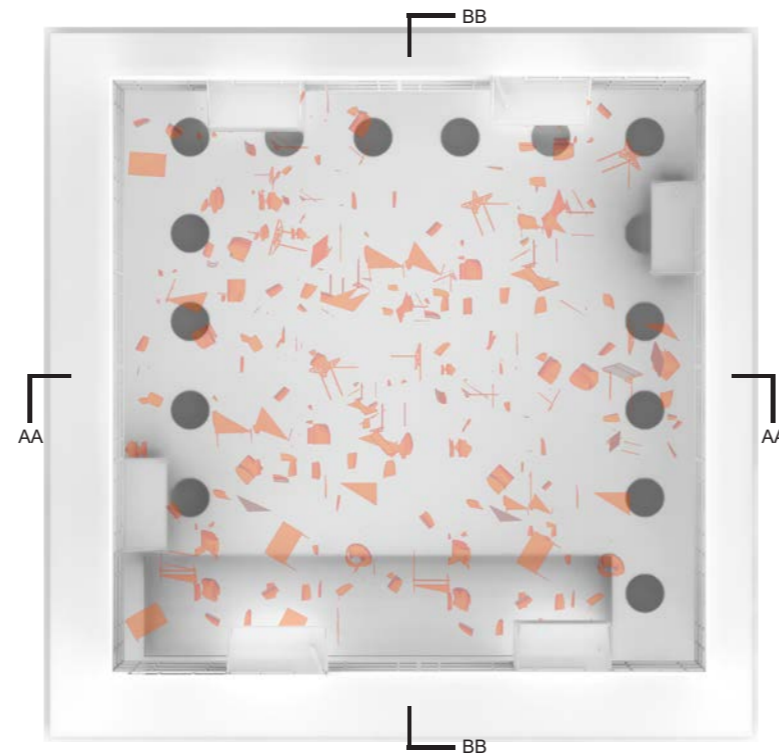


Figure 5.23 . Installation 3 scene 0

1:350 0 4 8 12 16 20m

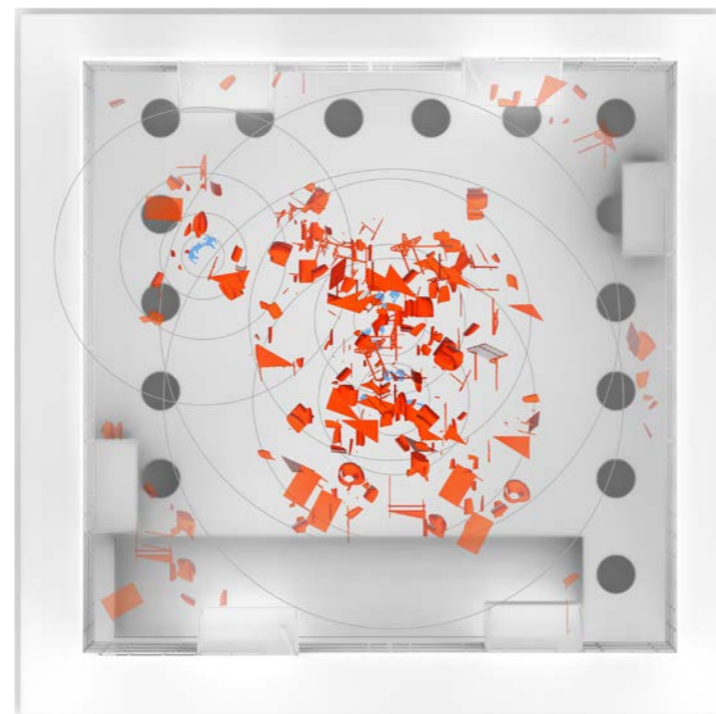


Figure 5.25 - Installation 3 scene 2

1:350 0 4 8 12 16 20m

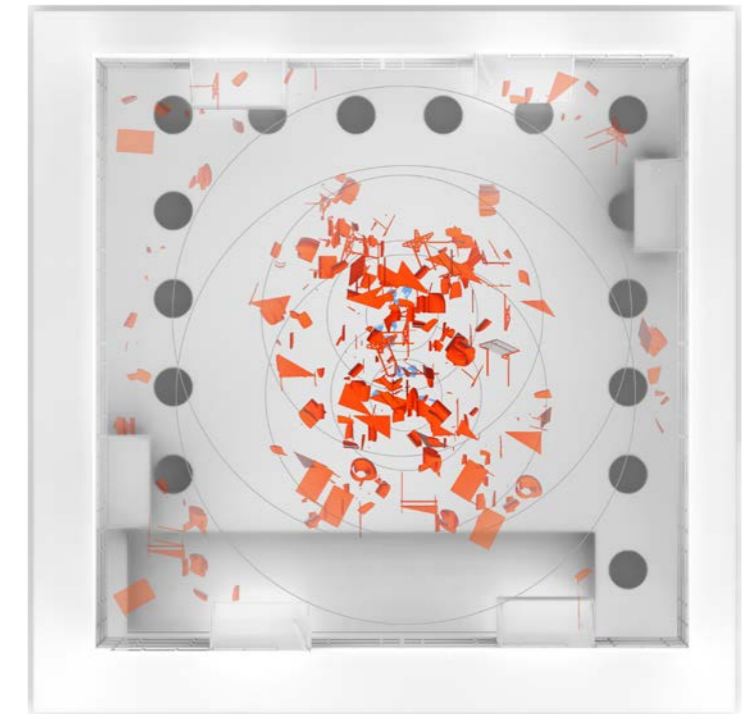


Figure 5.24 - Installation 3 scene 1

1:350 0 4 8 12 16 20m

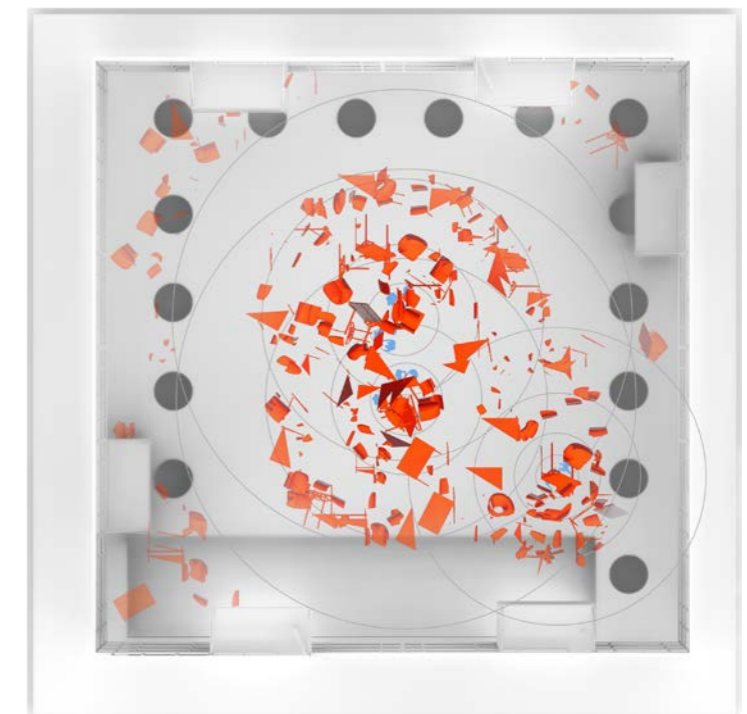


Figure 5.26 - Installation 3 scene 3

1:350 0 4 8 12 16 20m



Figure 5.27 - Visualisation of installation 3 scene 0



Figure 5.28 - Visualisation of installation 3 scene 1



Figure 5.29 - Visualisation of installation 3 scene 2



Figure 5.30 - Visualisation of installation 3 scene 3

05 Conclusion

Using the tools and technologies that exist now and having a perspective of them for the future, how will future designs look like and function?

This thesis establishes an understanding that to represent future design scenarios, one has to first define the properties of the tool-set that exist now and how they may develop in future. While we can define the properties of contemporary technologies, looking into the future is merely a game of guessing made of scenario calculations. It is not tangible for tech-savvy people, neither for those who are not interesting into technology but would like to see what the future holds. Therefore, the author of this thesis takes the approach of re-interpreting concepts of future technological possibilities or technologies that require a high technological literacy in order to use them for application, so that they are applicable in 2020 and are able to be used and understood by everyone who reads the thesis. The follows characteristics from GANs and generative designs are translated into a more understandable context.

1. Generative design's ability to use an algorithm to automatize the production of designs is translated into a easy to use program, in this case Grasshopper 3D.

2. GAN's ability to take use a library storage as an ability to create new designs, based on the storage, is translated into a library of objects

that are fed into the algorithm to form the installations.

3. GAN's ability to have two neural networks working simultaneously to create perfect outcomes, based on the library provided is translated into a manual-user-based approach where the user adjusts the object positions, scaling, rotation, the density and position of the entire installation if needed.

4. The GAN's latent space is translated from a numerical form that defining and manipulating a design outcome, to a physical form where the given space is divided up into a grid and people trespassing that area activate areas of the grid, changing the position of objects of the installation, thus changing the visual outcome.

The thesis reviews a set of theoretical literature that was chosen according to the interests of the author that developed during his exchange semester at the University of Strathclyde. This includes the use of generative design, generative adversarial networks, virtual and augmented reality and fictional proposals of future design scenarios. These then cumulate to form design boundaries and characteristics for a algorithm which is created to automatize the creation of design installations in the first part of the design proposal. This algorithm is then further adjusted and the theoretical idea of digital surveillance, social sustainability and virtual / augmented re-

ality gives a new dynamic characteristic to the installations.

The final installations are a representation of what the author believes to be a variation of how spaces could look like in the future - a digital form that doesn't intrude with the already established built environment. A structure that manages to change its form and visual outcome in an instant of a second without having to pay attention to the material properties used, due to it being digital. A structure that acknowledges the change in perception when faced with the issue of data protection laws after 2020 and that assists the visitors in tackling social problems like overcrowded spaces, creating a sustainable living standers for future generations to come. This view on the future of architecture and design, however, is strongly biased by the authors understanding, perception and translation of technologies that are already in use and are to come in the next decade. Thus, the thesis question of how will future designs look like and function is a question that will be answered by the definition of the sentence itself: In the future. We designers of the early 21st century can merely come up with our own developments and interpretations.

For the readers that are reading the post 2032, which will be a decade after this thesis has been written: Stay creative and think outside of the box. As you can probably see, the future is full of surprises.

Delimitations of the project

Several delimitations influences the working methodology for this design project:

- Computer hardware
- Technological literacy
- Research equipment

For the use of BioMorpher and the algorithm used, the computer processing power is essential to be able to feed it with endless amount of data. The first studies are made using a laptop which only let me feed one or two number slider into BioMorpher to work with. A switch to the supplied university computers revealed a slight increase, but still crashed after the use of five number sliders, thus limiting me to that. Accessing a third-party server made it possible to not only generate one Installation, but several and automatically solid subtracting them from another.

For the work with BioMorpher and Grasshopper, one has to have a high understanding of visual algorithmic design. As this topic is new to the author, part of the design phase was edited manually.

For the final representation of the installations, the thesis uses a physical model made out of plywood and glass, which represents the floating virtual structure. Future variations are set to be viewed in a virtual reality glass with a virtual rendered word.

Bibliography

1. Kelly, K. (2017). *The inevitable: understanding the 12 technological forces that will shape our future*. NY, NY: Penguin Books.
2. Carpo, M. (2017). *The second digital turn: design beyond intelligence*. Cambridge, MA: The MIT Press.
3. Carpo, M. (2011). *The alphabet and the algorithm*. Cambridge, MA: MIT Press.
4. Carpo, M. (2013). *The digital turn in architecture 1992-2012*. Chichester: Wiley, Cop.
5. Francis, S. (2019). *Bubbleecture*. PHAIDON PRESS LTD.
7. Reas, C. (2020). *Making Pictures with Generative Adversarial Networks*. Anteism Books.
8. Theobald, O. (2017). *Machine learning for absolute beginners: a plain English introduction*. United States: The author.
9. Chaillou, S. (2019). *AI + Architecture: Towards a New Approach (Master's Thesis)*. Retrieved from Issuu.com
10. Schmidt, L. (2019). *The Third Digital Turn: A manifesto on the future of professions*. Retrieved from University of Strathclyde
11. Schmidt, L. (2019). *A Remembrance Centre for Architects*. Retrieved from University of Strathclyde
12. Baldwin, E. (2019, June 5). *AI Creates Generative Floor Plans and Styles with Machine Learning at Harvard*. Retrieved March 6, 2020. Retrieved from <https://www.archdaily.com/918471/ai-creates-generative-floor-plans-and-styles-with-machine-learning-at-harvard>
13. Frey, C. B., & Osborne, M. A. (2017). *The future of employment: How susceptible are jobs to computerisation?* *Technological Forecasting and Social Change*, 114, 254–280. Retrieved from doi: 10.1016/j.techfore.2016.08.019.
14. *Architecture and Artificial Intelligence*. (2019). Retrieved from <https://youtu.be/ES-vDZ5Go6E0>
15. Neil deGrasse Tyson Explains The End Of 'Interstellar'. (2014). Retrieved from <https://www.youtube.com/watch?v=R1cexcjdyIE>
16. *The Difference Between Computational Design Vs. Generative Design Vs. Parametricism*. (2018). Retrieved from <https://www.youtube.com/watch?v=Fe64EMAt5zc>
17. ACADIA 2016 Keynote - Mario Carpo. (2019). Retrieved from at: <https://vimeo.com/210622365>
18. Nicholson, C. (2014). *A Beginner's Guide to Generative Adversarial Networks (GANs)*. [online] Skymind. Retrieved from <https://skymind.ai/wiki/generative-adversarial-network-gan>
19. esiegel (2016). *Why Dark Matter?* (Synopsis). Retrieved from <https://scienceblogs.com/startswithabang/2016/06/08/why-dark-matter-synopsis>
20. Houghton Mifflin Harcourt Publishing Company. (n.d.). *Definition of virtual reality*. Retrieved from <https://www.ahdictionary.com/word/search.html?q=virtual+reality>
Calderon, C. (2009). *Interactive Architecture Design*. *Interactive Architecture Design.*, 1–62. Retrieved from <https://doi.org/10.13140/RG.2.1.1372.2723>
21. Author of "Interactive Architecture" on the built environment in the age of ubiquitous computing. (2016). *Architect*. Retrieved from <https://architect.com/news/article/149950671/author-of-interactive-architecture-on-the-built-environment-in-the-age-of-ubiquitous-computing>
22. Jaskiewicz, T. (2010). *(In:)forming Interactive Architectural Systems, Case of the xMAiA Meta-model*. Retrieved from http://papers.cumincad.org/data/works/att/acadia10_203.content.pdf
23. Michailidis, K. (2013). *INTERACTIVE ARCHITECTURE: friend or foe?* (Master's Thesis). Retrieved from Issuu.com
24. Parsaee, M., Motealleh, P., & Parva, M. (2016). *Interactive architectural approach (interactive architecture): An effective and adaptive process for architectural design*. *HBRC Journal*, 12(3), 327–336. <https://doi.org/10.1016/j.hbrj.2015.01.001>
25. Foote, K. D. (2019, March 13). *A Brief History of Machine Learning*. DATAVERSITY. Retrieved from <https://www.dataversity.net/>
- 26

27. HSB Living Lab: student housing in Gothenburg, Sweden. (2017, November 15). Build Up. Retrieved from <https://www.buildup.eu/en/practices/cases/hsb-living-lab-student-housing-göteborg-sweden>
28. Tiu, E. (2020, February 4). Understanding Latent Space in Machine Learning - Towards Data Science. Medium. Retrieved from <https://towardsdatascience.com/understanding-latent-space-in-machine-learning-de5a7c687d8d#:~:text=Key%20Takeaways,representations%20of%20data%20for%20analysis>
29. Hadilou, A., Briscoe, D. (2013). COLLECTIVE INTELLIGENCE: AN ANALYTICAL SIMULATION OF SOCIAL INTERACTION WITH ARCHITECTURAL SYSTEM. Retrieved from <https://www.academia.edu>
30. Jiangtao, S. (2019, September 17). How China's surveillance state was a mirror to the US for whistle-blower Edward Snowden. South China Morning Post. Retrieved from <https://www.scmp.com/news/china/diplomacy/article/3027598/us-whistleblower-edward-snowden-left-hong-kong-because>
- 40 L. (2020, October 20). Statistics On How Security Cameras Deter Crime – Kansas City Security Cameras. Watchmen KC. Retrieved from <https://www.watchmenkc.com/2016/03/10/statistics-security-cameras-deter-crime-kansas-city-security-cameras/>
- 41 Carr, C. (2017, August 2). Facial recognition technology to be trialled at Berlin railway station. RailUK. Retrieved from <https://www.railuk.com/rail-news/facial-recognition-technology-to-be-trialled-at-berlin-railway-station/>
- 42 Wojtkiewicz, S. (2014). Generative Systems in architecture design. Retrieved from https://www.generativeart.com/GA2014papers/Slawomir_Wojtkiewicz_2014.pdf

Appendix

Research and Development

With the help of the three design methodologies and the reference project, it concludes in a design project that proves the concept of designing in the scope of GANs and generative designs using partially autonomous generative design.

However, this design project is not meant to be taken as an architectural proposal that must be realised in the given space of the atrium at Chalmers University of Technology, but is a concept design project that can, in future, be modified to suit any location and can be manipulated by any new author with new input data that transforms the composition of cubes into their own shape.

The project is categorised in three different design proposals that use the previously mentioned design methodologies of different scales, randomness and shapes. Multiple Installations are merged and subtracted together to form new alterations of the same Installation.

A main aspect of the design is the collaboration and participation of third-party user that feed in shapes into the algorithm.

All design methodology characteristics, the shapes and the generative design tool BioMorpher are all part of an algorithm using the Grasshopper plug-in in Rhinoceros 3D.

For representation purposes, the output from Grasshopper is then processed in post-produc-

tion to adjust the materiality to inflatable structures. This step could eventually also be handled by the rendering package in Rhino 3D.

Grasshopper

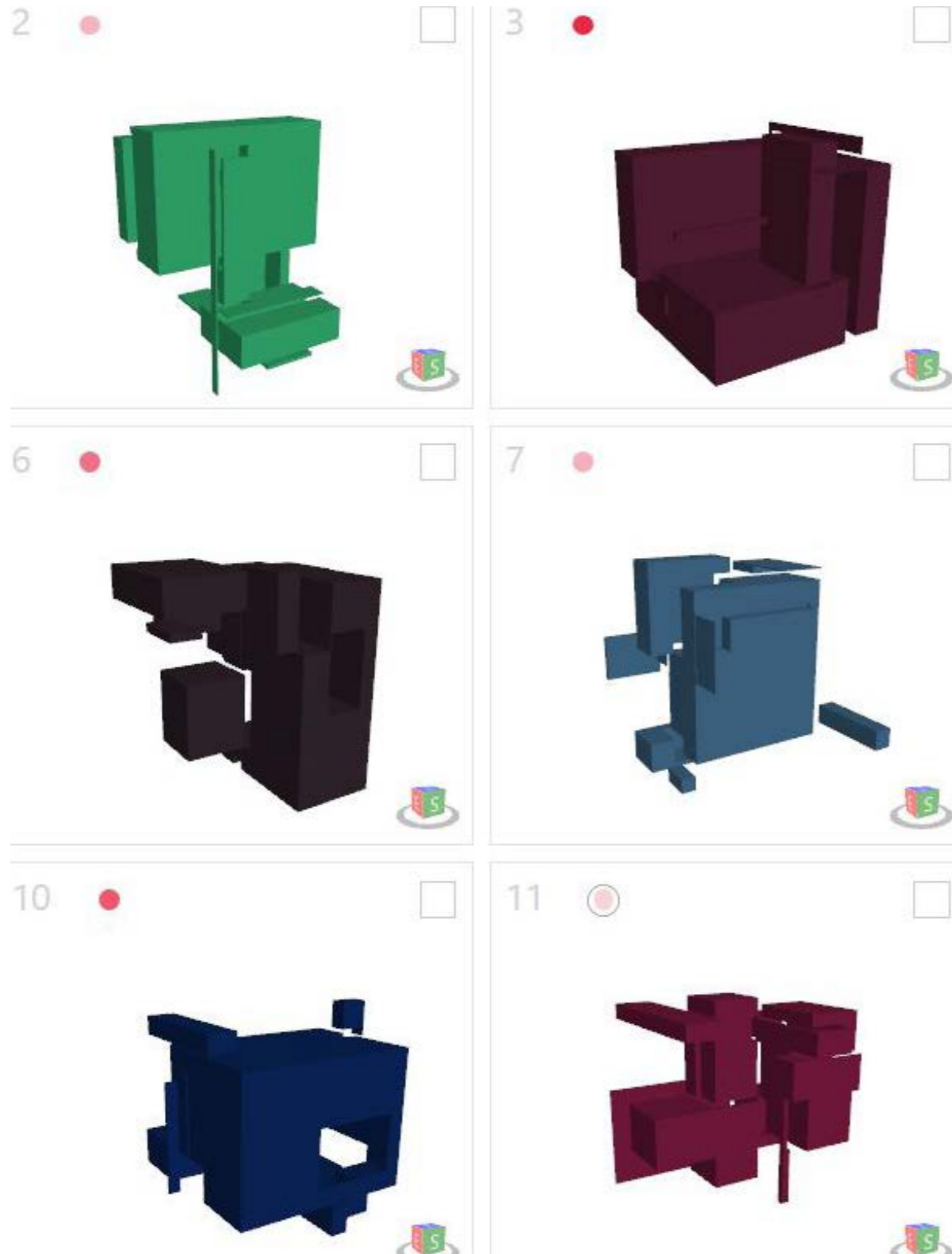


Created by David Rutten at Robert McNeel & Associates, Grasshopper is a visual programming language and algorithm solving plug-in for Rhinoceros 3D. By applying and connecting scripts, one can transform a simple point into an array of points that form a closed mesh, without having to model it manually in the Rhinoceros 3D interface.

BioMorpher



Created by John Harding, BioMorpher is a plug-in for Grasshopper and Rhinoceros 3D that acts as a generative design tool that features algorithms, assisting you and creating design alterations of a geometry. It does so by using genomes and variables that the user defines beforehand and manipulates these autonomously.



Generative design variations using BioMorpher

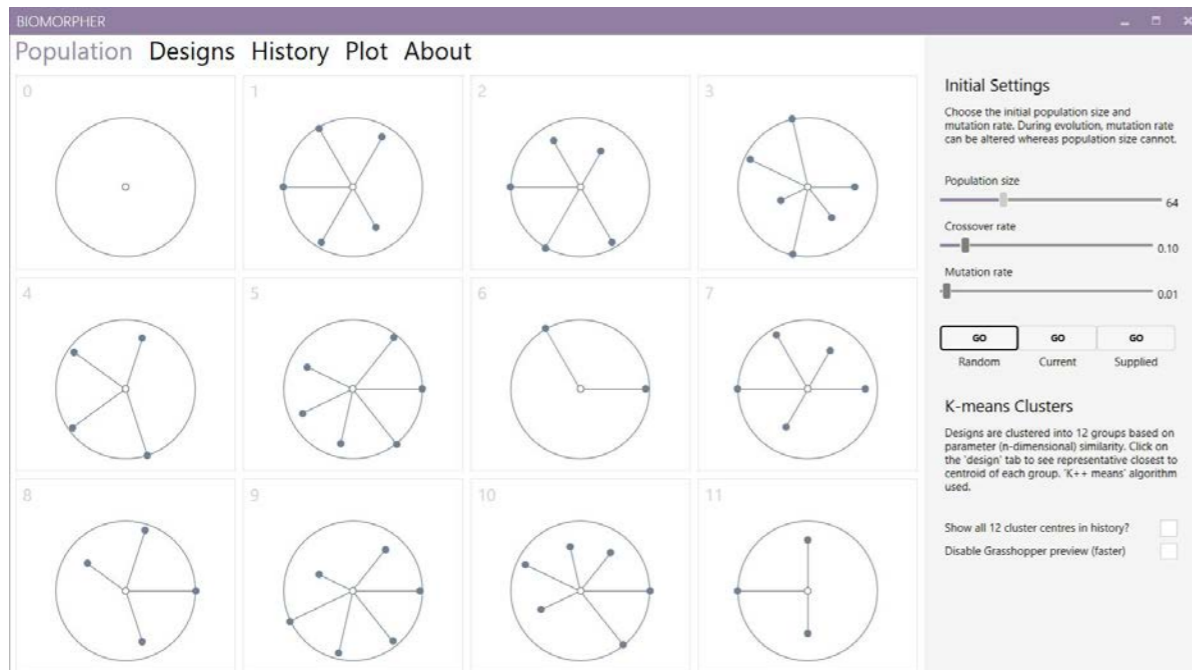
BioMorpher

BioMorpher is a plug-in for the Rhinoceros 3D software plug-in Grasshopper that lets to create object alterations through optioneering. Similar to the built-in software Galapagos, BioMorpher uses data input like number sliders that determine the form and shape of an object, in addition to a performance value like volume, surface area but also more complicated performances like the potential U-value of a generated proposal. One then opens BioMorpher from the Grasshopper user interface, which opens up the interface of the software itself. One then runs BioMorpher, which will automatically adjust all number sliders you fed into it and shows you the different generated design proposals.

One can have multiple BioMorpher programs running in one Grasshopper file that can, therefore, generate design alterations with different compositions and can then add a function that solid subtracts the different compositions to form a new, unified shape alteration as showcased for this thesis design proposals.

It is, however, important to note that this method of generative design is highly limited to the computer power available for generating the alterations. As of now, only simpler shapes work with a standard equipped computer.

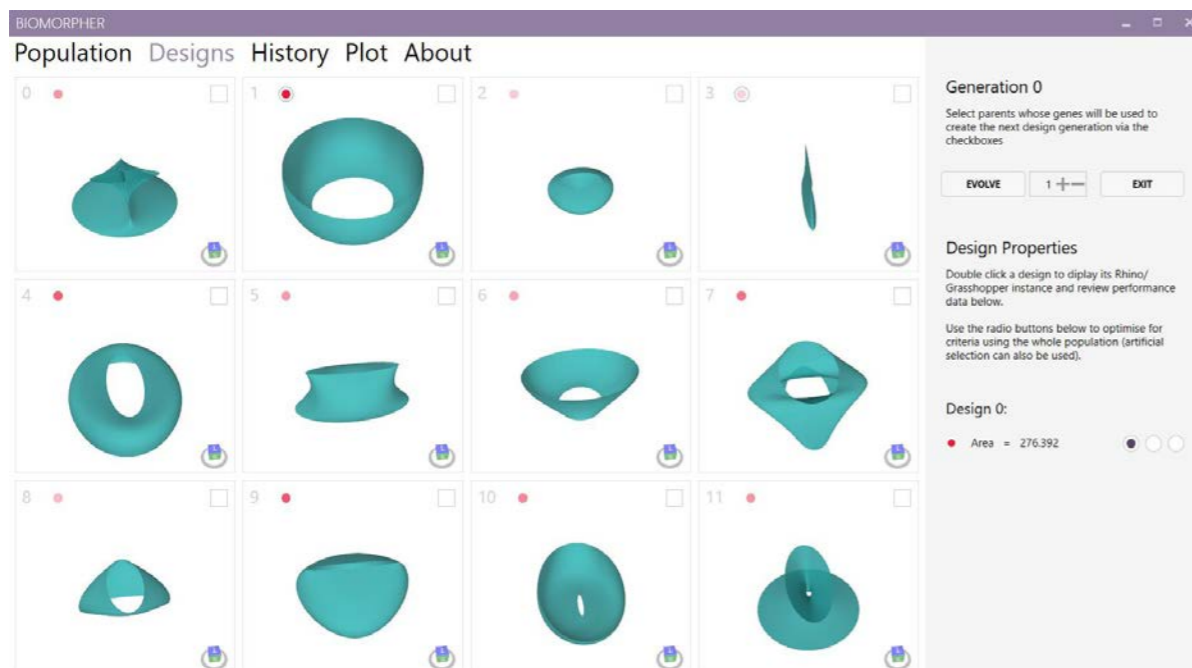
Interface 1 - Statistical analysis of designs



Interface 1 shows the main tab after running an evolution of alterations. The 'Population' tab shows us the statistical similarity with the previous generation of the alterations. Each line corresponds with a certain geometry of the old generation. With this overview, one can quickly trace back and see in what direction the alterations are developing.

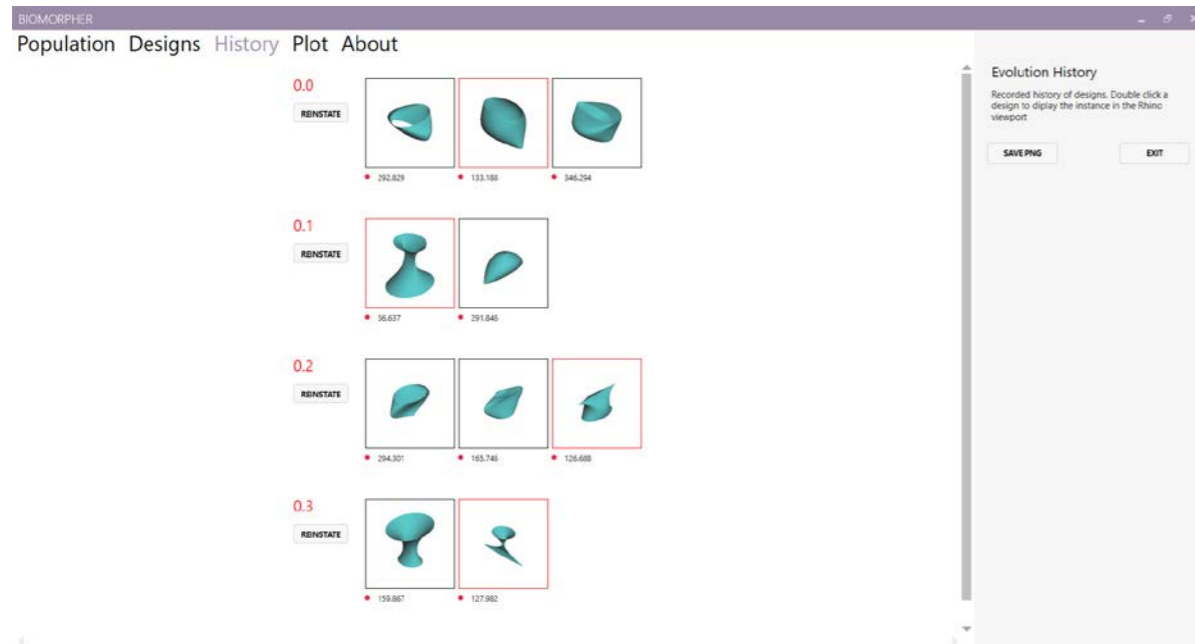
On the left-hand side, one can see the 'Initial Settings' section where one can adjust the population size of the structure, the crossover rate and the mutation rate. While the population size and crossover rate don't have a large influence on the design, the mutation rate determined how much the fed number sliders shift in positions, thus allowing for more random or less random alterations.

Interface 2 - Viewing designs and evolving them



Interface 2 shows the design tab on the BioMorpher interface. The design tab shows you a visual representation of the newly evolved alterations. When pressed on one, the model also changes to the pressed one in your Rhinoceros 3D environment and is then ready to bake. This tab also lets you further develop and optioneer your model. The user decides which alterations he likes, selects them and adjusts the performances which - in this example - is the surface area set. You can minimize, maximize or keep the performance value. One then chooses how many evolutions one wants and presses on evolve. Biomorpher will now evolve further alterations according to the alterations and performance value you chose.

Interface 3 - Viewing history and exporting it



On interface 3 one can see the history of past alterations evolved from the very first alteration to the last one you generated. This can then be exported for further evaluation by either saving it as a PNG file or - as stated previously - baked into Rhinoceros 3D for further individual usage.

Interface 4 - Graphing the performance



Interface 4 then shows further studies on the statistical data of your performance chosen. It shows you a development of the performance throughout your design alterations

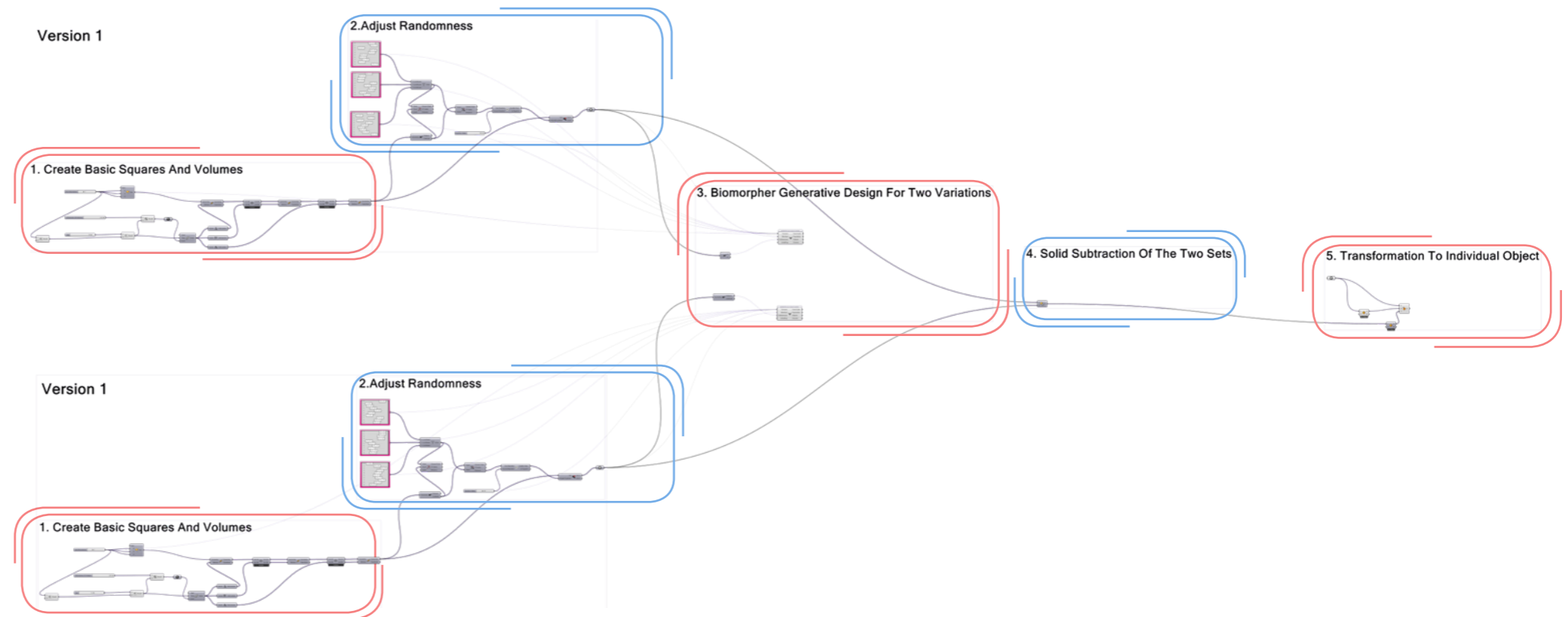
Grasshopper algorithm

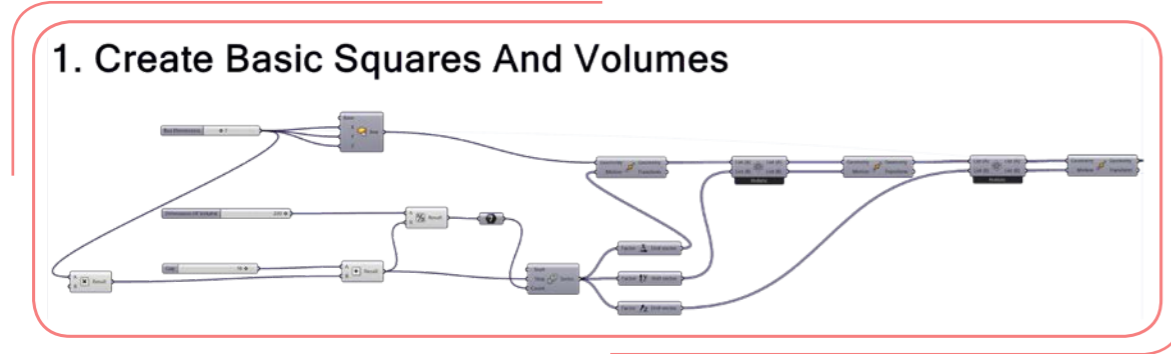
For the foundation data of the automated generative design project, It used a Plug-In for Rhinoceros 3D called Grasshopper, with which it also use the Plug-In BioMorpher. While the Ideal scenario for an automated generative design relies on In the lack of human Input, the project does use the ability for the user of the algorithm to manipulate the final Installation in order to make It more feasible for comprehending the ideology behind the design concept, but also to create a fun, interactive way of working with automated software. The algorithm tree is divided up into the following 5 parts:

1. The creation of basic squares And volumes as a starting object and reference space.
2. Adjusting the Randomness of the box positions
3. Generating and picking the design compositions
4. Subtracting the two generated designs from another
5. Transformation to a an individualised object

This algorithm then generates the Installation which is places into the exhibition space in a 3D model environment.

The following pages illustrate and tutorial how the different steps of the algorithm worked.



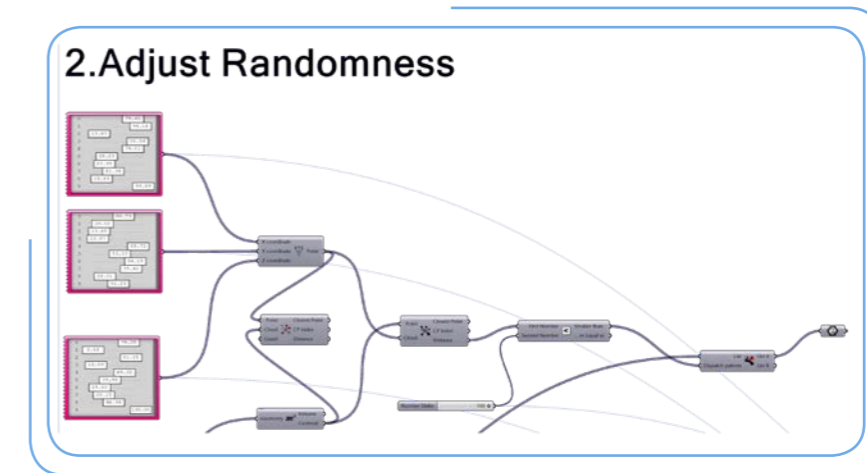
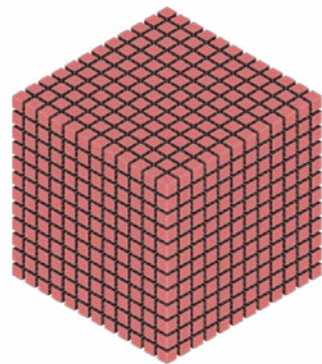


Create basic squares and volumes

The first step of the algorithm defines four main things:

1. Set maximum dimensions of the Installation
2. Creating a box according to X Y Z variables with slider
3. Array boxes along with the same variables with slider
4. Set the distance between boxes with slider

The outcome is a set of meshes that represent the maximum volume and space of the Installation in visual cubes. In the example of this project, the final volume is set by the volume of the space in the atrium of the architecture department of a user-defined volume.

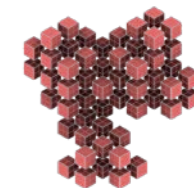
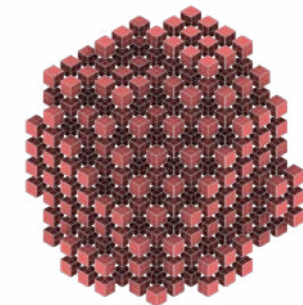


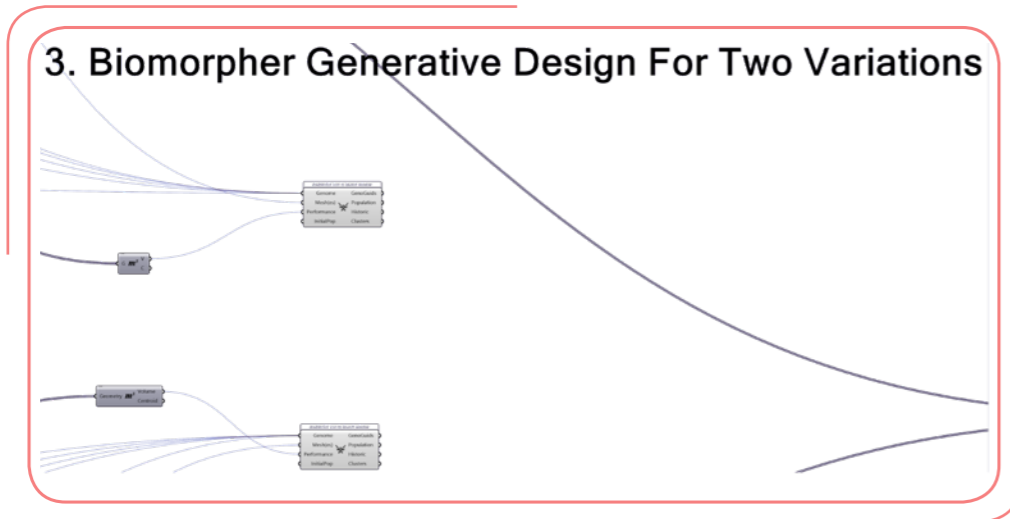
Adjust the randomness of the box positions

The second step of the algorithm defines five main things:

1. Reconstruction of boxes into volume points
2. Random point construction with random gene pools
3. Comparison of the distance between two point constructions
4. Only show volume points below a certain distance from random point construction defined by number slider
5. Reconstruct squares

The created geometry is now variable in density and can be randomly adjusted.



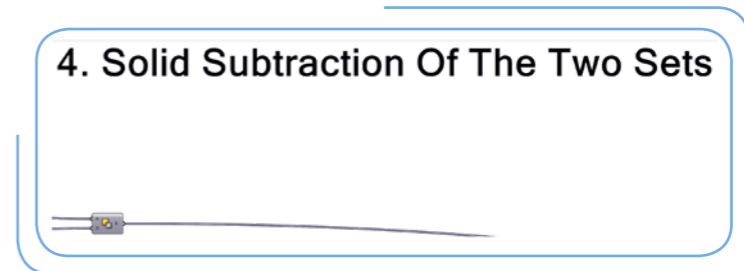
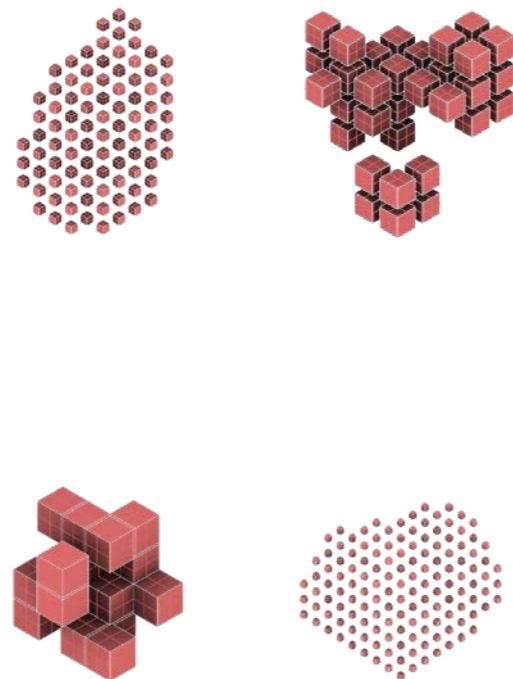


Generating and picking the design compositions

The third step of the algorithm defines four main things:

1. Divide newly formed of set geometry into volume and feed it into the performance of BioMorpher
2. Feed all the wanted variables (in this case sliders) into the genome generator of BioMorpher
3. Feed the mesh into the mesh generator of BioMorpher
4. Activate BioMorpher and generate wanted design

With the help of BioMorpher, a user can now generate a desired version of the geometry.

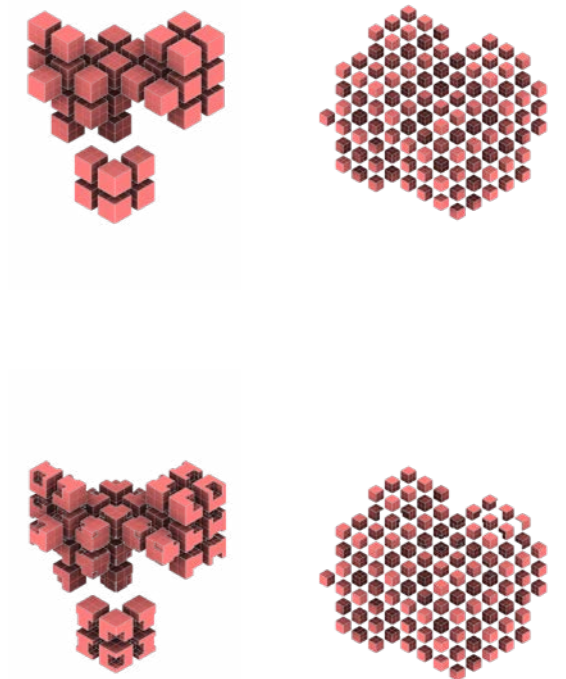


Subtracting the two generated designs from another

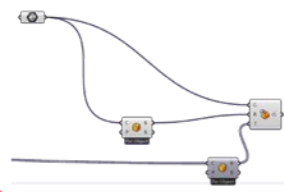
The fourth step of the algorithm defines five main things:

1. Repeat all the previously done steps to form a second set of cubes generated by BioMorpher
2. Feed first set of cubes into a solid subtraction
3. Feed the second set of cubes into solid subtraction
4. Bake your composition
5. Place into a model of the atrium and live render with Enscape

The combination of two geometries and a solid subtraction results in a more dynamic Installa-



5. Transformation To Individual Object

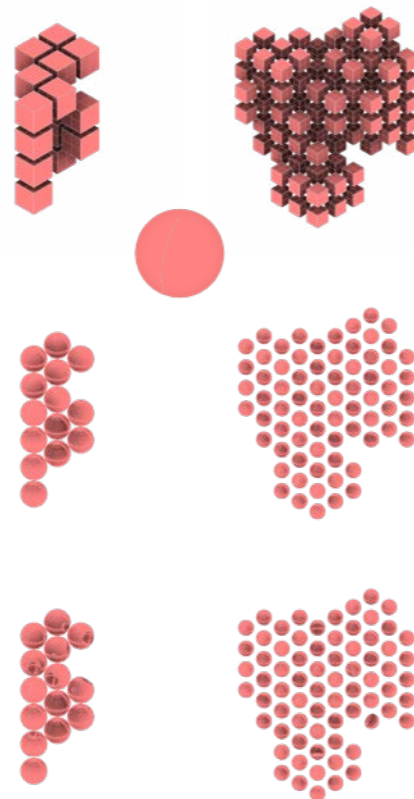


Transformation to a individualised object

The last and fifth step of the algorithm defines four main things:

1. Create wanted the shape to replace boxes and add to Brep
2. Enclose previously BioMorpher generated box layouts with a bounding box
3. Enclose Breped shape with bounding box
4. Feed both bounding boxes into a morph
5. Repeat previous step to subtract the two generated and now morphed designs

With this tool, we can not only use squared for the Installation, but any shape desires. An example could be sphered or more complex ge-



1.

Create basic squares and volumes

Start with creating a simple geometry using the "Simple Box" command and a number slider. Using further the number slide and the "Series" command, array the shape into the XYZ axes.

2.

Adjust the randomness of the box positions

Using several "Gene Pools", "Point Construction's", "Closest Point", "Smaller Than", a number slider, the "Dispatch" and "Brep" command, randomise the position, size and density of formed the formed objects.

3.

Generating and picking the design compositions

Feed all variables into the "Genome" section of BioMorpher. Use the "Volume" command to define the volume previously generated geometry and feed into "Performance". Feed geometry into "Meshe(s)".

4.

Subtracting the two generated designs from another

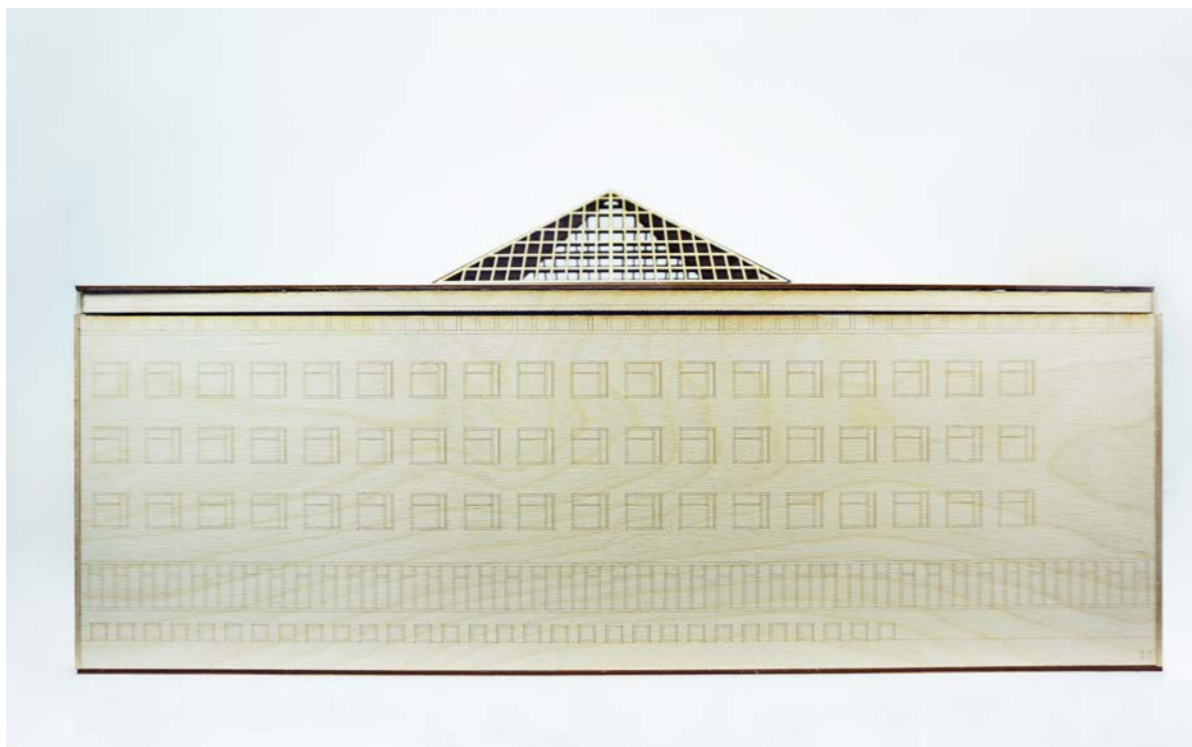
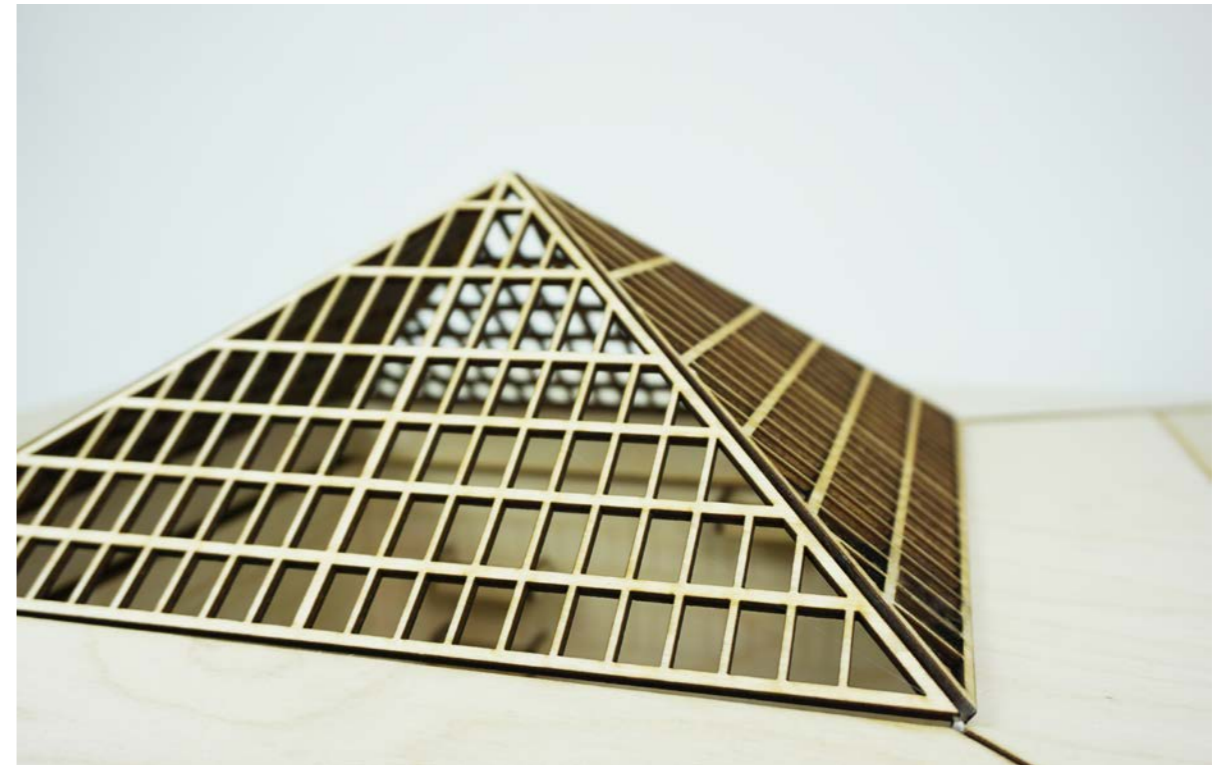
Repeat steps 1,2 and 3 to form second mesh geometry and use "Solid Intersection" to subtract from one another and form a new unique geometry.

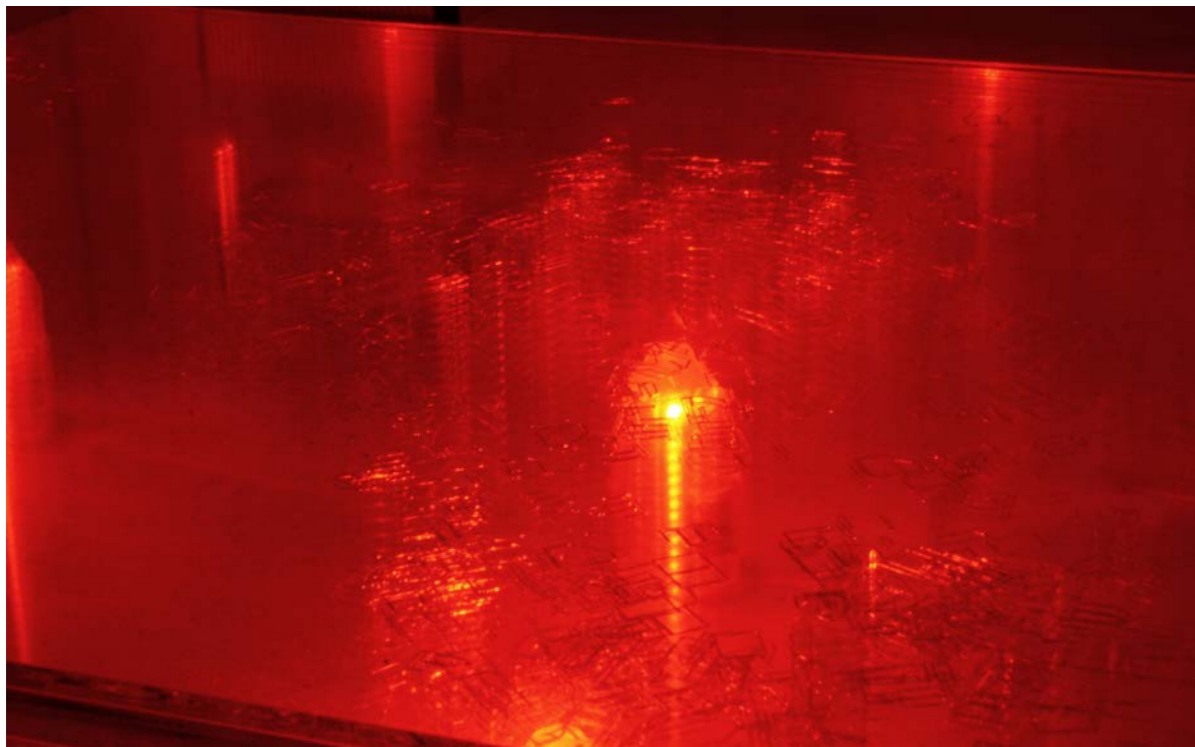
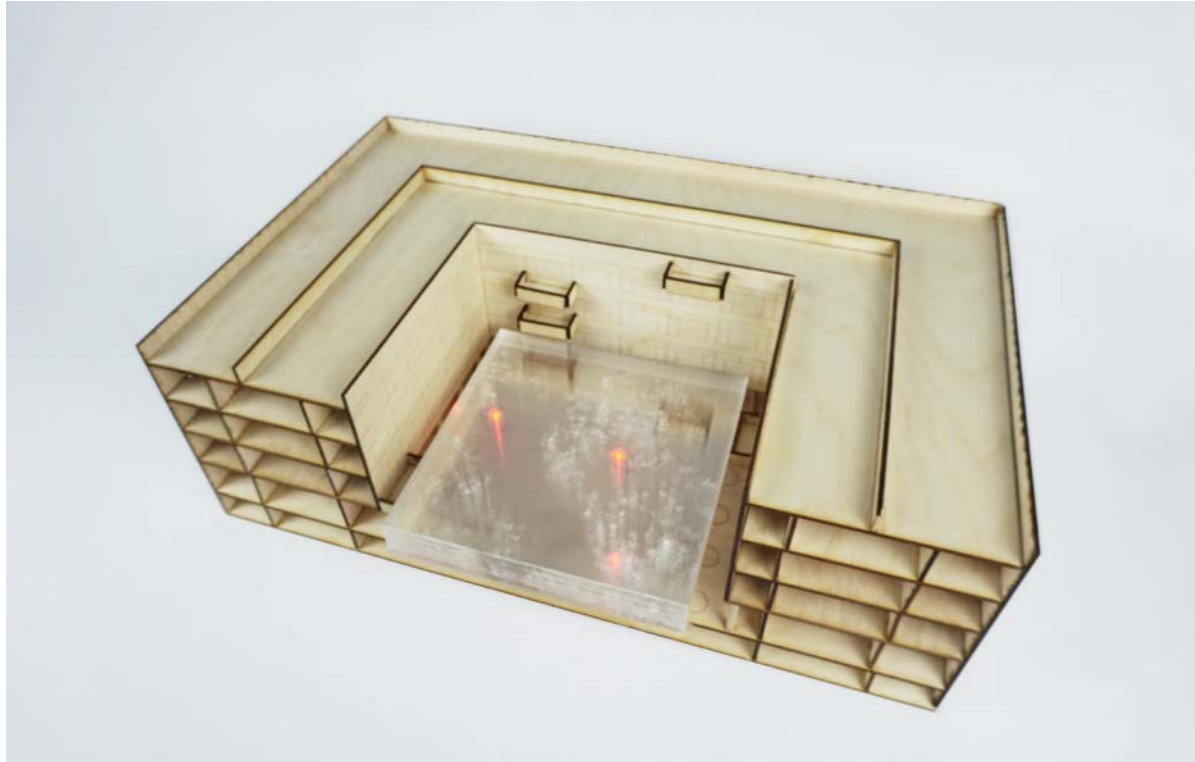
5.

Transformation to a individualised object

Use the "Bounding Box", "Box Morph", and "Mesh" or "Brep" command to transport the generated objects by BioMorpher into a unique, previously modelled object. Do this at the end to bypass a program crash.

Photos of physical model - 1:100





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