Master's thesis

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Climate adaptability and robustness of vernacular architectures

Master's thesis in Sustainable Architecture
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0.0 ABSTRACT

This master's thesis explores the adaptability and robustness of a specific kind of vernacular in Norway's cold climate. Using digital tools such as Rhino and Grasshopper, a parametric model is created to simulate under different climatic conditions and optimize its features.

Study begins by analysing the climatic context and identifying a specific vernacular typology. Characteristics of this typology were then traduced in numerical parameters that could be orientation, insulation, and design features etc. These elements are then incorporated into the parametric model to create a digitally optimized design that can respond to a range of climatic scenarios. The results demonstrate the potential of digital tools to stretch the model according to applied parameters and optimize its performance for different climatic contexts.

The study concludes by discussing the implications of the research findings for sustainable architecture design in cold climate regions, emphasizing the importance of preserving and learning from vernacular architecture as a valuable cultural and environmental resource. The thesis also suggests future research directions to explore the potential of digital tools to optimize the climate adaptability and robustness of vernacular architecture.

Keywords: Vernacular architecture, climate adaptability, robustness, optimization, digital tools.

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1.0 INTRODUCTION

Vernacular architecture represents the result of a refinement process in which construction and form of a building have been continuously revised in order to provide a shelter for the human habitat. Vernacular buildings have the inherent ability to optimally perform under specific regiona and climatic conditions. As a result of what is generally defined as a regionalist approach, these buildings express the result of a good interplay between human and natural environment, often implying the use of local materials and available craftsmanship, resulting in a unique expression of a region's architecture.

Today, vernacular structures are often identified as expression of a sustainable approach to architectural design, limiting the use of long-travelled materials and offering advanced solutions for climate sheltering. Today, environmental performance of principles embedded in vernacular architectures can be further enhanced thanks to the use of advanced digital tools available today.

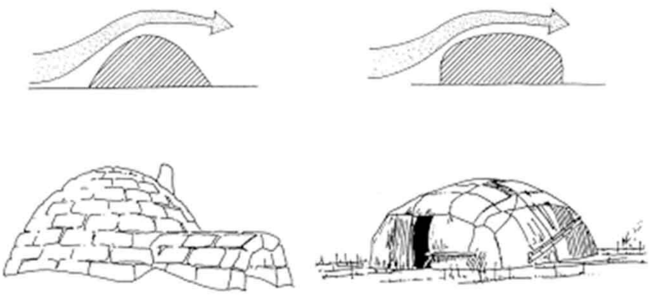


Figure 01: Bioclamatism in vernacular architecture.[1]

This master thesis aims to test the climate adaptability and robustness of a specific vernacular architecture in the cold climatic context of Norway, by digitally creating a parametric model using digital tools like Rhino and Grasshopper whose characteristics can be stretched and optimized to answer a wide range of possible climatic contexts and conditions. Norway's harsh winter climate makes it an ideal location to test the specified model to explore the potential of digital tools and eventually the relation with snow. This study will contribute to the ongoing conversation about the importance of preserving and learning from vernacular architecture as a valuable cultural and environmental resource.

Figure 1 presents an igloo as an exemplary representation of bioclimatism[1]. Bioclimatism involves utilizing natural resources and materials in building design to optimize local climate conditions. In the case of the igloo, the use of ice blocks for walls provides insulation, trapping heat inside and keeping the interior warm despite freezing temperatures outside. The igloo's rounded shape also reduces wind resistance, preventing snow drifts from accumulating around the structure.

Figure 02:Vernacular architecture in cold climate of Norway.[2]

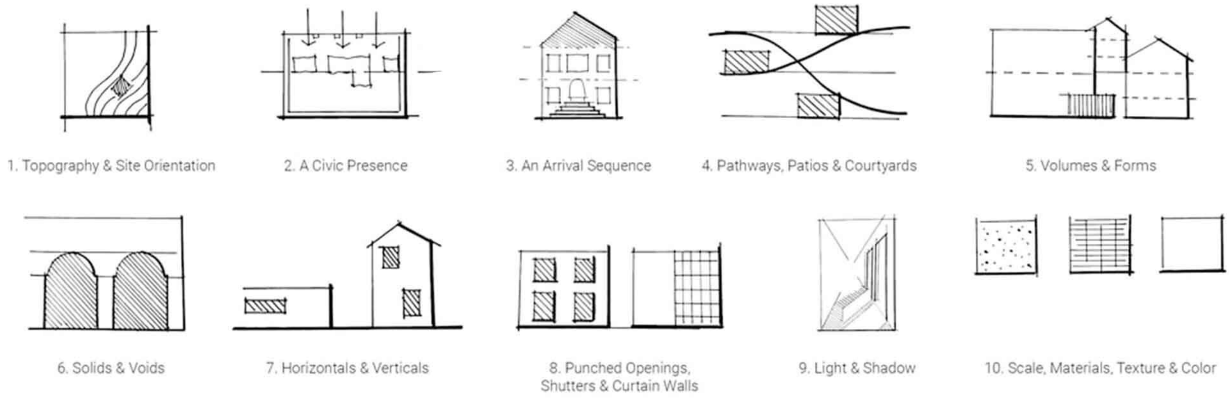


Figure 03: Vernacular architecture historic design principles.[3]

Figure 3 shows some of the essential historic design principles of Vernacular architecture.[3]

1.1 Importance of climate adaptability and robustness

Sustainability refers to the ability to maintain and balance ecological, social, and economic systems to meet the needs of the present without compromising the ability of future generations to meet their own needs. Climate change has brought about a pressing need for sustainability in architecture that can withstand and adapt to the increasingly extreme weather conditions experienced in many parts of the world.[4] Climate adaptability and robustness are key factors in the design of sustainable architecture, as they can help reduce energy consumption and limit the environmental impact of buildings. Robustness refers to the ability to adapt to changing environmental conditions while maintaining its performance and longevity.

Incorporating vernacular design principles into modern sustainable architecture can help create buildings that are better adapted to their local climates and can operate efficiently with minimal energy use. By prioritizing climate adaptability and robustness in sustainable architecture design, we can create more resilient and environmentally responsible built environments. Designing buildings in such regions requires consideration of factors such as heavy snow loads, strong winds, and extreme cold temperatures, as well as providing insulation to reduce energy consumption. With the potential impact of climate change intensifying extreme weather events, it is important to prioritize robustness in building design to ensure adaptability to changing conditions such as increased precipitation, melting permafrost, and shifting freeze-thaw cycles. Freeze-thaw cycles refer to the repeated process of freezing and thawing of water or moisture in a material or environment, which can lead to physical and structural changes. Figue 4 is an example of vernacular architecture in Norway. In this example the walls are sloped to allow for the shedding of snow, preventing heavy accumulations that could damage the structure.[5]

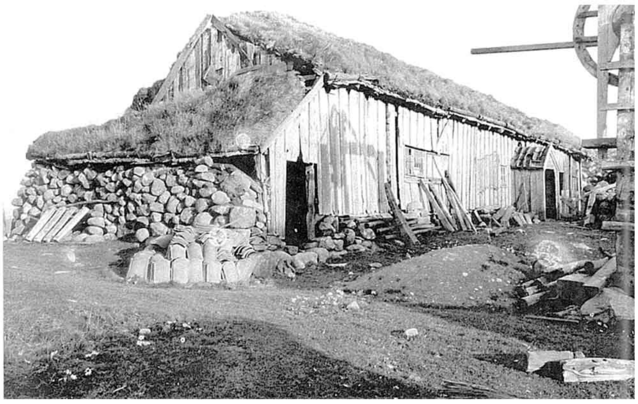


Figure 04: Jærhuset, Vernacular architecture in Norway.[5]

1.2 Research Question

How could we use digital tools in order to enhance inherent qualities of vernacular models and extend their climate adaptability?

1.3 Hypothesis and Scope

Vernacular buildings embed solutions for climate sheltering whose performance can be further enhanced by using digital tools.

The aim of this thesis is to explore the potential of parametric modeling tools for enhancing the climate adaptability of vernacular architecture in Norway's cold climate. To achieve this, we will digitally recreate a specific vernacular typology and analyze its performance under specific climatic conditions.

Through this process, we aim to test the climate adaptability and robustness of the digitalized vernacular model, and to identify potential design modifications that could improve its performance. Ultimately, this research aims to demonstrate how traditional vernacular knowledge and contemporary technological solutions can be combined to develop more effective solutions for climate sheltering in the context of cold climate.

2.0 METHODOLOGY

The methodology will start with a thorough literature review to establish the existing knowledge and theories related to vernacular architecture and its correlation with climate. A specific vernacular typology will be identified for the study, and a parametric modeling tool will be used to digitally recreate it.

The digital model will be subjected to climate simulation software to evaluate its performance under specific climatic conditions. The simulation will provide insights into the climate adaptability and robustness of the digitalized vernacular architecture and identify design modifications that could improve its performance. The results of the digital simulation will be compared to the existing knowledge and theories related to vernacular architecture and its correlation with climate. By combining traditional vernacular knowledge with modern digital tools, this study will demonstrate the potential for more effective solutions for climatesheltering. The research will contribute to the growing body of knowledge in the field of climate-responsive architecture and provide insights into how new tools can be used to enhance the climate adaptability of vernacular architectures.

The findings of this research could have significant implications for the field of sustainable architecture and construction, particularly in cold climate regions. The outcomes of this study may inform the design and construction of more effective, climate-responsive architecture solutions that take into account the unique challenges posed by Norway's cold climate. Figure 5 shows the general flow chart of this thesis.

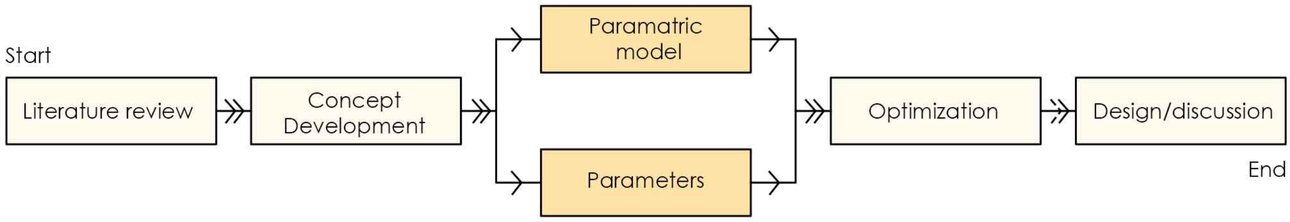


Figure 05: Methodology flowchart diagram.

3.0 TYPOLOGY AND CLIMATE

3.1 Selected typology

Goahti is a traditional example of Scandinavian vernacular architecture that has evolved over time to adapt to the harsh climate conditions of northern Norway, Sweden, and Finland. The design includes thick walls, and a roof covered with turf or shingles, which provide excellent insulation against cold temperatures, snow, and wind [6]. Therefore, the Goahti is an excellent example of how traditional vernacular architecture can be adapted to local climate conditions.

Its design could be considered as inherently sustainable because using locally sourced materials and traditional building techniques. This approach minimizes the environmental impact of the building process and ensures that the building blends into its natural surroundings.

The shape of the Goahti is also a notable feature that contributes to its climate adaptability. The circular shape allows for minimal exposed surface area, which reduces heat loss and enhances the structural integrity of the building in high wind conditions. This design also facilitates natural ventilation and the efficient use of space.

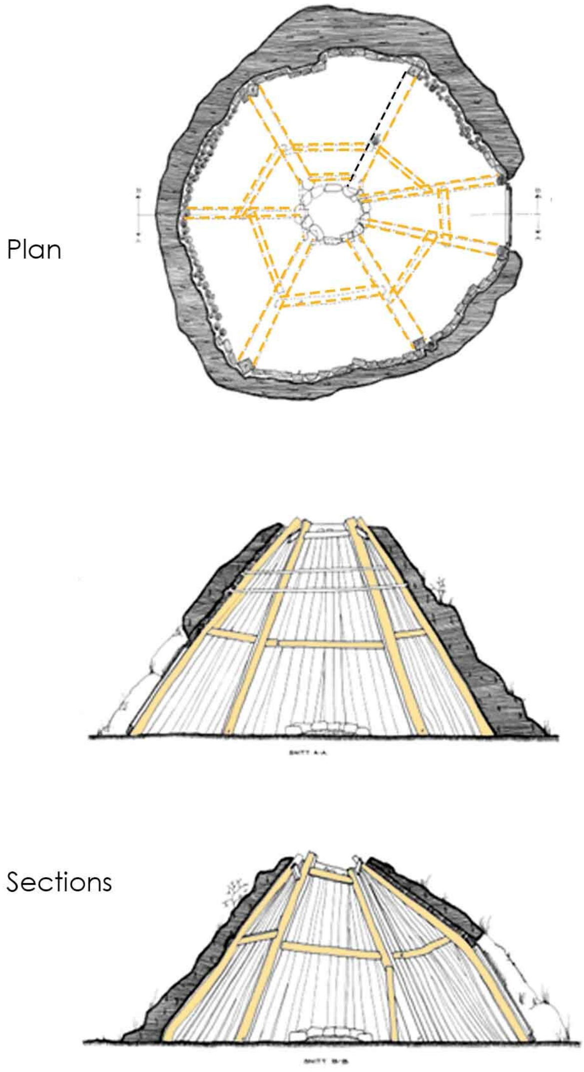


Figure 06: Goahti, Plan and sections.[6]

3.2 Strong qualities of the identified typology

- The utilization of a circular shape plays a vital role in enhancing thermal and wind efficiency. By eliminating corners and unused spaces, the circular design maximizes the utilization of available area. This design aspect further improves insulation, minimizing heat loss by reducing the surface area of the walls.

- As shape of base is circular or ellipse and can affect the way that wind and snow interact with the building, which can have a significant impact on snow accumulation. By varying one radius of the ellipse in the optimization process, it may be possible to create a shape that is better suited to the prevailing wind patterns in the area. For example, a longer radius on the side of the building facing prevailing winds may help to reduce snow accumulation on that side. In addition, an ellipse shape may also help to distribute wind more evenly around the building, which can reduce the likelihood of snowdrifts forming on one side of the building.

- The height can affect the amount of solar radiation that enters the building. A slimmer form stretching in height can receive more direct irradiation in the winter, which can increase solar gain and contribute to passive heating .By simulations and analyzing the results, we can identify the optimal combination of variables that maximizes solar gains and radiation while minimizing heat loss.

- Rotating variable around the X-axis can change its orientation relative to the sun's path throughout the day. By adjusting this we can optimize the building's exposure to direct sunlight, which can help increase solar gains and eventually gives suggestions about the optimal placment of windows and doors.

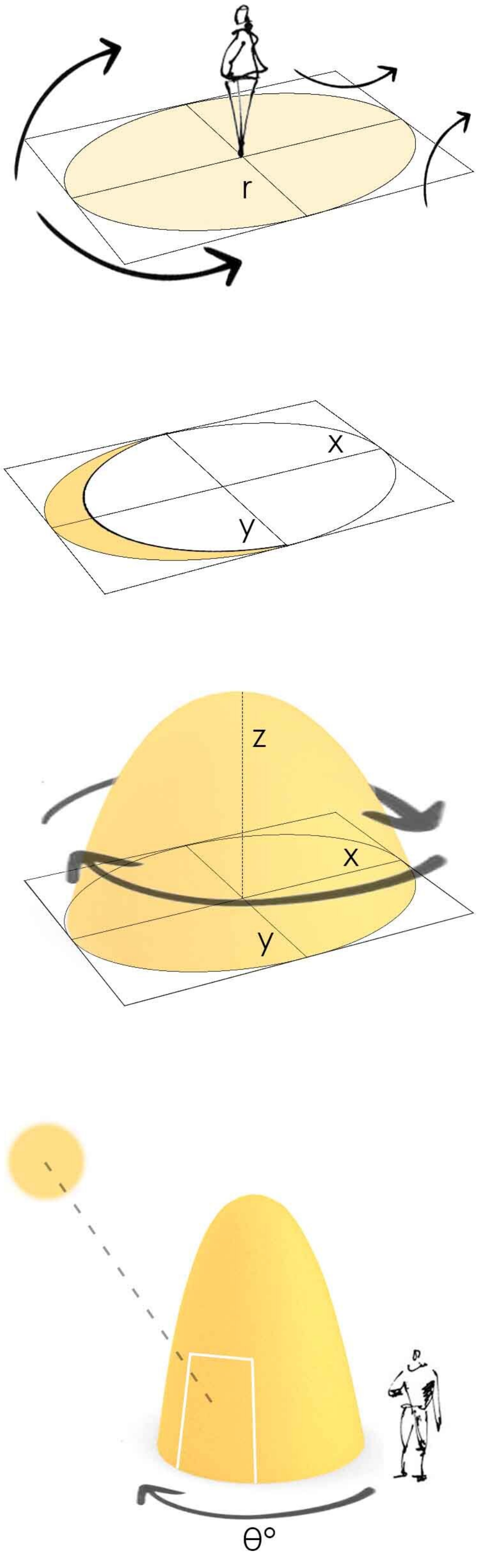


Figure 07: Graphical illustrations of strong qualities.
x = x axis, y = y axis, z = z axis, r = radius ,
θ° = Rotation angle

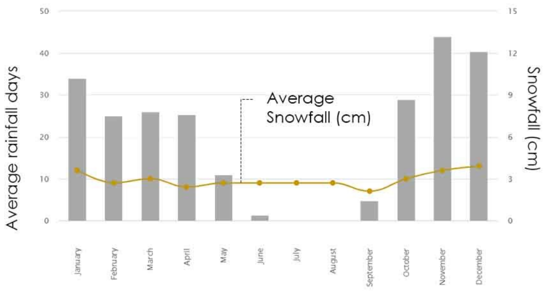
3.3 Selected region to test the model:

To test the model, Geilo city is selected. Geilo is a mountain town located in Norway, known for its scenic beauty and skiing opportunities. It is home to traditional architecture, including the famous stave churches and traditional log cabins [7].The selected typology (figure 06) might represents an alternative of these.

Geilo is located in a mountainous region and has a subarctic climate. The winter season is long, with snow covering the ground from November to May. The average temperature during winter ranges from -8°C to -12°C, with occasional drops to -20°C or lower.[8] The cold temperatures are accompanied by strong winds and snowfall, making it important for buildings to be well-insulated and protected from the elements. Traditional vernacular architecture in Geilo features steep roofs to shed snow, thick walls to provide insulation, and small windows to minimize heat loss. Additionally, the use of locally sourced materials such as timber and stone help buildings withstand the harsh climate. These traditional design elements have been developed over centuries of living in the region and offer a valuable source of knowledge for adapting to the cold climate. It is an optimal site to test the climate adaptability of the parametric model. This type of climate poses significant challenges in architecture. Other similar cities to test the model can be Røros, Trondheim and Alta.

Figure 08: Geilio Location - 60.5337° N, 8.2088° E. [9]

Average Snowfall



Average Temperature

Figure 09: Climatic charts. [8]

The warmest month in this location is July, with an average temperature of 11.0 °C (51.8 °F). This means that over the years, July has consistently had the highest average temperature among all the months.

On the other hand, the coldest month in this location is January, with an average temperature of -9.1 °C (15.7 °F). This means that January has consistently had the lowest average temperature among all the months.[8]

The difference between the warmest and coldest months is quite significant, with a range of 20.1°C (36.1°F). This suggests that the climate in this location may experience large seasonal variations in temperature, with cold winters and mild summers.

It's important to note that the temperature can vary significantly within a particular month, and this average temperature is just a generalization of the climate in that location. Also, it's worth noting that the average temperature of a location can be influenced by a variety of factors, such as altitude, proximity to water bodies, and prevailing winds.

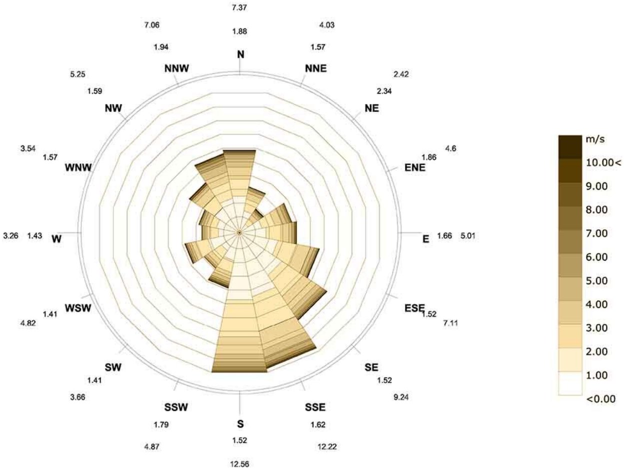


Figure 10: Wind Rose chart- Geilio, November til March.

Norway is known for its diverse and often unpredictable weather, with varying wind speeds throughout the year. The coastal regions tend to experience stronger winds, while the inland areas are typically calmer. In general, wind speeds are affected by a number of factors, such as topography, atmospheric pressure, and proximity to large bodies of water.

On average, wind speeds in Norway range from about 3-8 meters per second (m/s) inland, to 8-12 m/s along the coast. However, it's not uncommon for wind speeds to exceed 20 m/s during storms or extreme weather events. [10]

In Geilo, wind speeds can vary depending on the time of year and local weather conditions. The town is situated at an altitude of about 800 meters above sea level, which may influence the wind patterns. Generally speaking, wind speeds in Geilo may be slightly higher than in lower-altitude areas of the country.

The Wind charts in figure 10 and figure 11 is generated using Grasshopper with ladybug plugin with Geilo climate weather file in EPW format. An EPW file is a type of weather file that contains hourly weather data for a specific location, including temperature, humidity, wind speed, solar radiation, and other climatic variables. The major prevailing winds in Geilo blow from south to north between November and March. The decision to focus on winter months in the chart was based on the fact that snow is more likely to form during this time due to colder temperatures and lower humidity, which are also reflected in the EPW file.

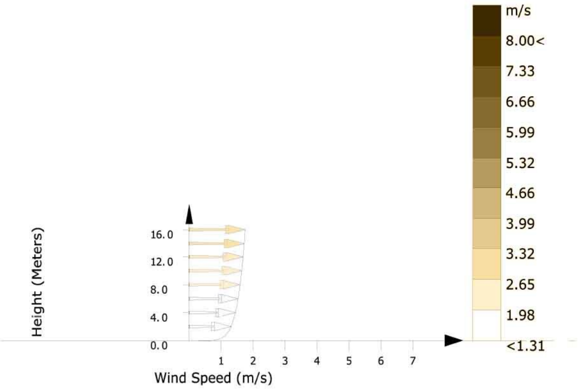


Figure 11: Wind Profile - Prevailing Wind average Velocity, November til March

As shown in the figure 11, the wind speed at heights of up to 16 meters in the Geilio is around 1-6 m/s. This means that the wind is relatively mild and not particularly strong, as wind speeds are typically measured in meters per second (m/s). This is general velocity and subject to change according to context.

4.0 OPTIMIZATION AND TARGETS

Optimization refers to the use of computational tools and algorithms to enhance the efficiency, precision, and performance of design solutions. This chapter will highlight the optimization methodology and targets.

4.1 Optimization methodology

To optimize the design of a building, architects and engineers often use advanced tools and techniques, such as parametric modeling, simulations, and analysis softwares. In this particular case, the process began with creating a parametric model of a selected typology using Rhino and Grasshopper software. This model incorporates all the variables and constants derived from the concepts and requirements of the selected parameters.

Once the parametric model is created, simulations can be conducted based on selected targets. These simulations evaluates the building's performance. The results of these simulations are subject to optimize. To perform this optimization Wallacei simulation software is used, which is a multi-objective optimization tool that identifies the Pareto front results. The Pareto front results represent the optimal solutions based on multiple performance criteria.

After obtaining the Pareto front results, the next step is to evaluate the building's behavior under wind and snow loads. This is done using Simscale software, which is a cloud-based simulation platform that allows for virtual testing of building designs. By testing the building's form and structure under different weather conditions, it was possible to identify areas for improvement and further optimize the design based on the chosen concept.

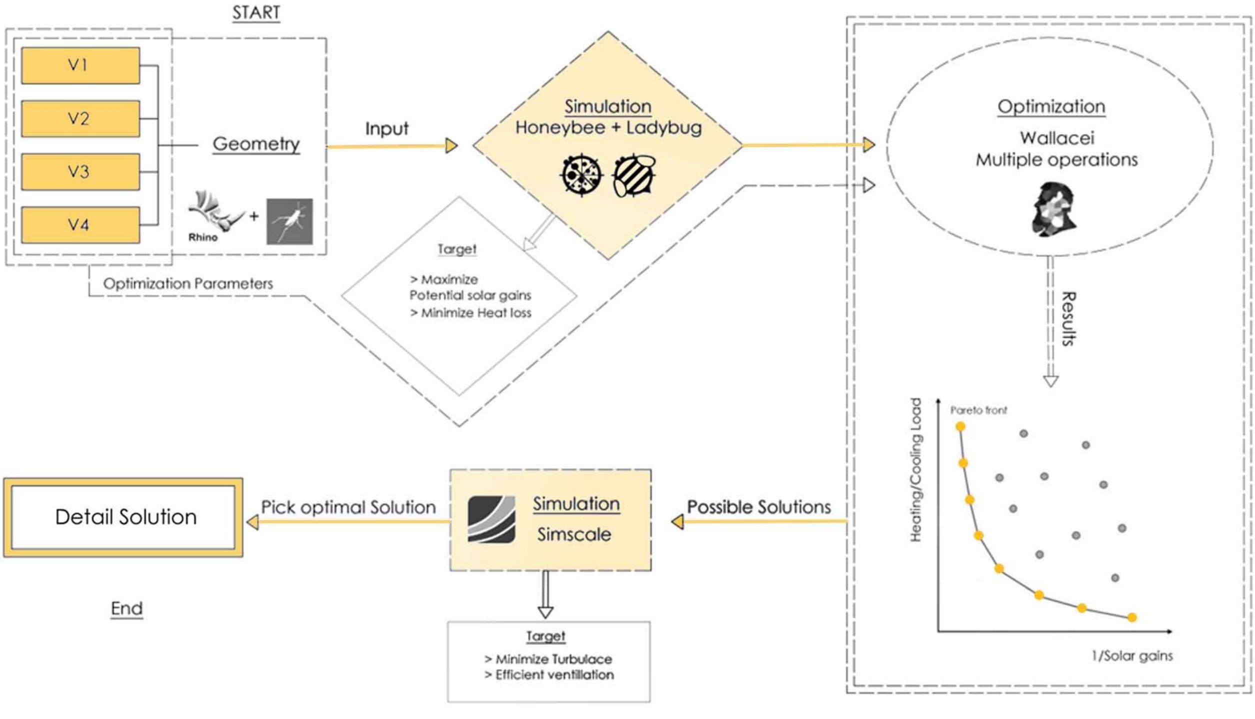


Figure 12: Optimization flow chart diagram.

4.2 Digital tools

4.2.1 Rhino and Grasshopper

Rhino and Grasshopper are widely used in architecture for creating parametric models due to their flexible and intuitive workflow. The software allows designers to create complex 3D geometries and manipulate them easily. Grasshopper, a visual programming language, makes it possible to create parametric models by defining relationships between variables and parameters, enabling the creation of complex systems with many interdependent variables.

Integration of simulations and optimization software with Rhino and Grasshopper allows real-time evaluation of designs based on specific performance criteria. The resulting optimized designs lead to more energy-efficient, sustainable, and functional buildings. This approach enables architects and designers to explore various design options quickly and make informed decisions based on the performance of the design. In summary, Rhino and Grasshopper provide powerful tools for creating parametric models in architecture, making it possible to create buildings that meet both aesthetic and functional requirements.

4.2.2 Wallacei optimization

Wallacei is a powerful optimization tool in Grasshopper, capable of handling multi-objective optimization problems with efficiency and ease. Its intuitive interface, ability to handle complex problems, and capacity to incorporate uncertainty and variability make it a valuable tool for architects and designers. It enables the discovery of optimal solutions for selected targets, making it a standout tool in the field of architecture.

The Pareto front, also known as the Pareto set or Pareto frontier, is a set of optimal solutions in multi-objective optimization. In such optimization problems, there are multiple objectives that need to be optimized simultaneously, and these objectives may be in conflict with each other, meaning that improving one objective may lead to a deterioration in another.

The Pareto front consists of those solutions that are not dominated by any other solution in terms of all objectives. In other words, a solution is Pareto optimal if no other solution is better than it in all objectives. Solutions that lie on the Pareto front are called Pareto optimal solutions or non-dominated solutions. An example of pareto front is shown in the optimization flow chart diagram. Another approach is to use simulation-based methods, such as Monte Carlo simulation, to explore the solution space and identify the Pareto front.

4.2.3 Simsclae

SimScale is a valuable simulation platform for architects and engineers, enabling them to analyze wind behavior surrounding buildings.It accurately predicts wind patterns and identifies areas of high wind pressure. Where as it cannot directly forecast snow formation but examining Vortex information can help to identify slow speed. This information is instrumental in analyzing snow deposition and optimizing the building's design to reduce snow accumulation.

By leveraging SimScale's capabilities, architects and engineers can enhance their understanding of wind effects, optimize building performance, and create more resilient structures.

4.3 Optimization Targets

The selected parameters for this optimization study, includes heat loss/gains, radiation analysis, and wind/snow analysis. These are crucial in evaluating the climate adaptability of vernacular architecture in cold climates.

4.3.1 Heat loss/gains

As general principle, heat gains refer to the heat accessing the building, while heat losses refer to the heat that dissipate from the building. In order to maintain thermal comfort inside the building, it is important to achieve an optimal balance between them [11]. This means that the building should not be too hot or too cold, and the temperature should be consistent throughout the building.

An optimal balance between heat gains and losses can be achieved through various means, such as through proper insulation, the use of energy-efficient windows and doors, and the installation of ventilation systems that allow for controlled air exchange. By reducing the amount of heat that enters or leaves the building, it is possible to significantly improve the energy efficiency of the building.[11]

By optimizing the heat loads of a building, it is possible to reduce the need for additional heating or cooling systems, which in turn reduces the amount of energy required to operate the building, ultimately reducing its carbon footprint

4.3.2 Radiation

When designing a building in a cold climate, it is important to consider the impact of solar radiation on the building's energy efficiency and occupant comfort. Solar radiation can be used to provide passive solar heating, which can significantly reduce the amount of energy required to heat the building [12].

A radiation analysis involves studying the solar radiation patterns in the building's location to determine the best building form to maximize solar gains and reduce heat loss. By optimizing the building form to maximize solar gains and reduce heat loss, it is possible to significantly improve the energy efficiency of the building. For example, a building with a south-facing facade that is properly insulated and designed to capture solar radiation can significantly reduce the amount of energy required to heat the building.

In addition to enhancing energy efficiency, conducting a radiation analysis in architecture can contribute to occupant comfort. By optimizing solar gains, natural and passive heating can be achieved, thereby maintaining a pleasant indoor temperature. This, in turn, reduces the reliance on additional heating systems that may cause noise and disturbances for occupants. By prioritizing solar radiation analysis, architects can create designs that promote thermal comfort and minimize the use of mechanical heating, resulting in a more peaceful and comfortable environment for building occupants.

4.3.3 Wind / Snow

Wind analysis involves studying the patterns and strength of the winds in the building's location to determine the impact on the building's structural integrity and thermal performance. Wind can cause heat loss through infiltration of cold air, and can also damage the building's structure if it is not properly designed to withstand the forces of the wind [13].

A snow analysis involves studying the patterns and accumulation of snow in the building's surrounding to determine the impact on the building's thermal performance and safety. Snow can cause heat loss through insulation compression and can also cause damage to the building's structure if it is not designed to withstand the weight of the snow.

A comprehensive wind and snow analysis empowers architects and engineers to optimize building shape, orientation, and materials for enhanced performance. By adjusting the building's orientation, exposure to prevailing winds can be minimized, leading to improved thermal comfort. Additionally, the analysis aids in designing doors and openings strategically to minimize wind-driven infiltration and optimize natural ventilation.

These insights enable the creation of resilient, energy-efficient buildings that prioritize occupant well-being in adverse weather conditions.

5.0 CONCEPT AND MODEL FORMATION

In this chapter we will first go through the concept development and eventually how it helped forming the parametric model. The concept of the design has been developed based on the fundamental circular plan of the chosen typology. In order to achieve the target values of the optimization parameters, which include heat gains and losses, radiation analysis, and wind/snow analysis, the constants and variables of the design have been defined accordingly. The qualities of the selected vernacular architecture typology, that has been discussed in chapter 3.2, have been taken into consideration during this process. By aligning the design concept with the identified qualities of the traditional architecture, the resulting design is more likely to be successful in terms of climate adaptability and energy efficiency. The selection of appropriate constants and variables is critical in ensuring that the design meets the desired performance targets while also being aesthetically pleasing and culturally appropriate.

5.1 Variables

Variable 01 = V1

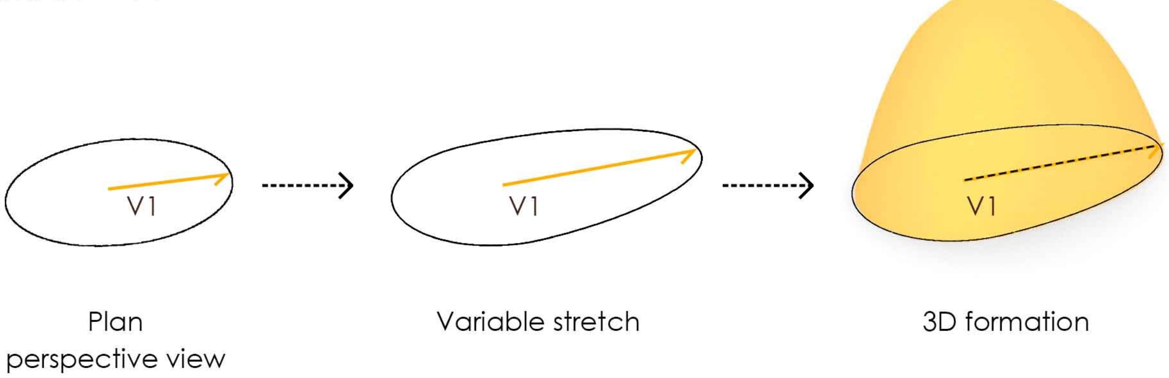


Figure 13: Variable 01 - Concept development illustration

Variable 02 = V2

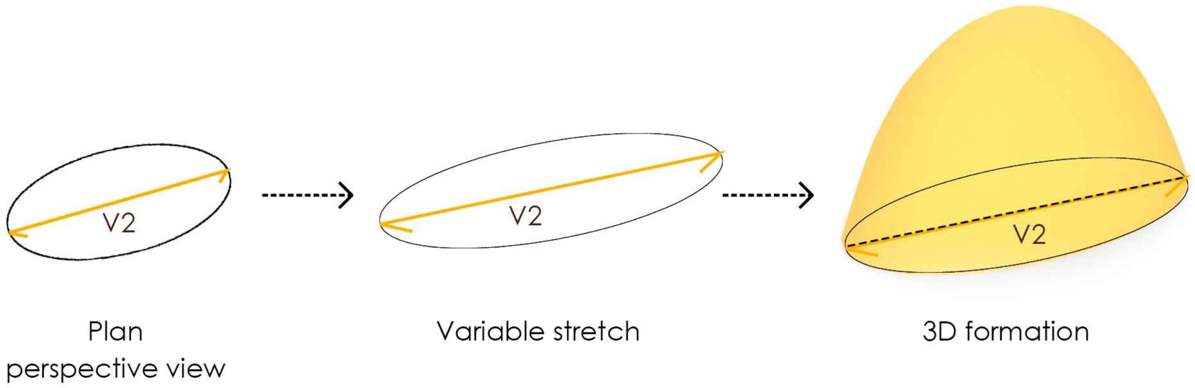


Figure 14: Variable 02 - Concept development illustration

Variable 03 = V3

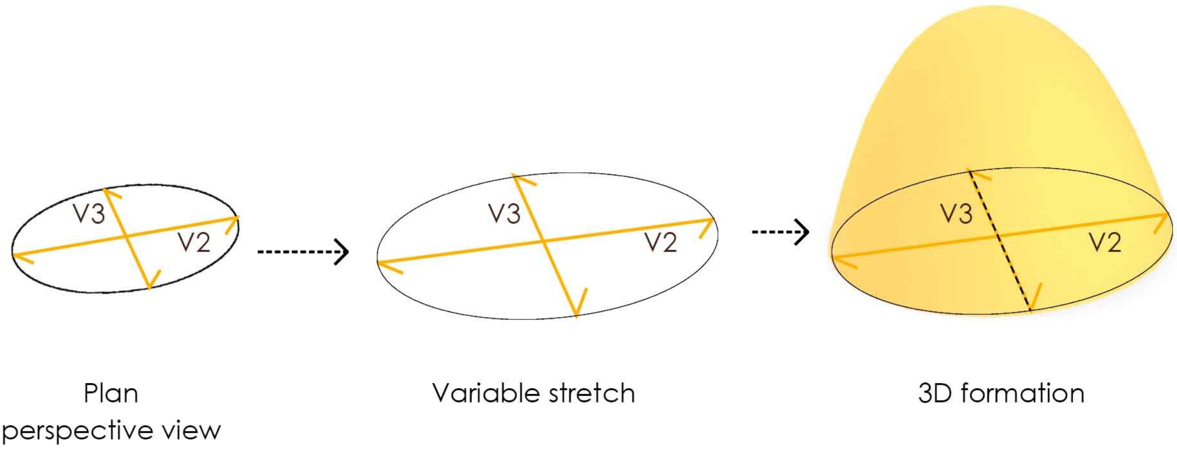


Figure 15: Variable 03 with variable 02 - Concept development illustration

Variable 04 = V4

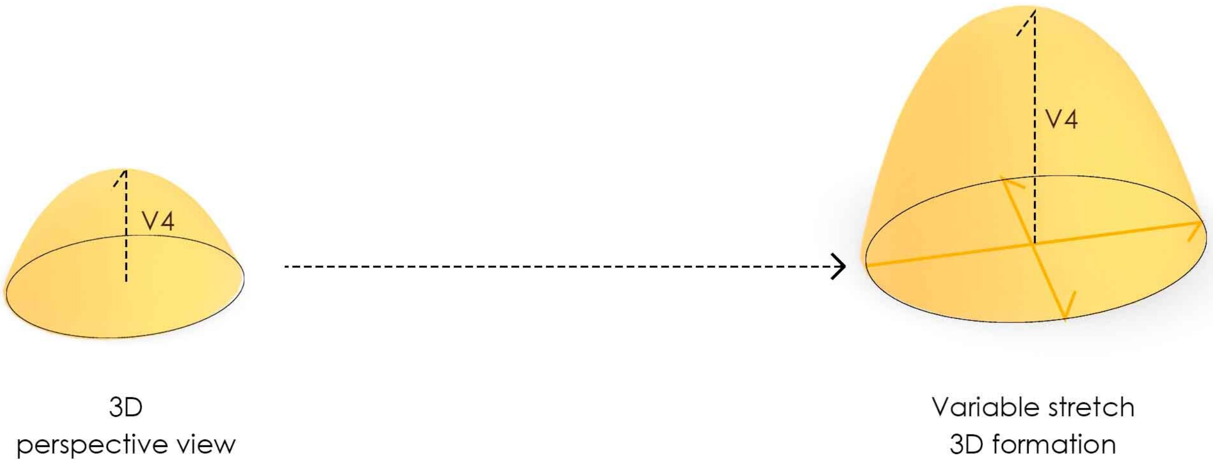


Figure 16: Variable 04 - Concept development illustration

Variable 05 = V5

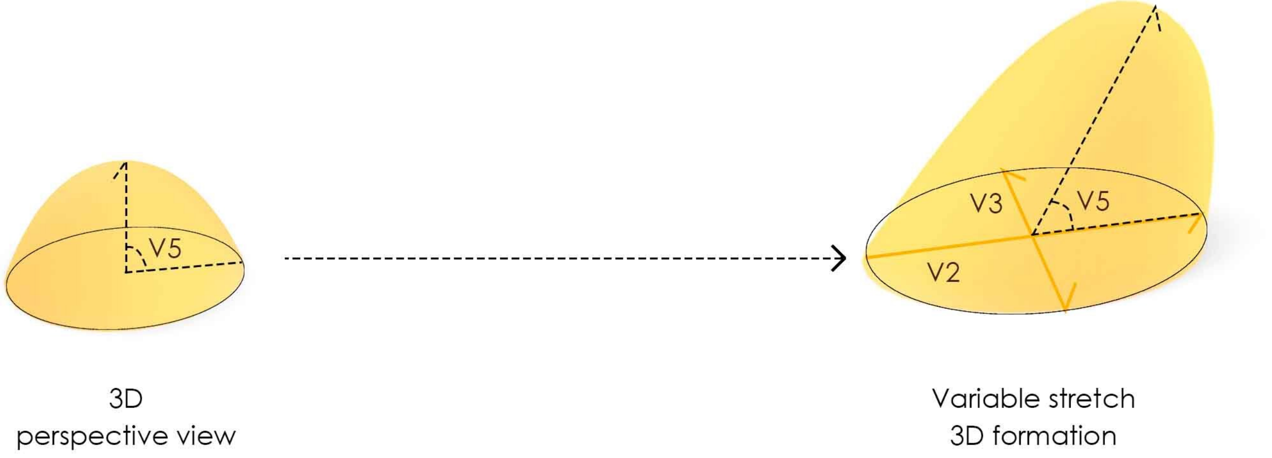


Figure 17: Variable 05, measued in angle - Concept development illustration

5.2 Constants

The typology is set to be a residential unit and the constants are defined according to the limitations set by requirements of a residential units. In this thesis, we are testing Microhouse category. The requirements of a microhouse have been pre-defined and implemented in the parametric model according to the new TEK 17 regulations of Microhouse. These regulations that are set to be implemented from 1st July 2023. The residential unit that is being tested for climate adaptability is subject to various constraints and considerations. It is important to note that the optimization process only considers a discrete number of variables that has been discussed in the chapter 5.1.

It is important to consider that the building must be designed exclusively for residential purposes and must include all main functions necessary for comfortable living. These functions include a living room, kitchen, sleeping area, bathroom, and toilet, standards for safety, functionality, and livability.

TEK 17 is a set of Norwegian building regulations that outlines requirements for the energy performance of new and existing buildings. It is the latest version of the technical regulations for energy performance in buildings in Norway and it was introduced in 2017.[14]

The main objective of TEK 17 is to ensure that buildings are designed and constructed to be energy efficient, sustainable, and environmentally friendly. It sets out minimum standards for energy use in buildings, including requirements for insulation, ventilation, and heating systems. In addition to energy performance, TEK 17 also includes requirements for indoor climate and air quality, water supply and sanitation, and fire safety. It aims to ensure that buildings are comfortable, healthy, and safe for occupants.

5.2.1 Microhouse in accordance with TEK 17

A microhouse is a type of residential dwelling that is typically smaller in size than a traditional house, and is designed to be a compact, functional, and efficient living space. These types of houses have become increasingly popular in recent years due to rising housing costs, population growth, and concerns about sustainability.

Microhouses are an increasingly popular housing option due to their small size, affordability, and efficiency. However, it is important to note that while microhouses have fewer building technical requirements than a traditional detached house, there may be restrictions set by municipal land plans. These restrictions can relate to the location of the house, as well as how much and how the house can be built on an individual plot. It is therefore important for individuals interested in building a microhouse to research the local building codes and regulations in their area before embarking on a project. Proper planning and adherence to regulations can help ensure that the microhouse is a safe and functional. Some of the regulations according to TEK 17 are:

- Totalt BTA cannot exceed 30m². BTA stands for "building total area" or "brutto totalareal" in Norwegian. It is a measurement of the total floor area of a building, including all interior spaces such as rooms, hallways, and stairwells, including exterior walls.[15]

To implement this, we have used “Expression” component in grasshopper as shown in the figure 18. An expression is a single line of code that can be used to process data.

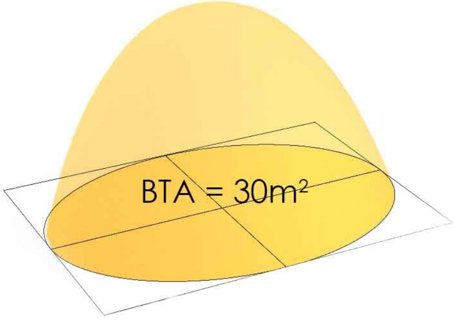


Figure 19: Illustration floor plan, total BTA.

It is also specified that the microhouse should have only one floor without a basement, so the total maximum BTA has to be adjusted in one floor.[15]

- The building is not allowed to exceed a certain height, specifically 4.5 meters above the ground level. This restriction ensures that the building does not go beyond a specified maximum height.[15]

To implement this restriction in a Grasshopper script, Variable V4 is employed. In the script, Variable V4 represents the height of the microhouse. By directing this Variable to the z-axis (which typically

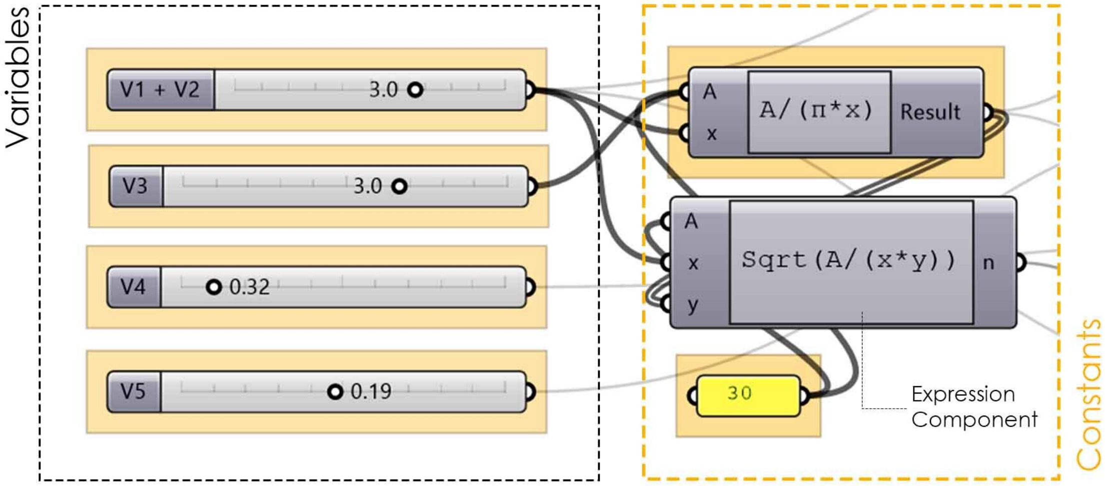


Figure 18: Grasshopper script showing variables and constants.

represents the vertical direction in three-dimensional space), it determines the total height of the structure.

To abide by the height limitation, Variable V4 is constrained within a specific range. The range is set from 2.6 meters (which is likely the minimum acceptable height) to 4.5 meters (the maximum height allowed). This constraint ensures that the microhouse's total height, as represented by Variable V4, does not exceed 4.5 meters above the ground level at any point.

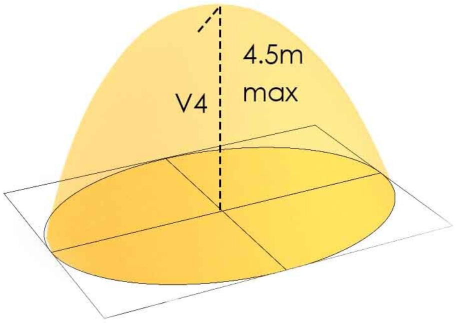


Figure 20: Illustration, maximum height.

In addition to the specific limitations or height restrictions mentioned earlier, there are other regulations that are associated with the design of a microhouse. These regulations may not directly impose limitations but provide guidelines and requirements that are helpful in the design process.

One such regulation is that even for a microhouse with a size of up to 30 square meters, it still needs to adhere to the requirements outlined in the Planning and Building Act. This Act sets forth various provisions and regulations related to construction and building projects. Despite the small size of a microhouse, it must comply with these regulations, ensuring that certain standards are met.

These regulations cover various aspects, including the location of the house. This means that the microhouse must be built in accordance with the designated areas or zones specified by the local planning authorities. The regulations may outline specific requirements regarding the permitted areas for residential construction or other zoning considerations.

Furthermore, the regulations related to water and drainage solutions come into play. The microhouse must meet the requirements for water supply, plumbing, and drainage systems. This ensures that the house has access to clean water and proper waste management systems, maintaining sanitation and hygiene standards.

Waste disposal is another aspect covered by the regulations. The microhouse must have appropriate solutions for waste management, including provisions for garbage disposal and recycling, in accordance with the local waste management guidelines.

5.2 Model Formation

Designing a parametric model encompassing various variables, limitations, and constants posed a formidable challenge. The objective was to develop a model capable of conducting the necessary optimization simulations as discussed in chapter 4.3. By analyzing the results obtained from these simulations, a refined solution could be achieved, incorporating crucial design elements such as doors and openings.

Furthermore, the parametric model considered important factors like U values, which play a vital role in energy simulations. These values were determined based on the desired targets. The next chapter will delve deeper into the discussion of these U values, providing a comprehensive understanding of their impact on the overall design. ultimately leading to an informed and well-considered design solution.

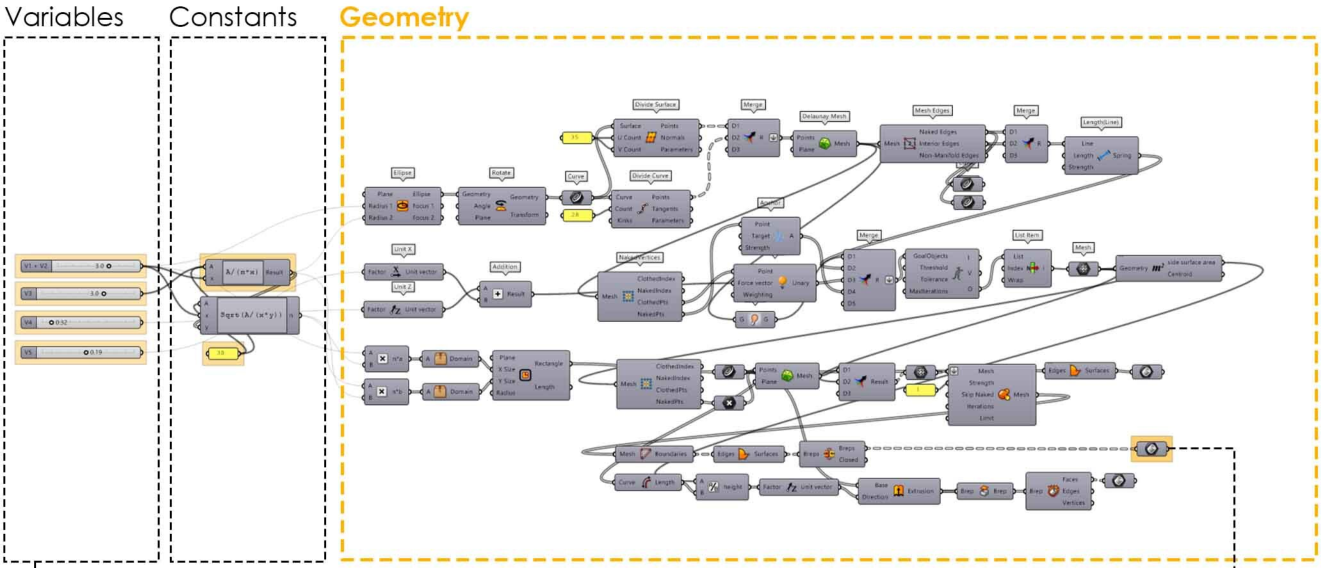


Figure 21: Grasshopper script of parametric model.

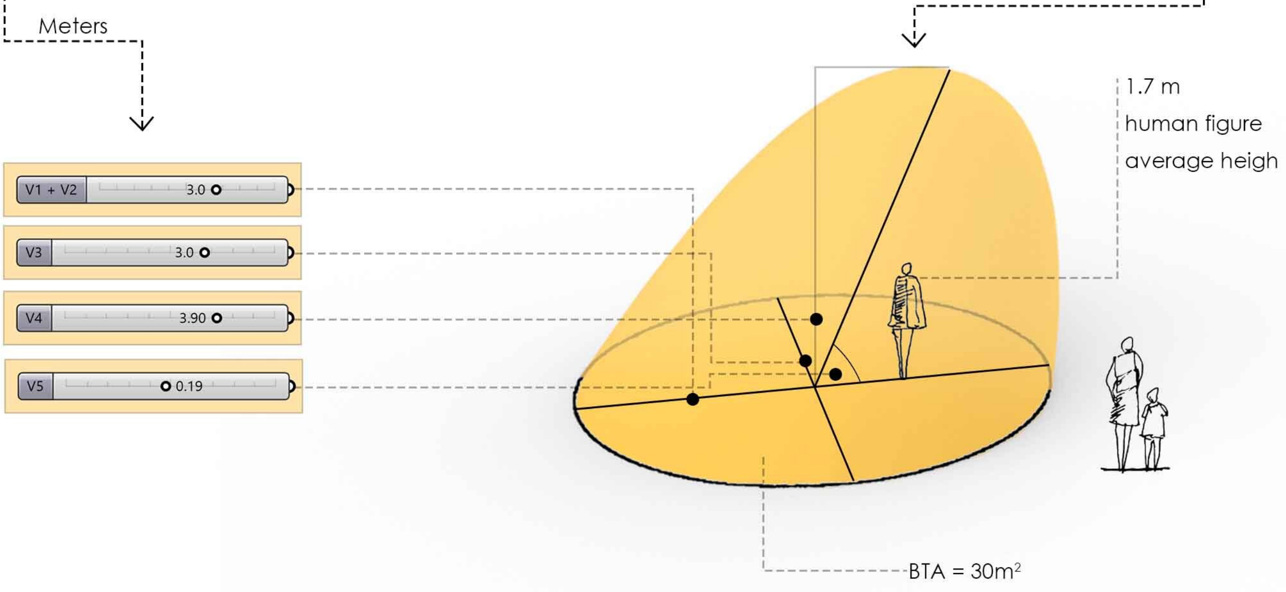


Figure 22: Parametric model, Baked Brep from grasshopper script. Human figure is used to hightlight the scale of model.

After establishing the basic curves and meshes, the "Kangaroo2" solver was chosen for the parametric modeling in this thesis. Its physics-based simulation capabilities allowed for dynamic behavior exploration. Through simulations of bending, stretching, and collision detection, the model's performance and structural integrity were refined. Kangaroo2 seamlessly integrated into Grasshopper, providing real-time feedback for efficient design exploration [16]. Its reputation and widespread usage made it a reliable and trusted choice, enabling the project to push boundaries and achieve desired outcomes.

6.0 SIMULATIONS AND RESULTS

This chapter summarizes the process of developing a script for simulations . It explains how the script was developed through integrating different numericals in computation to make it perform efficiently and accurately. Testing and validation procedures were also done to ensure the script's reliability. After obtaining the simulation results, the analysis and comparison against the predefined targets and objectives enabled the selection of the final result for further detailing. The selection criteria encompassed various factors, such as the model's feasibility, compliance with regulations, and overall design performance.

6.1 Radiation simulation and results

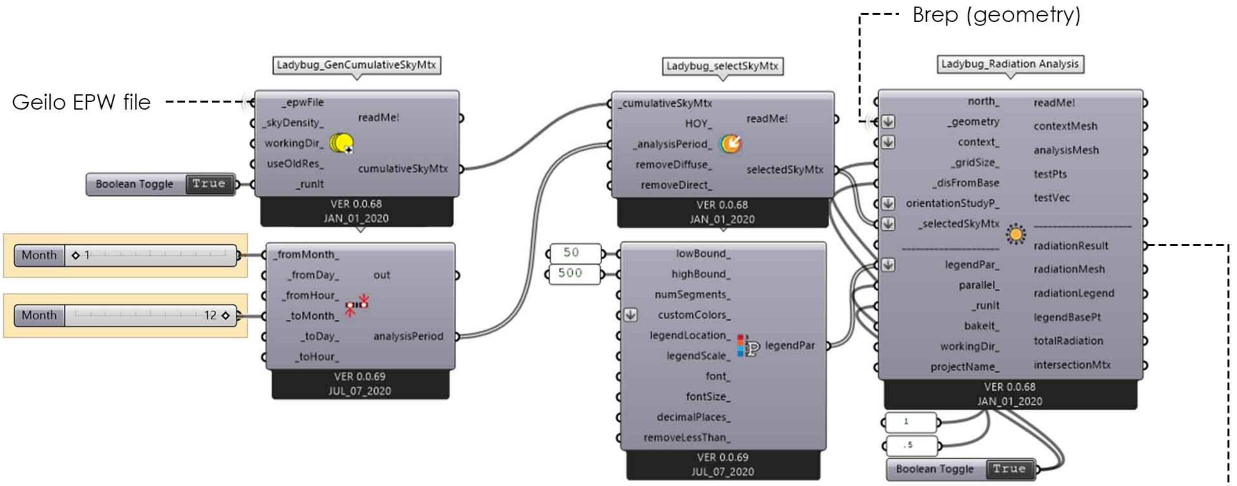


Figure 23: Grasshopper script of Radiation analysis.

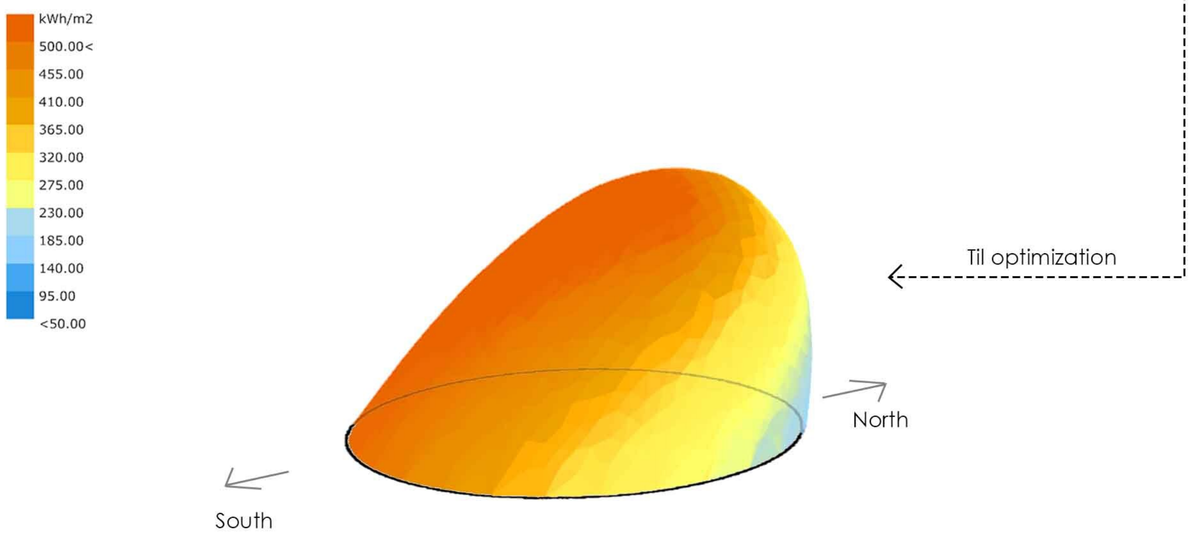


Figure 24: Radiation simulation result, January til december analysis period.

When performing radiation analysis in Grasshopper, two critical aspects to consider are time and duration, as well as simulation parameters. Time and duration refer to the specific time range and length for which the solar radiation analysis will be conducted. It is essential to define the time steps and frequency at which the simulation will be performed, whether it is analyzing daily variations, monthly trends, or yearly solar exposure. The duration selected will depend on the project requirements and the level of detail needed. Simulation parameters play a crucial role in the accuracy and computational efficiency of the analysis. Solar radiation analysis take into account the morphological characteristics of the model in relation to sun movement and radiation patterns, so the only input is geometry and not the elements related to construction or other specific characteristics. Accuracy settings control the precision of calculations, allowing to balance computational efficiency with the desired level of accuracy.

6.2 Heat gain/loss simulation and results

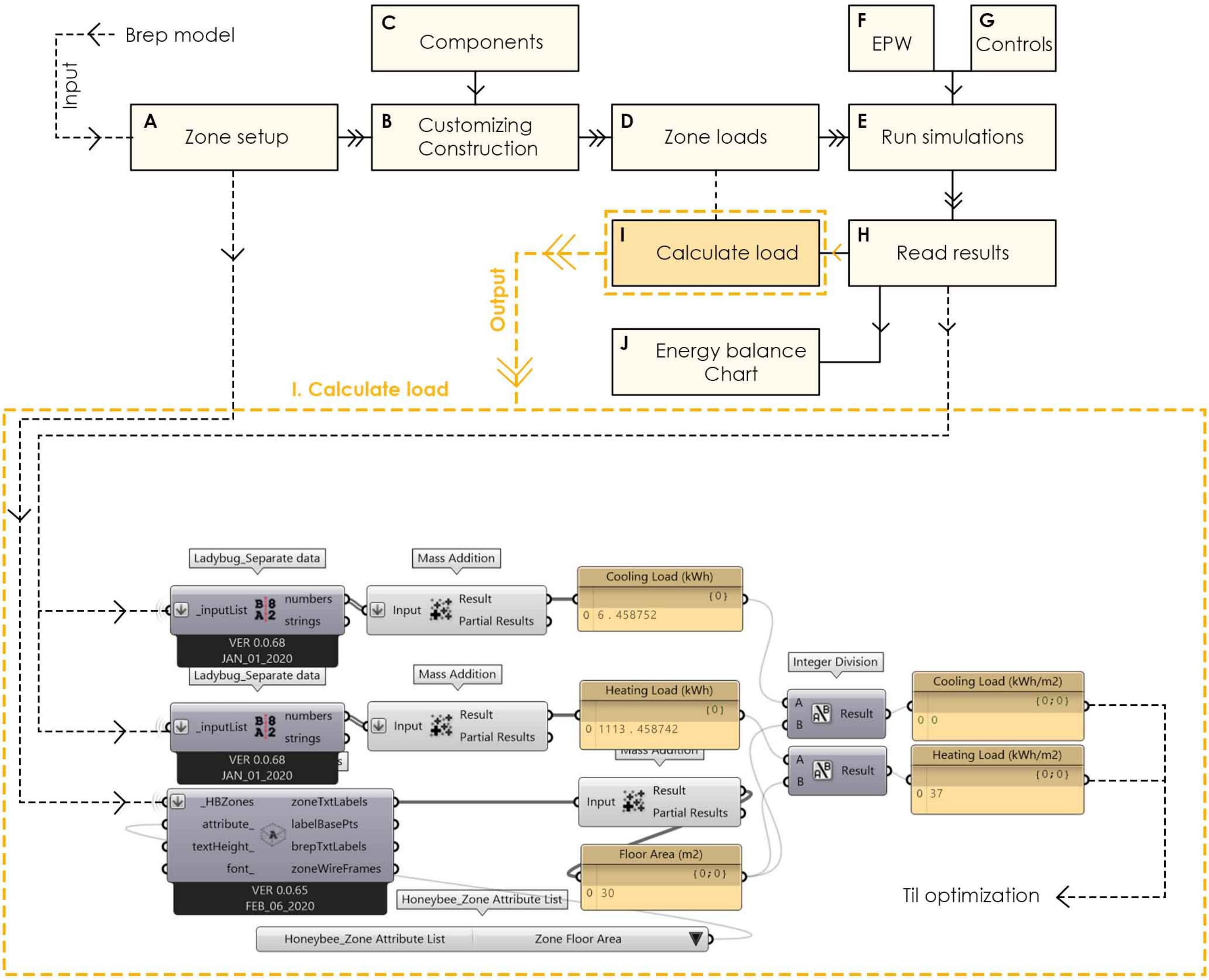


Figure 25: Heat gain/loss simulation flowchart with detial script of "Calculate load" from grasshopper.

A. Zone setup:

In zone setup the component " Masses2Zones" is used. the primary purpose is to convert mass models into thermal zones for energy calculations and simulations.
To begin, the mass model, typically represented as a Brep (Boundary Representation) in Grasshopper, is connected to the input of the "Masses2Zones" component. The Brep represents the simplified geometric shape of the building.

However, in order to perform accurate energy calculations, it is necessary for the model to have planar faces. This means that all the surfaces of the building should be flat, without any curved or complex geometries. To address this issue, a workaround is implemented.

A box geometry is created within the Grasshopper script, which has the same overall wall, roof, and floor areas as the original mass model. The box acts as a proxy or substitute for the complex mass model, allowing for energy calculations to be performed accurately.

The box is then connected to the relevant variables and parameters within the Grasshopper script, effectively replicating the important characteristics of the original mass model. This ensures that the energy calculations and simulations conducted using the thermal zones derived from the box geometry provide meaningful and representative results.

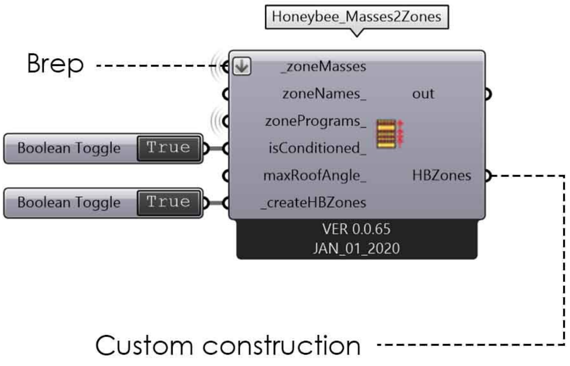


Figure 26: Honeybee Masses2zones component

B. Customizing construction:

To add customise components, the" EnergyPlus Construction component" is used. This enables users to create their own building constructions. It accepts inputs in two forms: the name of a material from the OpenStudio construction library or custom material generated using EnergyPlus Material components that we used in this simulation, by specifying properties like material thickness and conductivity.

C. Components:

To accurately calculate heating loads in a building model, it is crucial to define the materials used and their corresponding U values. The U-value represents the overall heat transfer coefficient of a building element, such as a wall. In cold areas, like Norway, achieving suitable wall formations that meet specific requirements involves conducting a comprehensive study considering both construction feasibility and climate conditions.

In this context, a detailed analysis is necessary to determine an optimal wall and roof construction that balances thermal performance and climate suitability. Factors such as insulation thickness, insulation materials, air gaps, and thermal bridging need to be considered. Additionally, local building standards and guidelines, such as the NS3701:2012 passive house standard in Norway [17], can provide valuable benchmarks.

The NS3701:2012 standard focuses on passive house principles and sets rigorous energy efficiency requirements for buildings. By adopting these standards, the aim is to reduce heating loads and optimize overall energy performance. In the mentioned example, a targeted U value of 0.10 W/(m^2.K) for the walls has been chosen based on this standard, where as for roof it is 0.10 W/(m^2.K) [17].

A U value of 0.10 W/(m²·K) indicates that the walls provide a high level of thermal insulation, minimizing heat loss and optimizing energy efficiency. Achieving such thermal transmittance. requires careful consideration of wall compositions, including insulation materials with appropriate thermal conductivity, insulation thickness, and other factors that contribute to reducing heat transfer.

To make the composite that matches the targeted U-values, Byggforskserien U-value calculator has been used. Byggforskserien is a comprehensive collection of research-based publications providing guidance and knowledge on building and construction practices in Norway. These composites shows the most common solutions.

In the cold climate of Norway, a U-value of 0.10 W/(m²·K) for a roof is essential. It signifies exceptional insulation performance, minimizing heat loss and maximizing energy efficiency. This high level of insulation ensures that homes and buildings stay comfortably warm during harsh winters, reducing the need for excessive heating.

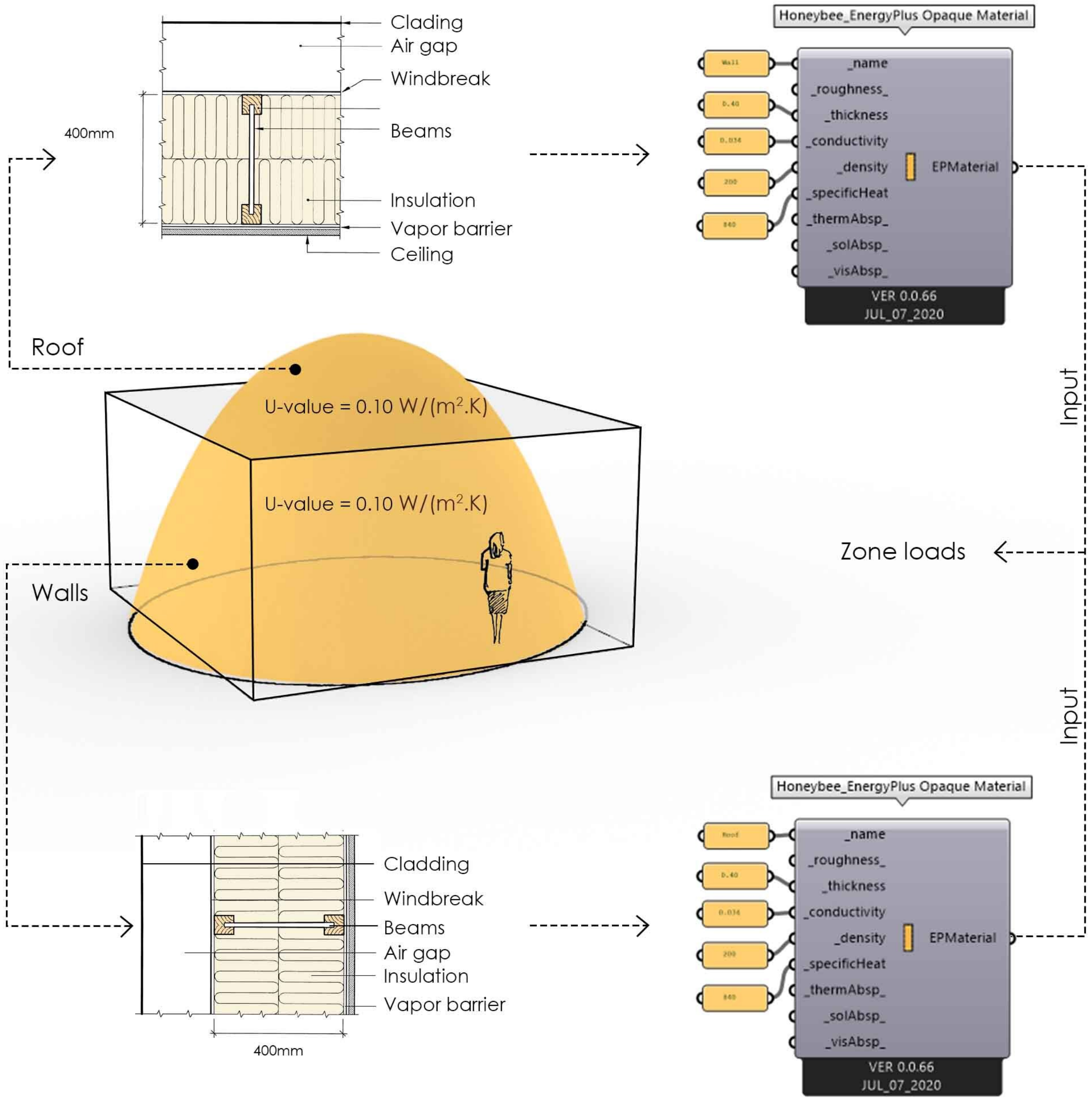


Figure 27: Illustration of the components of customize construction with grasshopper Material script.

D. Zone loads:

The simulation process then continues by using honeybee component “Energy Plus Zone Loads”. These refers to calculated heating and cooling demands for specific areas within a building. These loads consider factors like occupancy, equipment, lighting, and weather conditions. The input values in the simulations are heating and cooling loads.

E. + F. Run simulation with EPW

Honeybee's "Export to OpenStudio" feature enables users to export their energy model, along with the EPW (EnergyPlus Weather) file to the OpenStudio platform. This integration allows for further analysis and advanced energy simulations in OpenStudio, which offers additional tools and capabilities. By leveraging OpenStudio, users can gain more in-depth insights into their building's energy performance, enabling optimized design and energy efficiency strategies.

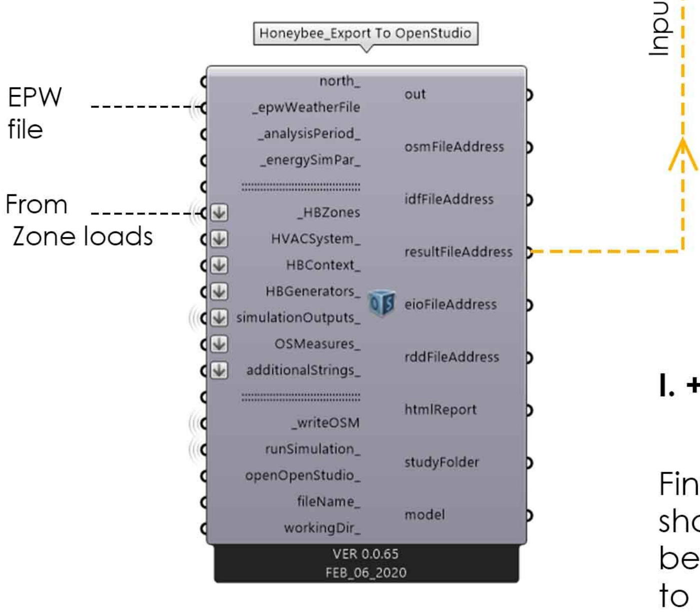


Figure 28: Honeybee “Export to openstudio” component.

G. + H. Controls and read results:

“honeybee Generate EP Output" These EP output files contain detailed information about various aspects of the building's energy performance, such as heating and cooling loads, airflow, temperature distribution, and energy consumption.

Honeybee's "Read Results" is a feature that enables users to import and analyze the results of EnergyPlus simulations. After running an energy simulation using EnergyPlus through Honeybee, the "Read Results" feature allows users to access and extract data from the simulation results files.

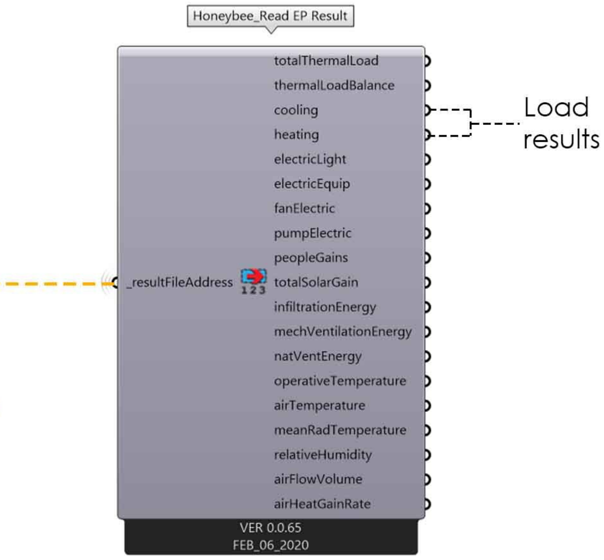


Figure 29: Honeybee “Read EP Result” component.

I. + J. Calculate loads and Chart:

Finally with the calculated loads, as shown in figure 25, the energy chart can be created, These loads are then subject to put in wallacei optimization togehter with radiation results.

6.3 Wallacei optimization and results

The results generated from both the discussed simulations (radiation and heat load) can be utilized for optimization purposes. The Wallacei plugin, which has several components, can be used for this optimization process. The optimization is subject to the "Wallacei X" component, which uses an evolutionary solver to optimize the inputs and outputs of the energy simulation. Figure 30 shows the general flowchart of the Wallacei X simulation, highlighting the steps involved in the optimization process.

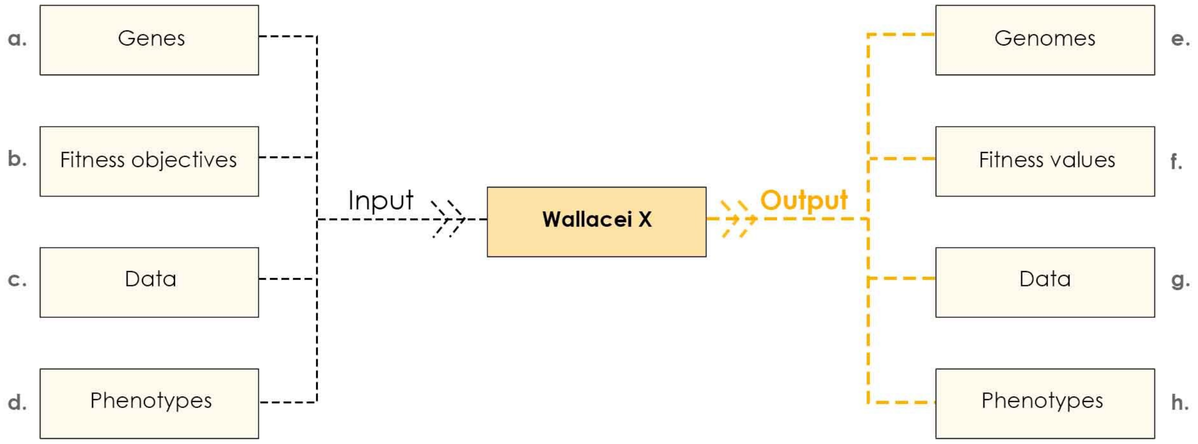


Figure 30: Flowchart diagram Wallacei X component. [18]

a. Genes

Genes are comprised from sliders or genepools. In the algorithm, these are defines variables i.e. V1, V2 etc.

b. Fitness objectives

Fitness objectives are values contained within a 'number' component. In the algorithm it is as:
1. wlc_Total Radiation.
2. wlc_Heat load.

c. Data

Any data type to be saved for every solution in the population.

d. Phenotypes

The phenotypes that will be exported through the solver i.e. Breps, mesh etc.

e. Genomes

This outputs the genomes of all solutions in the population.

f. Fitness values

This outputs the fitness values of all solutions in the population.

g. Data

This outputs the inputted data of all solutions in the population.

h. Phenotypes

This outputs the phenotypes of the exported solutions. To access the geometry within the phenotype, use the 'Decode Phenotypes' or 'Distributor' components, which will output the data into different streams (numbers, meshes, breps, etc.)

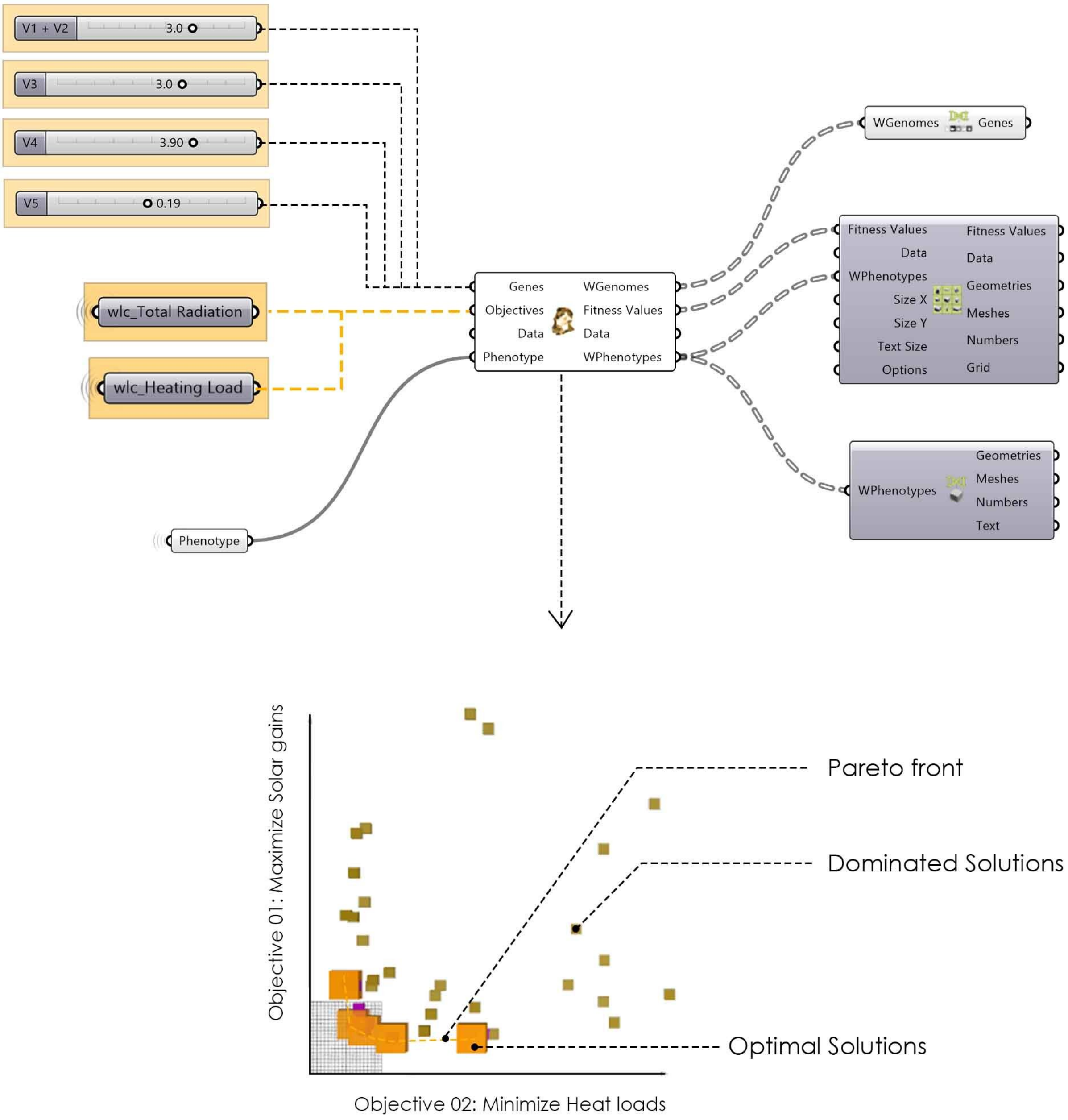


Figure 31: Grasshopper script optimization inputs with pareto front graph.

The optimization results are visualized in Figure 31 using a production possibilities frontier graph. Among the obtained solutions, only the Pareto front optimal ones are exported. To achieve this, a script is created to extract the Pareto front solutions from the phenotypes represented as Mesh objects. Phenotypes refer to the various design outcomes or variations generated during the optimization process. These exported solutions hold immense value for further development, providing a curated selection of designs that exhibit optimal trade-offs. By exploring and evaluating these solutions, designers gain insights into the design space and can make informed decisions.

They serve as a foundation for subsequent design iterations, driving the optimization process towards more efficient and effective design solutions, depending on the input objectives.

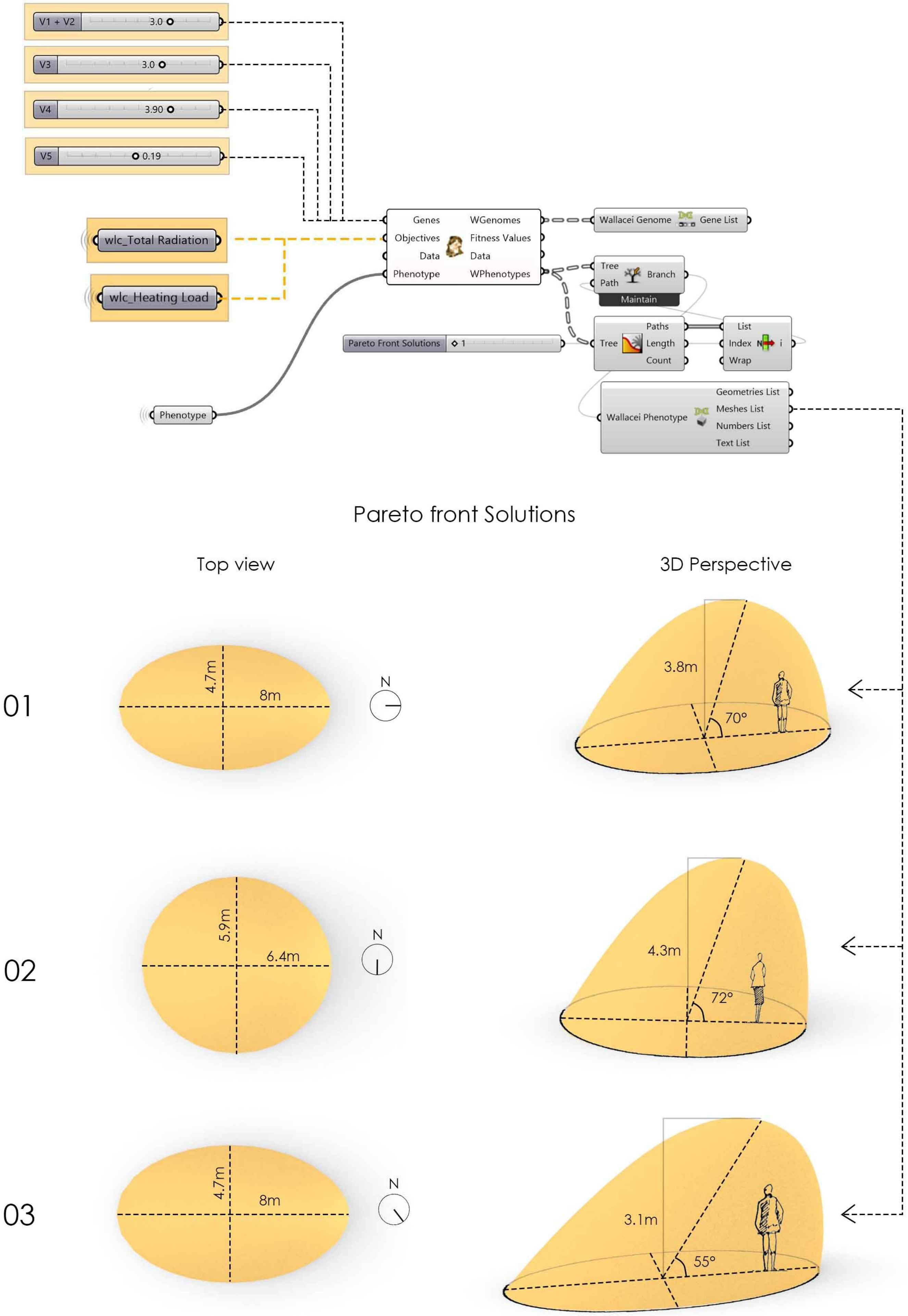


Figure 32: Grasshopper script, Phenotype decoding mesh, resulting pareto front solutions.

6.4 Simscale Simulations and results

The Pareto front solutions, referring to a set of optimal solutions in multi-objective optimization, have been prepared for export to SimScale. SimScale is a powerful simulation platform that encompasses a range of flow analysis techniques. In the specific context of this analysis, the focus has been on utilizing Incompressible Fluid Flow Analysis.

Incompressible Fluid Flow Analysis is a computational approach employed to study the behavior and characteristics of fluid flows where the assumption of incompressibility holds true. This assumption implies that the fluid density remains constant throughout the simulation, allowing for simplified calculations and more efficient analysis.

By utilizing SimScale's Incompressible Fluid Flow Analysis capabilities, the Pareto front solutions can be further evaluated and examined. This analysis helps uncover valuable insights into how fluid flows, such as airflow around objects or within enclosures, may affect various parameters of interest. These parameters can include pressure distribution, velocity profiles, temperature gradients, and more, depending on the specific objectives and constraints of the given problem.

Pareto Solution 01:

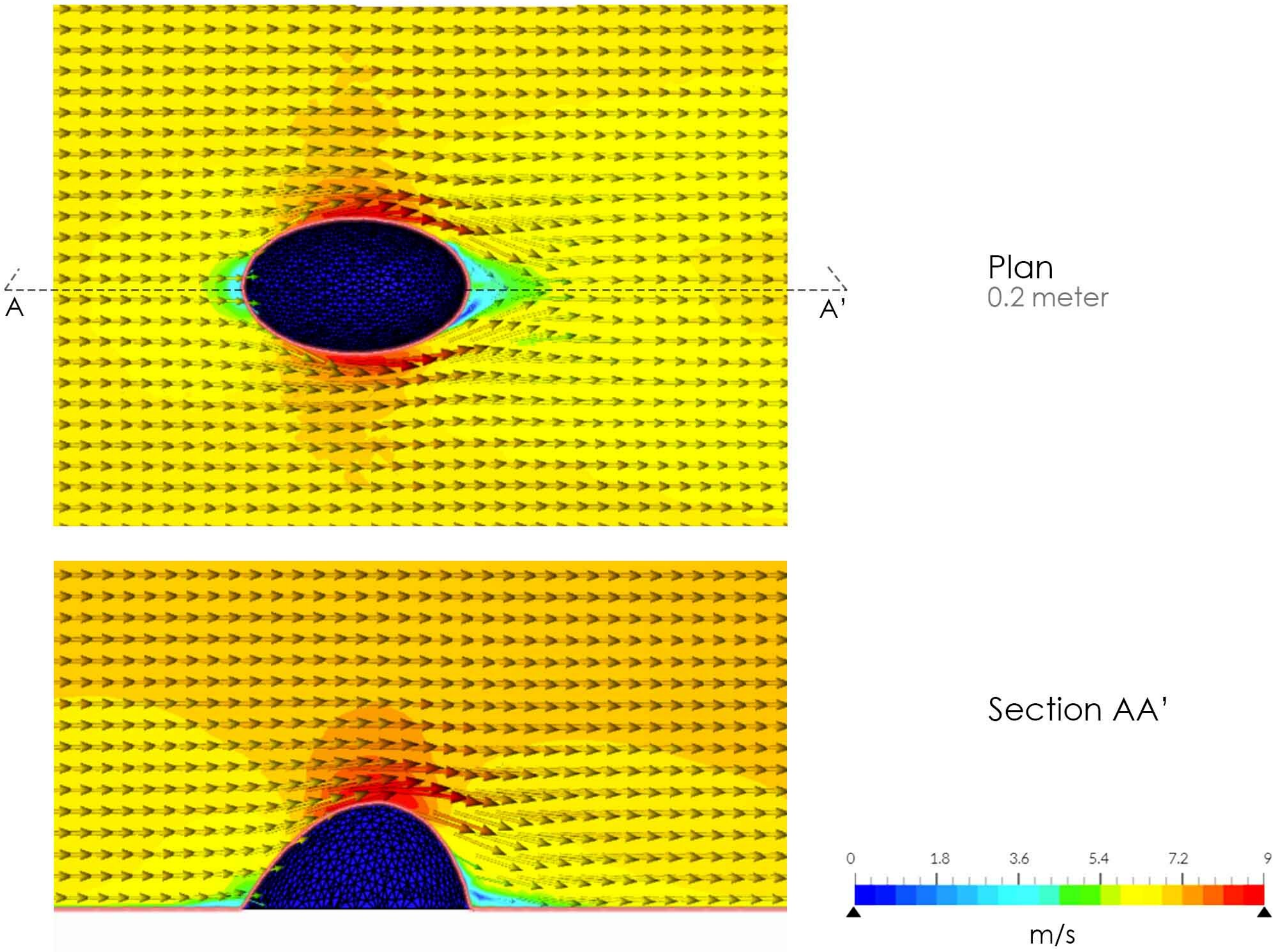


Figure 33: Simsclae wind analysis of pareto solution 01, ledgend in Velocity m/s

Pareto Solution 02:

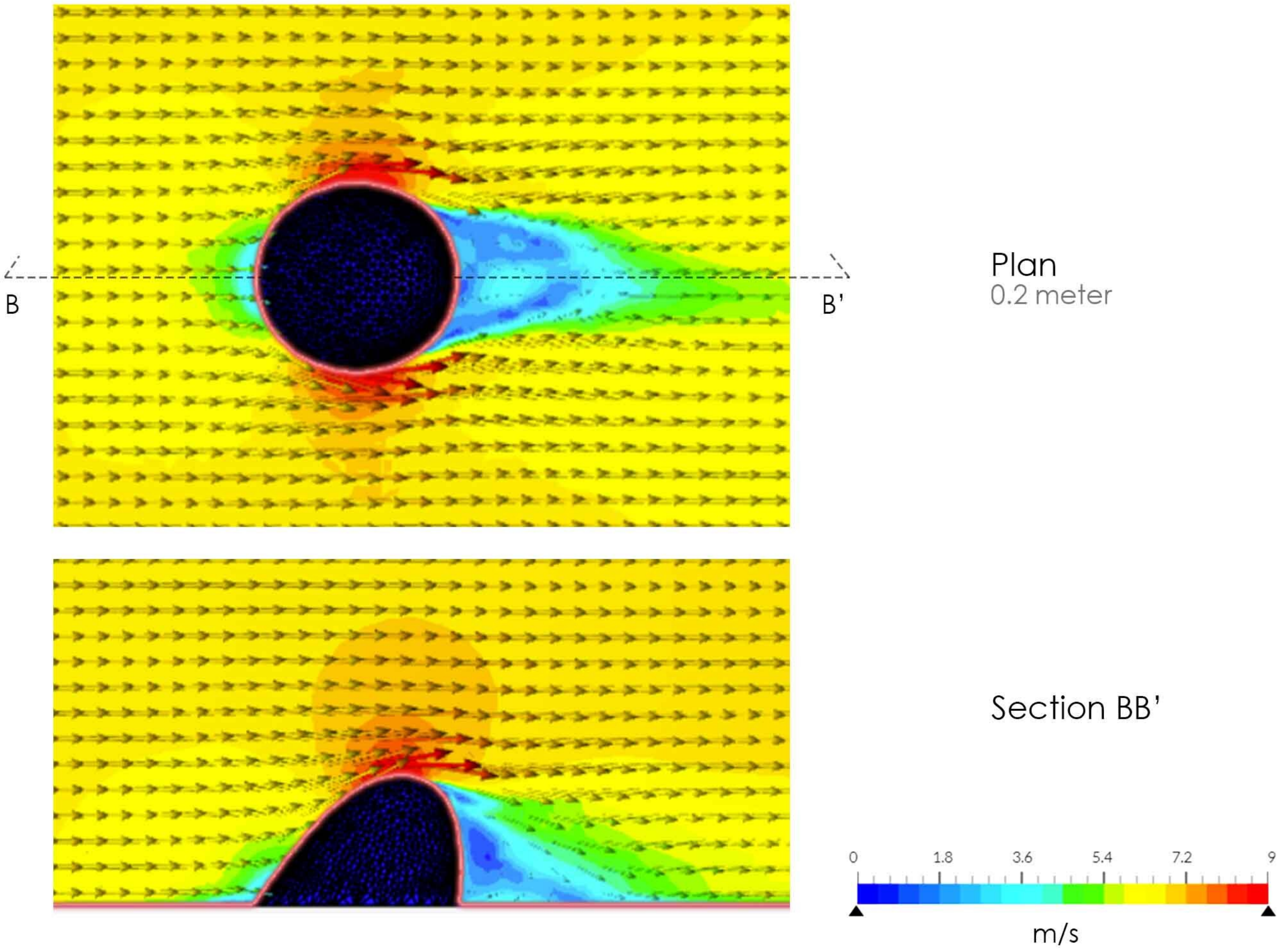
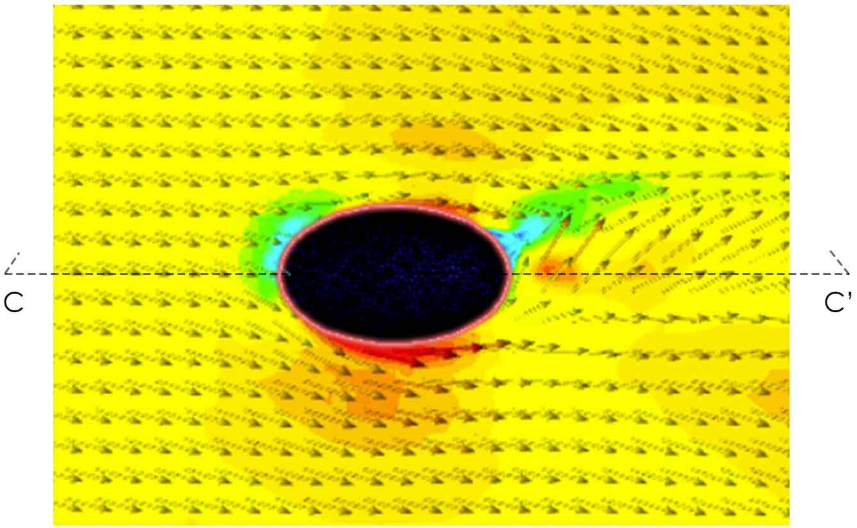


Figure 34: Simsclae wind analysis of pareto solution 02, ledgend in Velocity m/s

Pareto Solution 03:



Plan
0.2 meter

6.4 Simscale Simulations and results

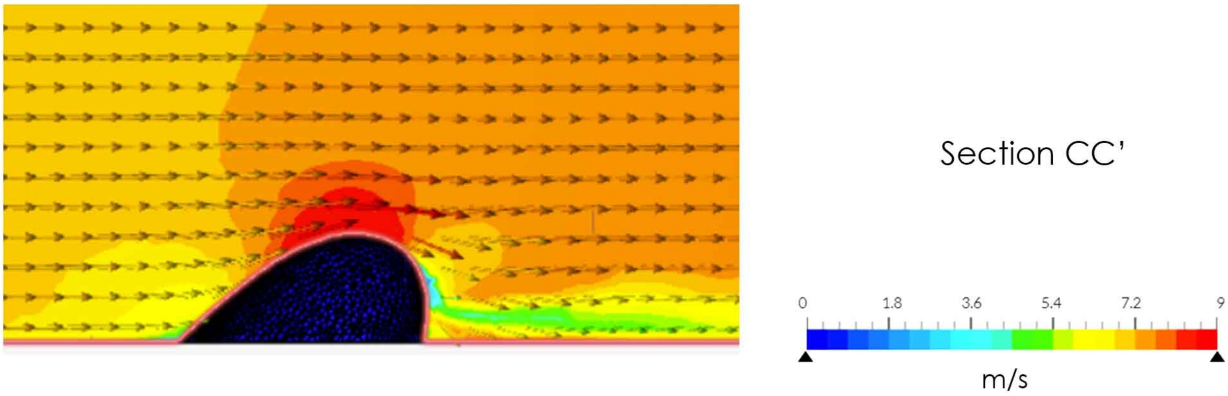


Figure 35: Simsclae wind analysis of pareto solution 03, ledgend in Velocity m/s.

The presence of snow is determined by area characterized of low speed where we can assume that the snow would stop on the ground. Vortexes sometimes determine slow speed, sometimes not. Figure 36 is an example of general vortex formation.

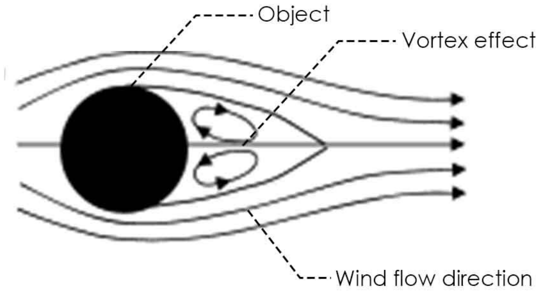


Figure 36: Illustration of Vortex effect around Cylinder shape object on a plan view.

6.5 Discussion

Upon closer examination, solution 1 demonstrates an approximate vortex area of 2m^2, while solution 2 shows a significantly larger area of around 20m^2. In contrast, solution 3 exhibits a comparatively smaller vortex area of only 1.5m^2. Based on this evaluation, it becomes evident that solution 3 is optimized due to its minimal vortex area around the building. This suggests that the probability of snow formation in close proximity to the structure is significantly reduced when employing solution 3 compared to the other alternatives. Analyzing vortex areas in building design has implications beyond snow formation; it more then helps to optimize door and windows design, it makes it possible to identify the optimal position for door and windows as solar capturer, avoiding snow to stop at any of these two components. Reduced vortex areas around doors result in lower wind pressures when opening or closing, reducing strain on the door mechanism and preventing drafts for enhanced energy efficiency. Similarly, minimized vortex areas around windows decrease air turbulence, improving insulation, reducing heat loss, and promoting occupant comfort.

By considering vortex areas in door and window design, buildings can be optimized for smooth operation, energy efficiency, and occupant satisfaction. This approach minimizes snow formation while maximizing the functionality and performance of these key building elements. It ensures a comfortable indoor environimproved energy efficiency, creating a well-designed structure overall.

Solution 1 and Solution 3 have heights that are deemed appropriate for the interior design program. This means that these solutions align well with the desired aesthetics and functionality of the space.

When it comes to heat demand, Solution 1 requires 31 KWh/m^2, Solution 2 requires 24 KWh/m^2, and Solution 3 requires 32 KWh/m^2 annually. Among these options, Solution 2 stands out with a relatively low heating demand. This can be attributed to its circular shape, which results in a smaller surface area compared to the elliptical shape of Solution 1 and Solution 3. With less exposed surface area, Solution 2 experiences less heat loss, leading to lower heat demand.

However, both Solution 1 and Solution 3 demonstrate minimal snow formation around the building. This validates the hypothesis that these forms are less prone to snow accumulation. The specific shape and design elements of these solutions likely contribute to the shedding of snow from the building's surfaces.

These optimization results are based on the consideration of both heat loads and solar gains. While Solution 2 excels in terms of heat loads, the other two solutions perform better in terms of solar gains. Solar gains refer to the amount of solar energy that can be captured and utilized within the building. Solutions 1 and 3 likely have more surface area exposed to sunlight, allowing for greater solar heat gain.

Given that the heat demand is around 30 KWh/m^2 for all the Pareto solutions, additional factors such as snow formation are taken into account to determine the most suitable solution for detailed design. Solution 1 is ultimately chosen for detailed design because it strikes a good balance between heat demand and solar gains. It offers a practical compromise, considering both energy efficiency and the ability to harness solar energy. Although solution 3 has more or less same heat demand and radiation values, still solution 1 has higher angle of variable 5 (figure 32) that makes the interior useable area more promising.

During the detailed design phase, the heat demand can be further refined and adjusted by incorporating specific features such as windows and doors. These architectural elements play a vital role in controlling heat loss and can be optimized to meet the specific requirements and objectives of the building.

Windows and doors act as interfaces between the interior and exterior environments. They are responsible for the exchange of heat, light, and air. By carefully selecting the type, size, and placement of windows and doors, the heat transfer through these openings can be managed effectively.

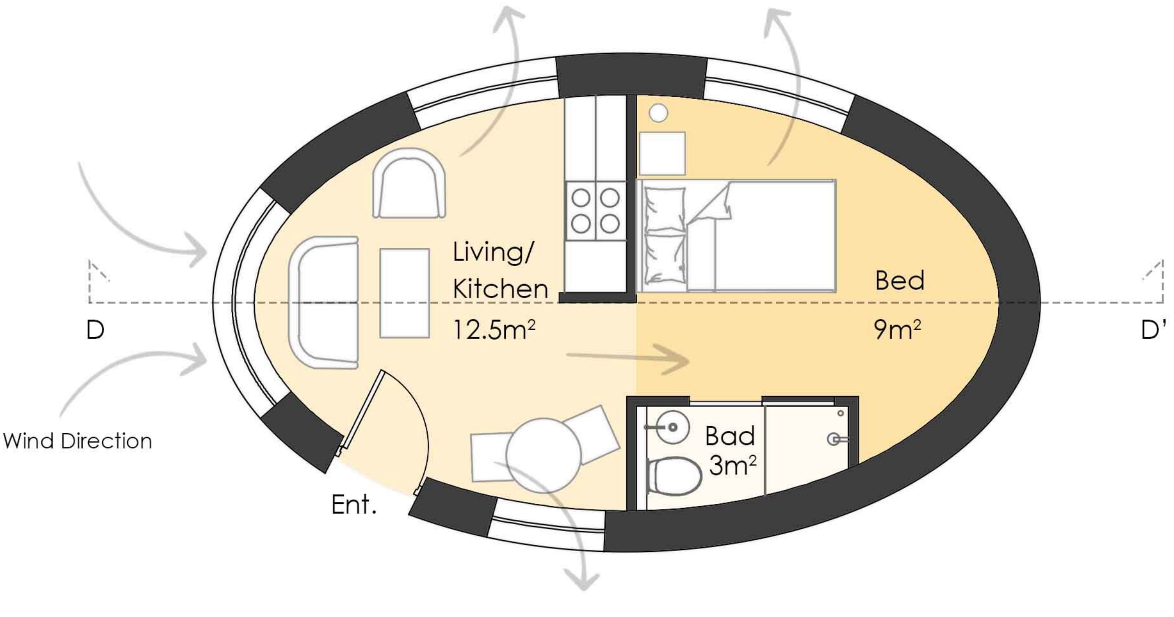
For instance, the choice of window glazing can greatly impact the insulation properties of the building envelope. Double or triple glazing, combined with low-emissivity coatings, can enhance thermal performance by reducing heat loss and minimizing thermal bridging. Additionally, proper sealing and weatherstripping techniques help prevent air leakage and drafts, further improving energy efficiency.

Strategic placement of windows and doors can also optimize solar gains. Orienting windows towards the sun's path allows for passive solar heating during the colder months, reducing the reliance on artificial heating systems. Conversely, shading devices or overhangs can be designed to limit excessive heat gain during warmer months, reducing the need for cooling. The results form optimization and analysis, gives a comprehensive design guidelines for detailing the solution.

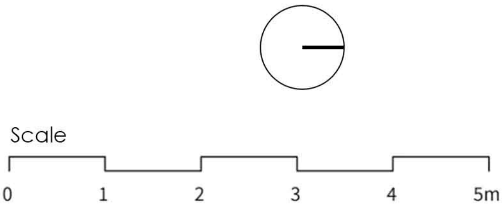
7.0 DETAIL SOLUTION

In this chapter, the detailed design phase will be the main focus, driven by the results and discussions derived from simulations and optimization. A specific constraint to consider is the limited total building area (BTA) set at 30m² as discussed in chapter 5. This restriction necessitates an innovative design approach that prioritizes spatial efficiency and maximizes the use of available space. To address this, the design solution will embrace a more open plan layout. By adopting an open plan, the aim is to create a sense of openness, enhance flexibility, and optimize the functionality of the limited area. The open plan approach allows for fluidity between different spaces while ensuring efficient circulation and utilization of the available square footage. Through a combination of sustainable design principles, thoughtful spatial organization, and the integration of optimized systems, this chapter seeks to develop a detailed design solution that balances sustainability and functionality.

7.1 **Plan**



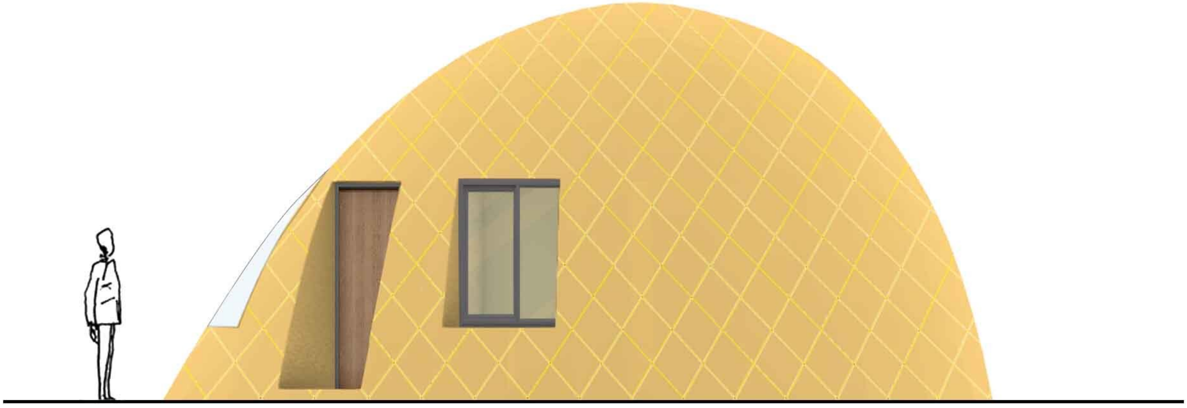
Ground floor plan



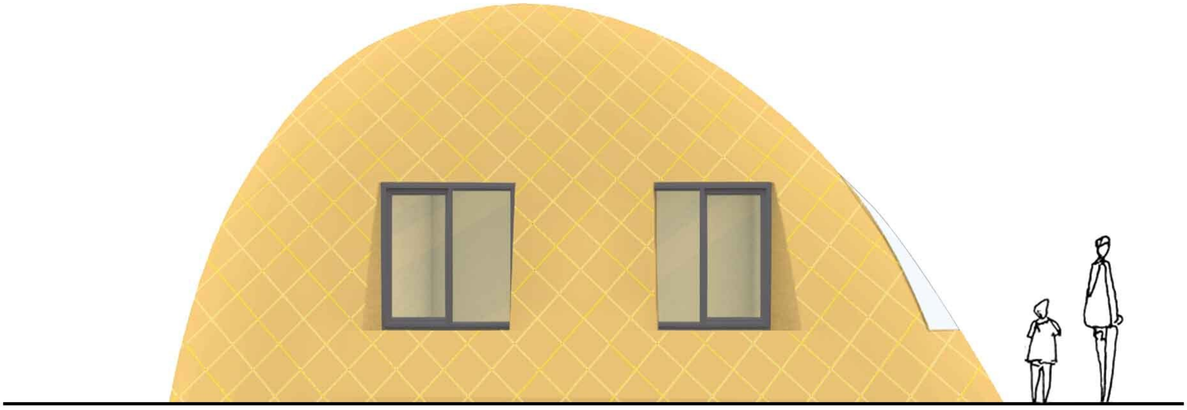
BTA = 30m²
BRA= 25.2m²
NTA= 24.5m²

BTA= Bruttoareal, BRA= Bruksareal, NTA= Nettoareal

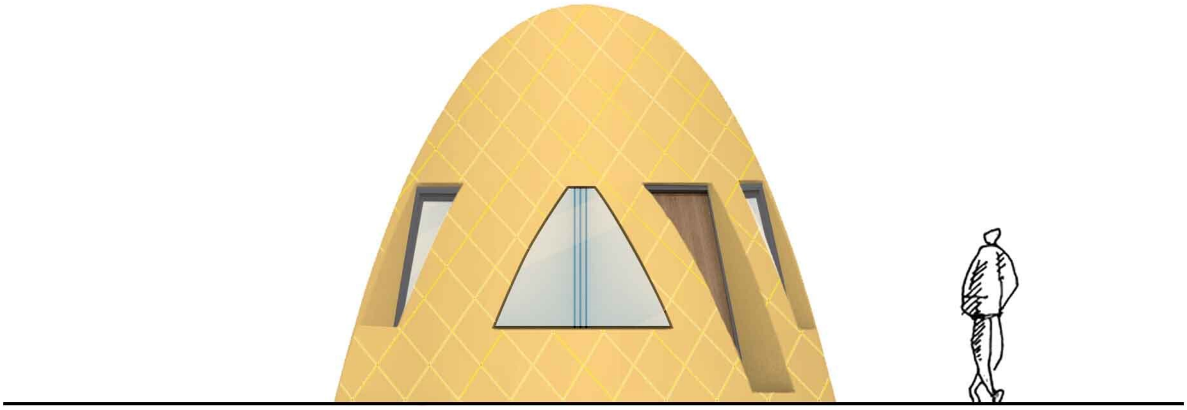
7.2 Elevations



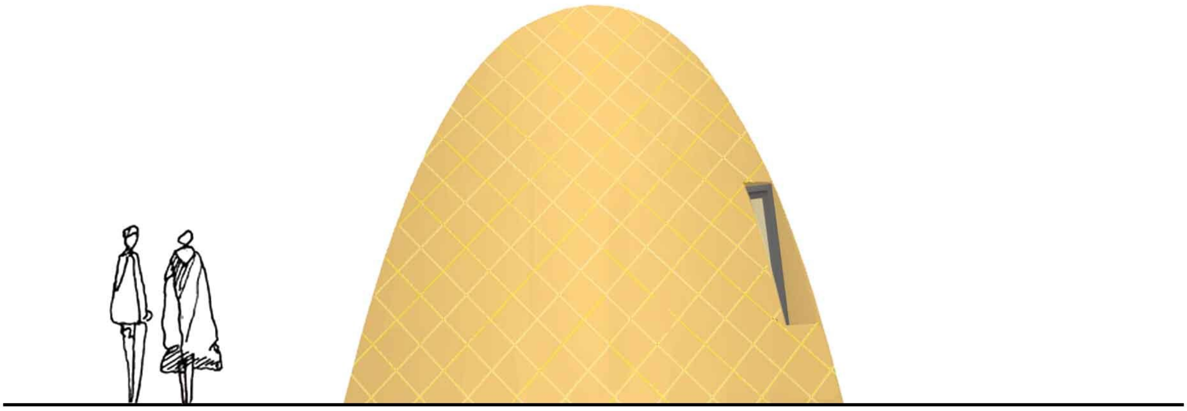
East Elevation



West Elevation

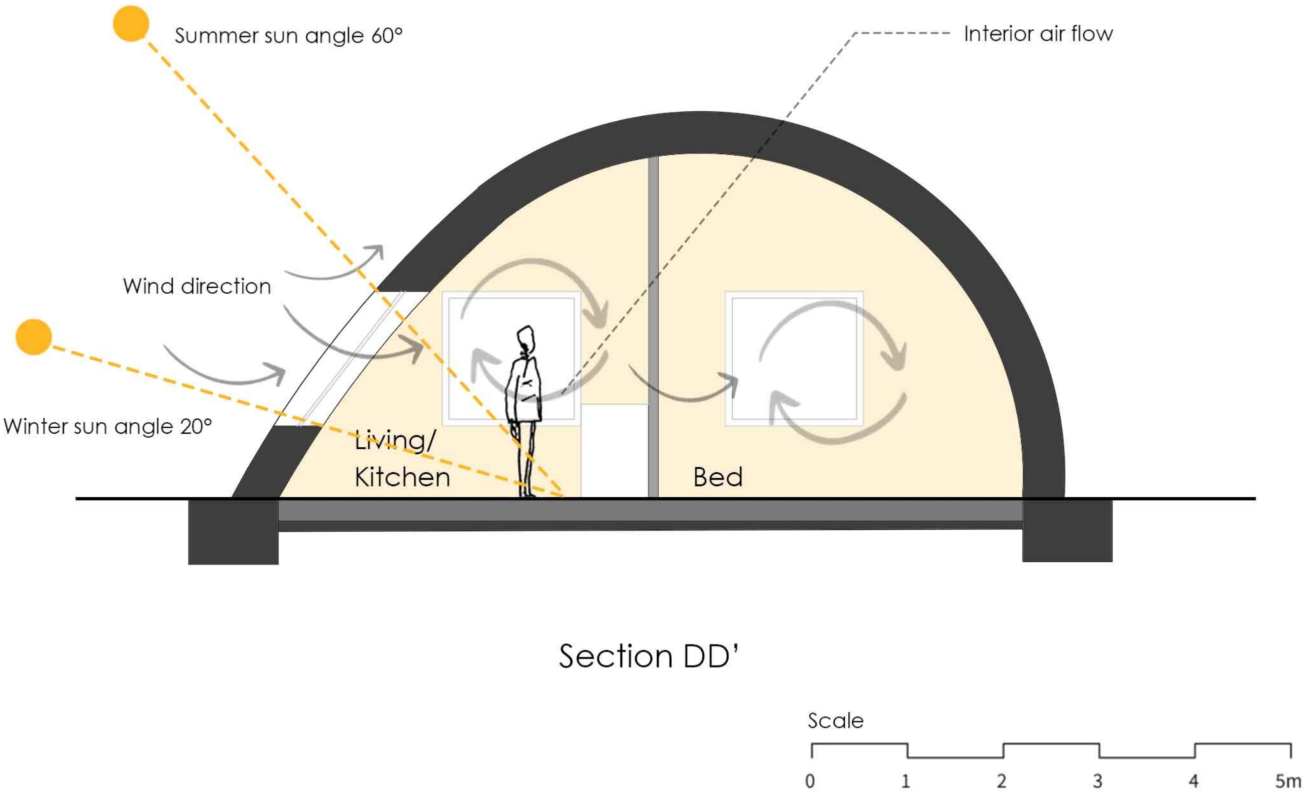


South Elevation



North Elevation

7.3 Section



Section DD'

7.4 Simulations and Discussion

The design of the windows and doors for the project took into consideration both radiation and wind simulation results to optimize their placement and orientation. An important aspect of this design approach was the window located on the south side of the building. Through wind simulations (as illustrated in Figure 38), it was determined that this particular window would have maximum exposure to wind.

Furthermore, the entrance was strategically placed on the windward side, taking into account the occurrence of snow formation. By locating the entrance where there is less snow accumulation, the practicality of its use during the winter period was improved.

In addition to wind considerations, the height of the window on the south side was carefully designed based on additional sun path analysis.

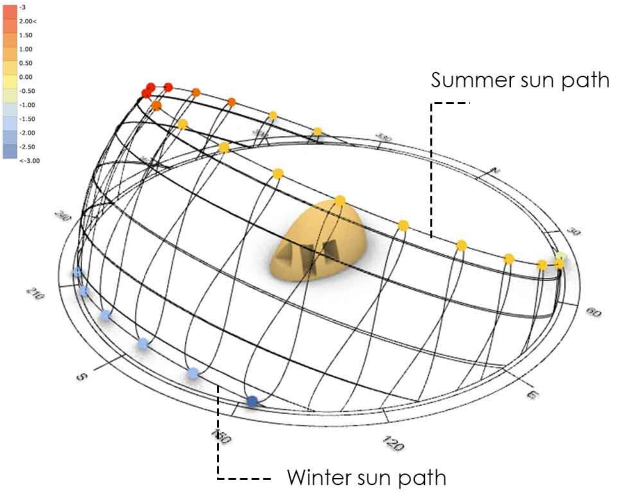


Figure 37: Sun path diagram, generated from Grasshopper.

This analysis aimed to ensure that during the warmer summer months, direct sunlight does not shine directly on the kitchen area. This design decision helps to maintain a more comfortable environment by minimizing excessive heat gain.

To inform the design further, specific data such as the maximum and minimum angles of the sun during both winter and summer periods were obtained (as depicted in Figure 37). This information, along with the analysis of sun intensity, played a crucial role in determining the optimal placement and orientation of windows and doors.The legend in the figure 37 indicates as:

-3 = Extreme cold
-2 = Cold
-1 = Cool
0 = Comfort
1 = Warm
2 = Hot
3 = Extreme hot

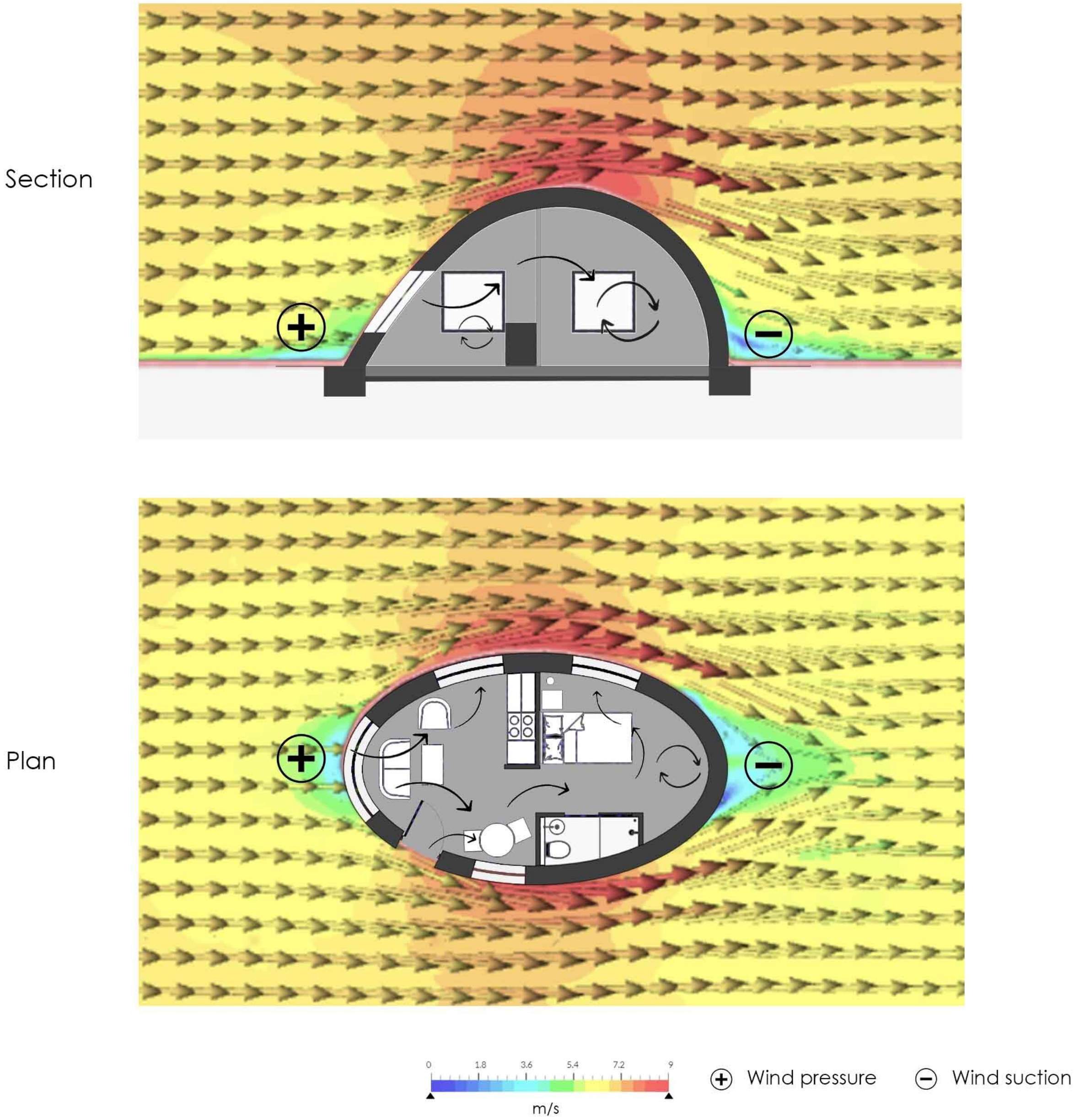


Figure 38: Image manipulation, Detail design solution and Simscale Wind simulation.

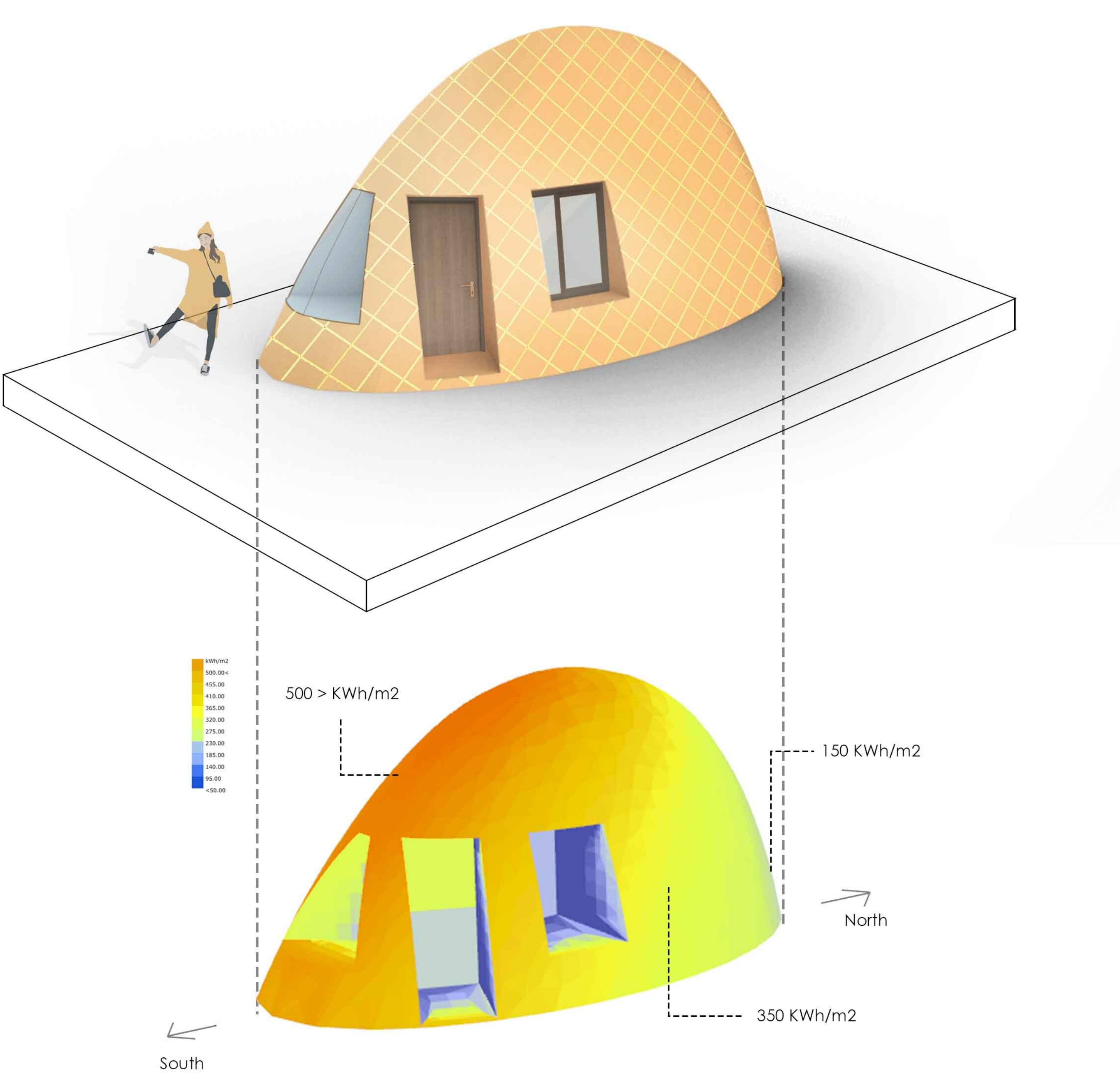


Figure 39: Above: 3D perspective of detail solution, Below: Radtiation analysis simulation results.

The form has been optimized to get the maximum solar radiation, these results also suggest placement of windows, when solar radiation enters a building through windows, it can directly heat the interior spaces. The radiation is absorbed by surfaces inside the building, such as floors, walls, or furniture, increasing the temperature and contributing to the overall heat gain. Solar radiation can also indirectly contribute to heat gains by heating the building's thermal mass. Thermal mass refers to materials with high heat capacity. The absorbed solar energy is stored in the thermal mass and slowly released into the interior space, contributing to the overall heat gain over time.

Based on the radiation analysis conducted over the annual period, it is evident that the windows receive the highest levels of solar radiation. To enhance the energy efficiency of the building design, have been implemented. This choice oftriple glazed windows with a U-value of 0.8 have been implemented. This choice of windows prioritizes energy conservation by minimizing heat loss and maximizing insulation properties, resulting in improved overall energy efficiency.

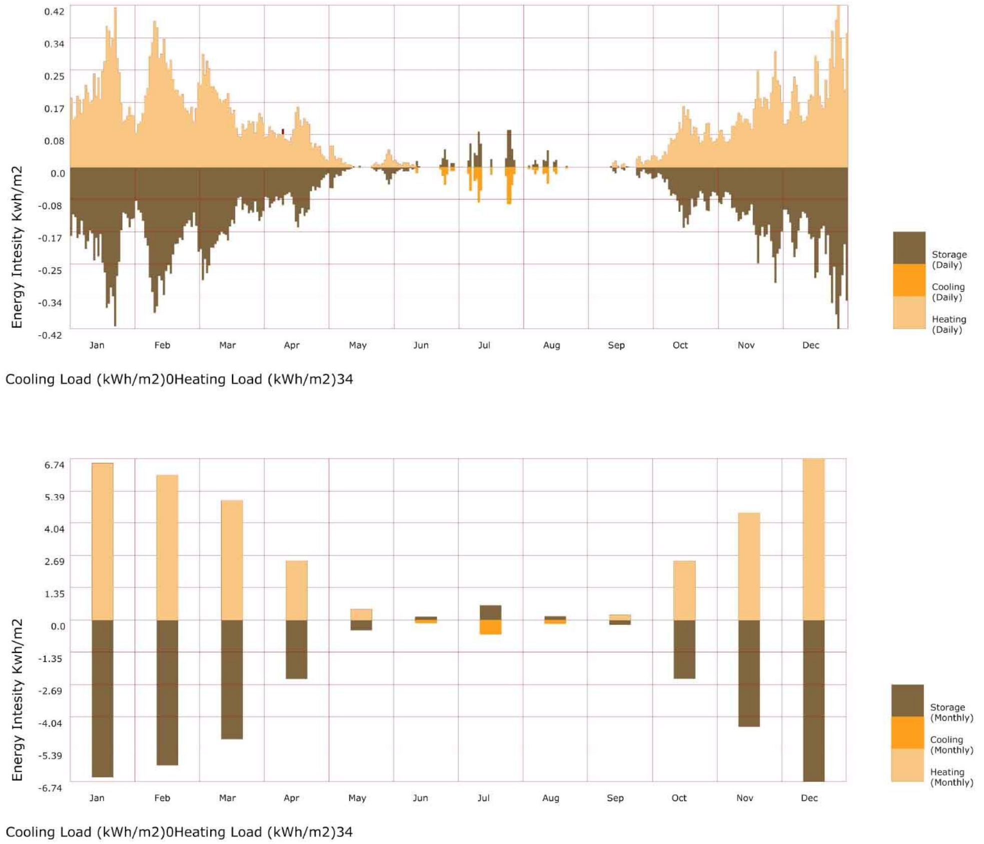


Figure 40: Energy simulation bar chart. Above: Totaled daily. Below: Totaled monthly

During the detailed design phase, the energy demand of the Pareto solution increased from 31 kWh/m² to 34 kWh/m², mainly attributed to openings like windows and doors. It is important to highlight that several energy calculation parameters were not taken into consideration, including lightning density per area, mechanical ventilation, appliances, and equipment. These factors significantly influence the overall energy consumption of the building. Integrating these parameters into the energy calculations is crucial for accurately assessing and optimizing the building's energy performance. . Considering these factors will enable a more comprehensive understanding of the building's energy usage and facilitate informed decision-making for energy-efficient design and operation.

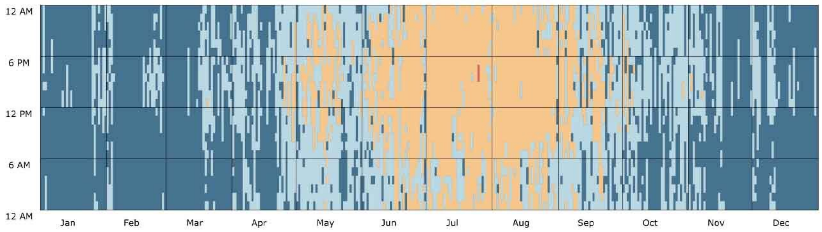
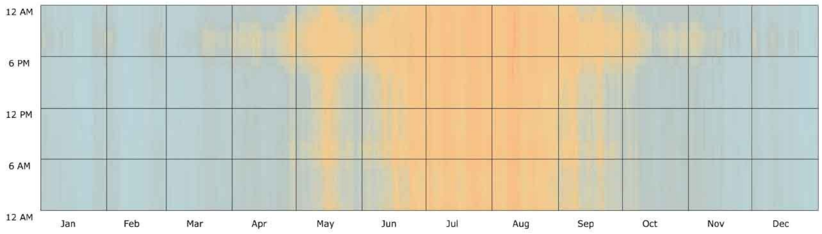


Figure 41: Outdoor thermal comfort, generated with Ladybug, grasshopper.



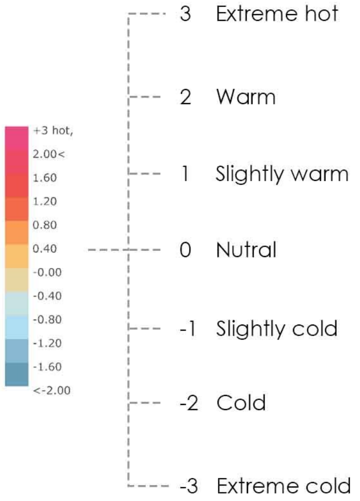


Figure 42: Indoor thermal comfort, generated with Ladybug-Honeybee, grasshopper.

According to the data presented in the outdoor and indoor comfort charts (figure 41 and 42) , we can clearly observe that the indoor temperature maintains a comfortable and neutral level during the summer months. This implies that the indoor environment remains adequately cool, allowing occupants to escape the sweltering heat outside. It provides a pleasant atmosphere that promotes relaxation and relief from the scorching temperatures associated with the summertime.

Furthermore, during the winter season, the indoor temperature is slightly colder than the neutral range. Although it may not reach uncomfortably low levels, it suggests that additional heating measures may be desirable to ensure optimal warmth and coziness indoors. This information highlights the need to prepare for colder temperatures by utilizing heating systems or implementing insulation to maintain a comfortable indoor environment.

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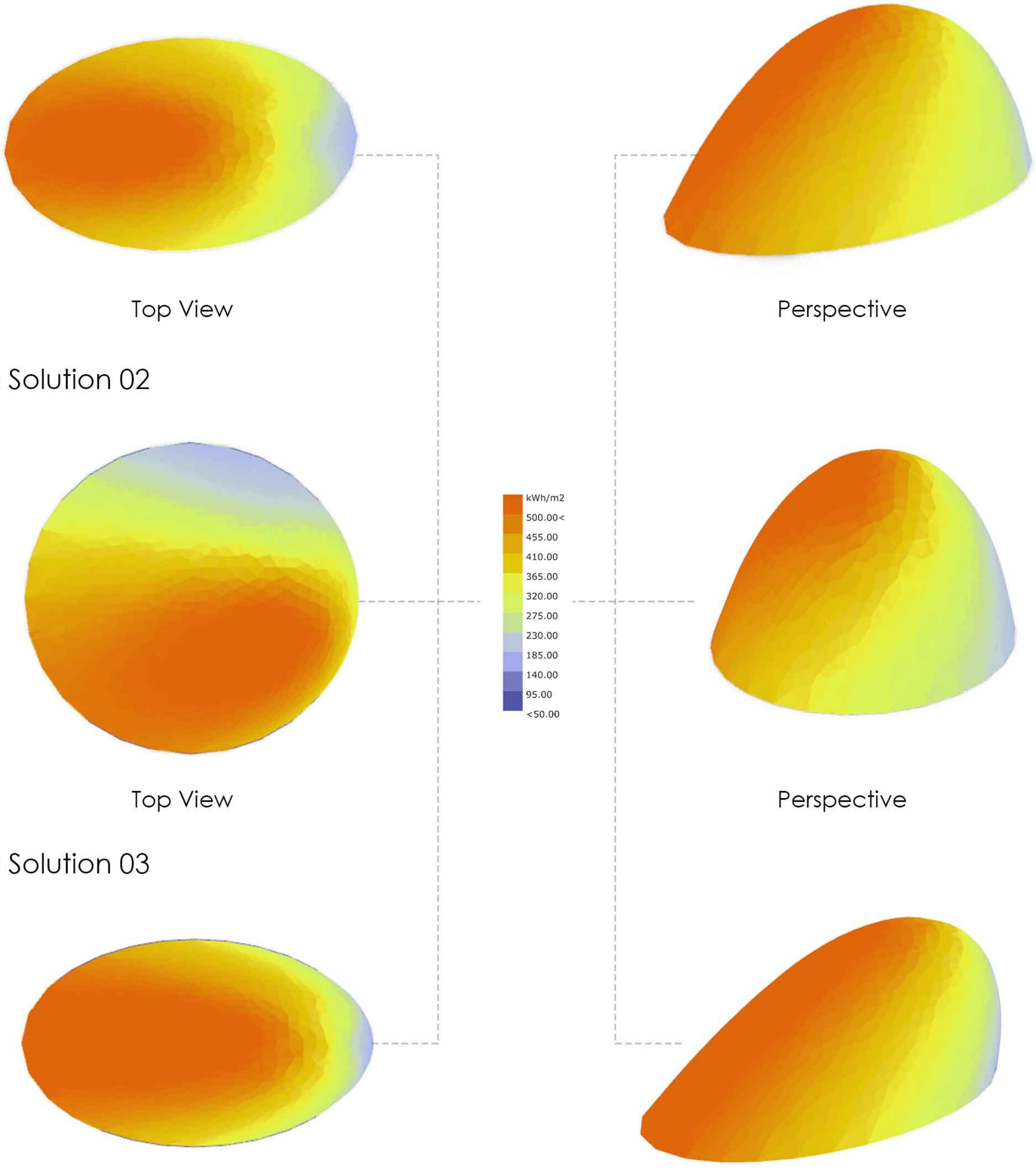
APPENDICES

Appendix A: Radiation simulation Pareto font Solution



Pareto Solution 01

Top View

Perspective

Pareto Solution 02

Top View

Perspective

Pareto Solution 03

Top View

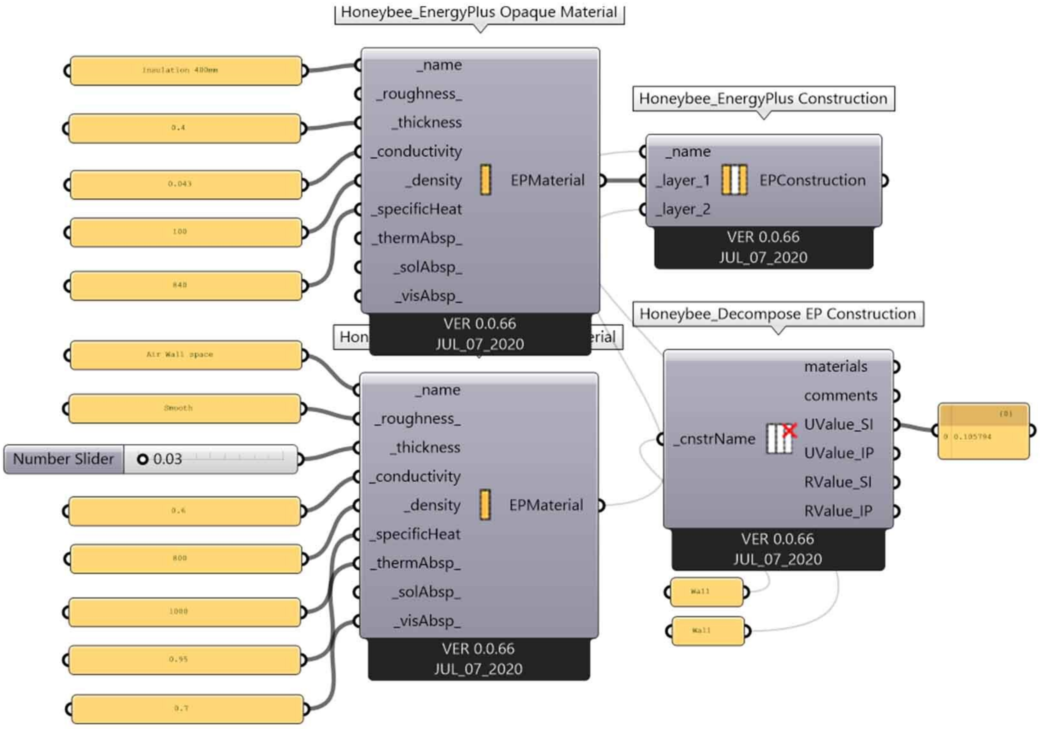
Perspective

Figure A1: Radiation results of Pareto front solutions, Winter period.

Appendix B: Customizing material in Energy simulation

Construction of material in grasshopper to get targeted U values.

Walls and Roof:



Window:

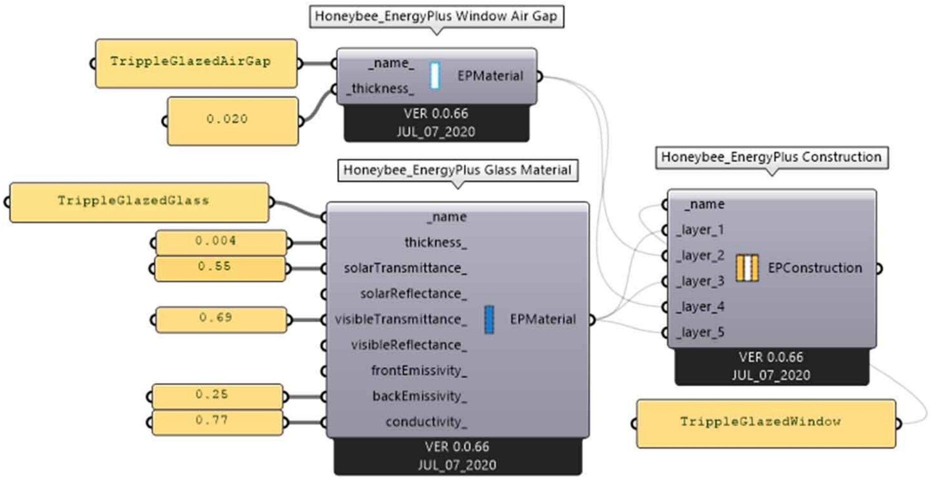
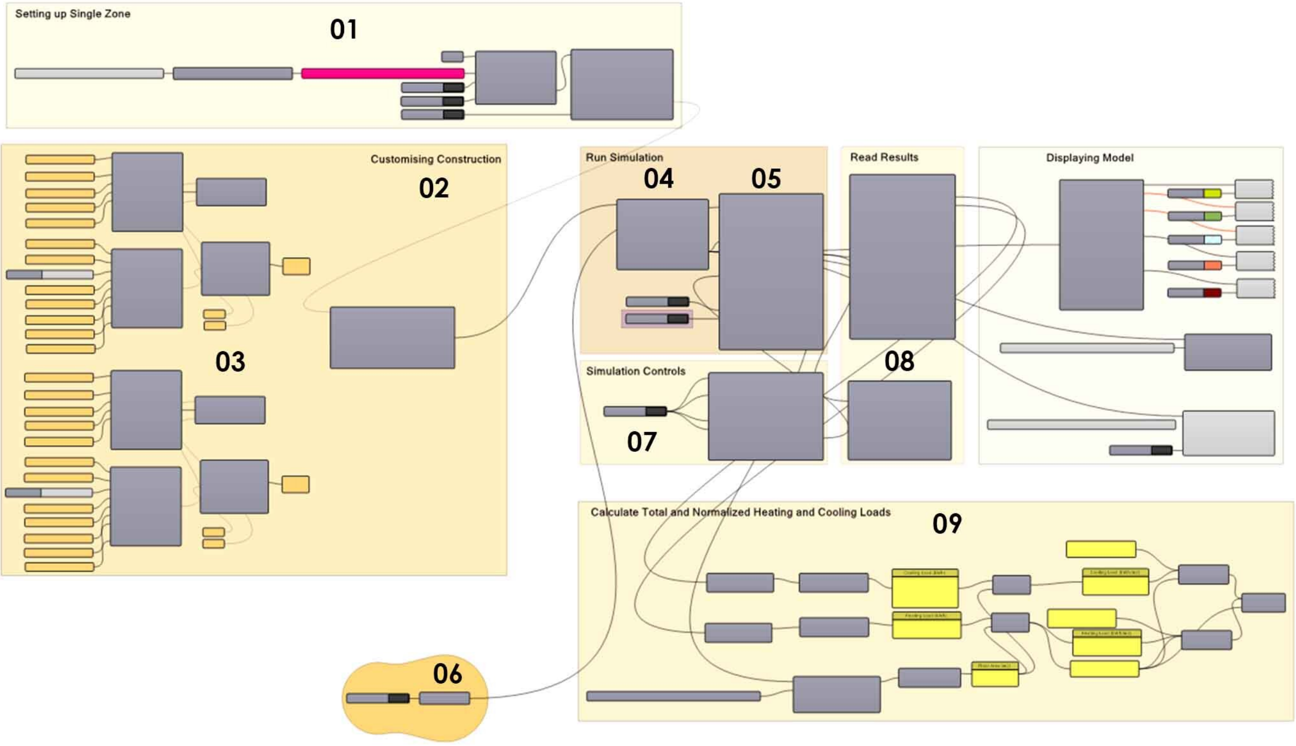


Figure B1: Honeybee_EnergyPlus Opaque Material component, customize materials with target U values.

Appendix C: Heat load simulation

Grasshopper script flow chart, with reference to figure 25.

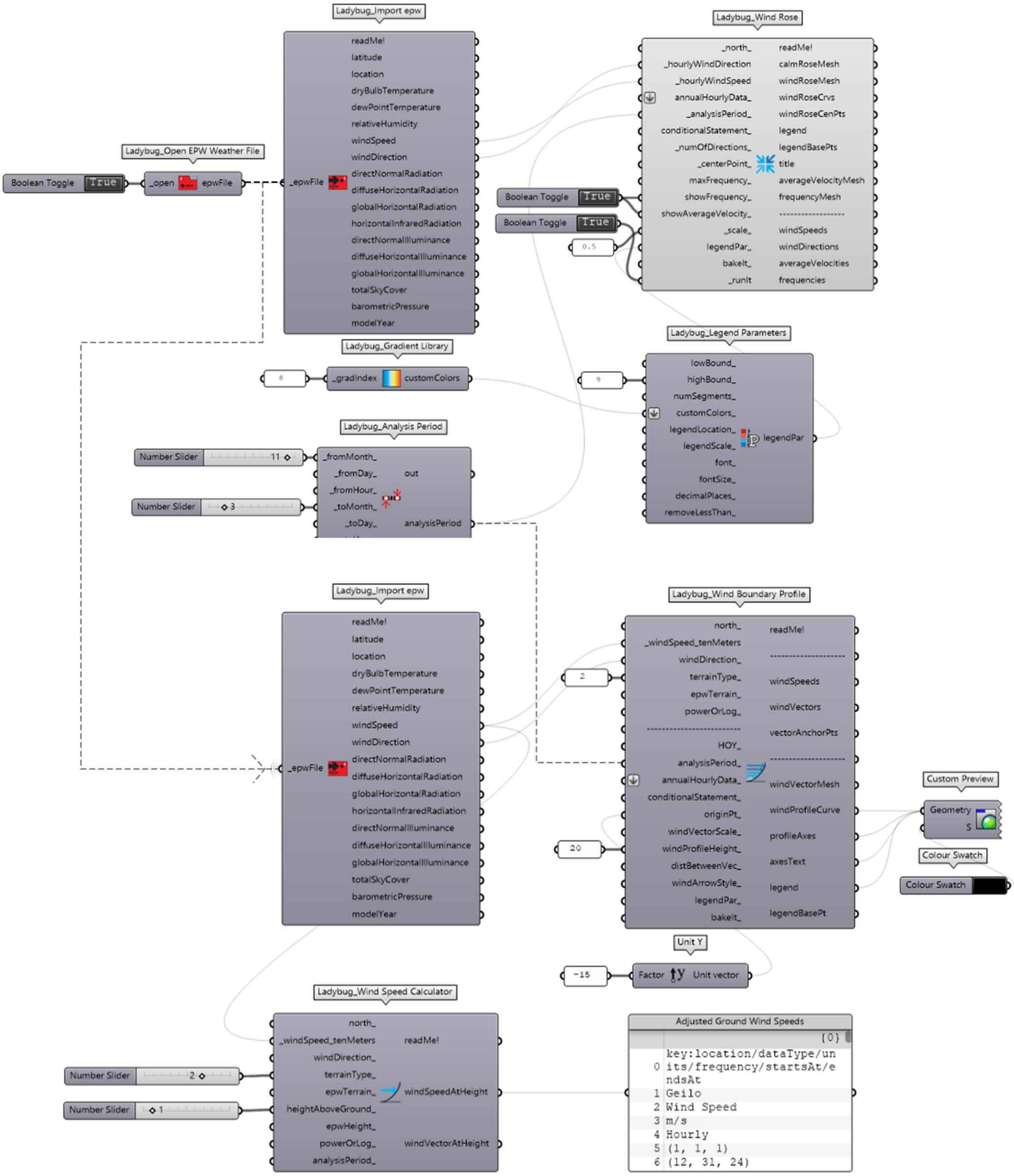


01: Zone Setup
02: Customizing construction
03: Components
04: Zone loads
05: Run Simulation
06: EPW file input
07: Simulation controlls
08: Read results
09: Calculate loads

Figure C1: Honeybee Energy simulation flowchart screenshot of grasshopper script.

Appendix D: Climate analysis, Wind rose script.

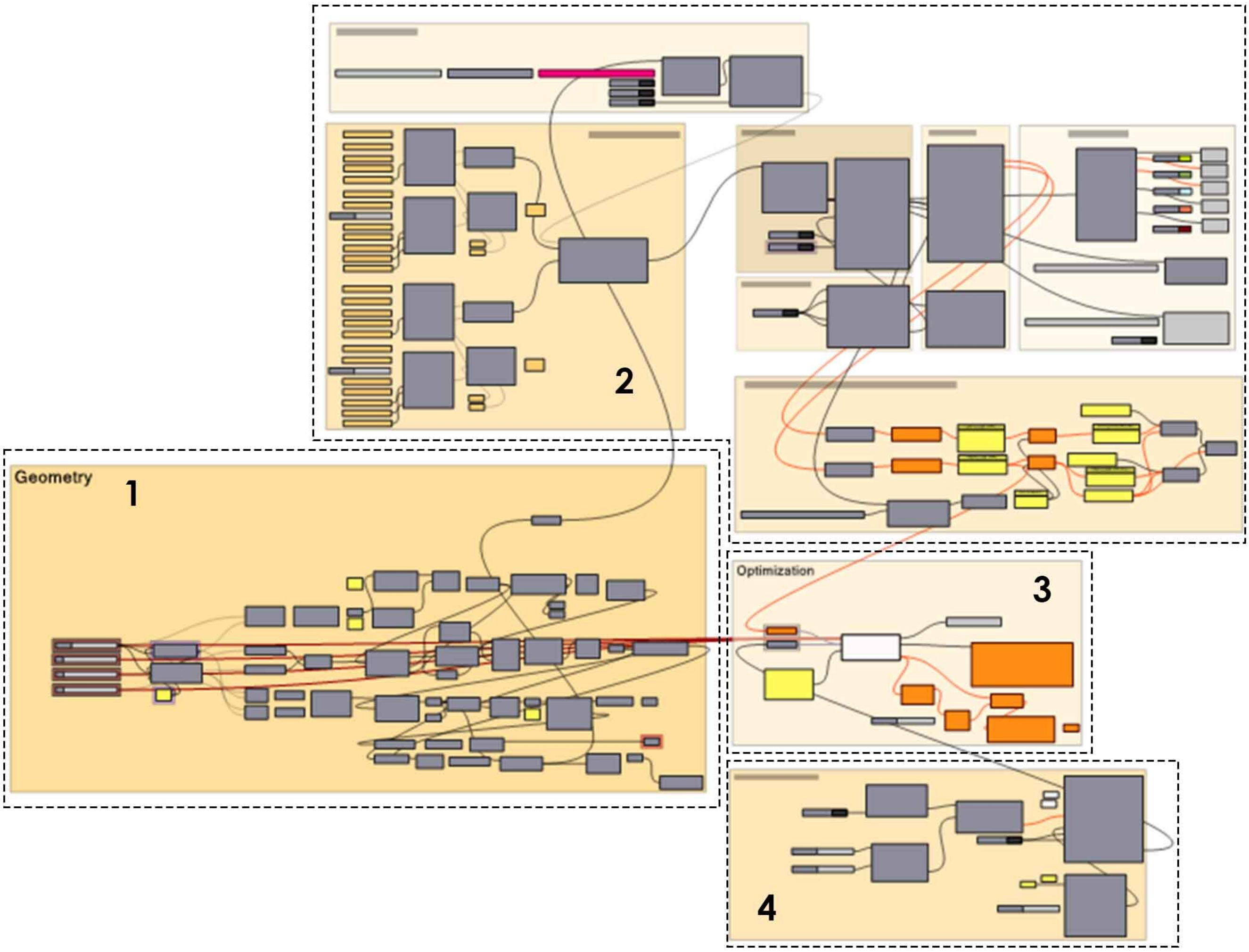
The following script is used to generate Wind charts in Chapter 3.3.



```
{0}
0 key:location/dataType/units/frequency/startsAt/endsAt
1 Geilo
2 Wind Speed
3 m/s
4 Hourly
5 (1, 1, 1)
6 (12, 31, 24)
```

Figure D1: Ladybug Wind Rose and Wind boundary profile Simulation script in grasshopper.

Appendix E: Modular nature of the opptimization set-up



1: Geometry
2: Energy simulation
3: Optimization
4: Radiation Simulation

Figure E1: Modular nature of optimization setup, grasshopper script.

Appendix F: Sun path diagram inputs

The following script is used to generate Sun path in Chapter 7.4.

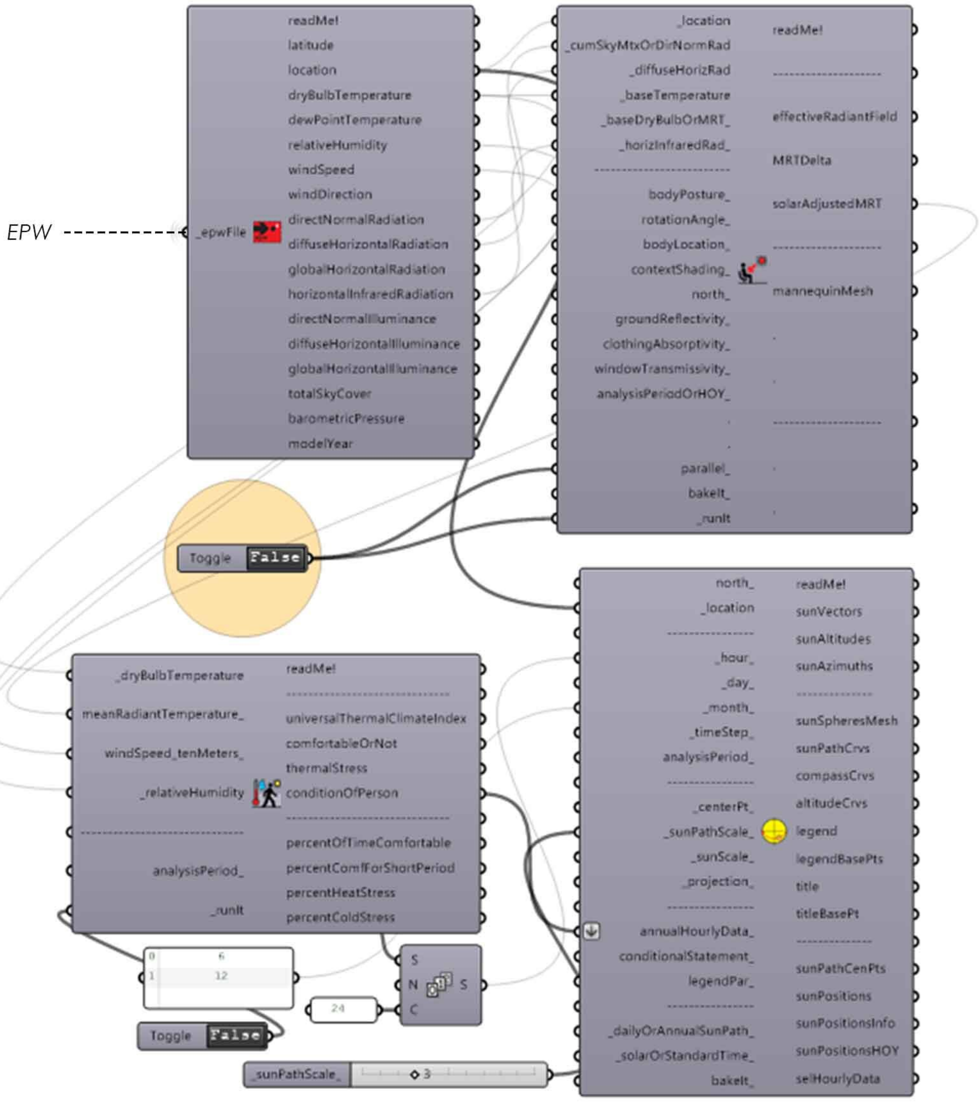


Figure F1: Sun path diagram input values, grasshopper script.

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