CPLX
Cave Pulse Light Experiment

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Abstract

"The Cave Pulse Light Experiment" investigates the limitations and potential of living within one or more container modules in remote scientific stations in Antarctica. Inhabitants are facing long-term physical and psychological challenges associated with extreme arctic conditions, harsh environmental constraints, isolation, confinement and inadequate lighting. The research seeks to understand how spatial configuration, environmental stimuli and interior design strategies can improve the daily routine of researchers. In particular, the study aims to design a habitable and reconfigurable cave-like stacked container interior where sleeping, working, exercising and social interaction can coexist within a limited spatial footprint, while simultaneously promoting physical health, mental wellbeing and overall comfort for its occupants.

Building on background research into Antarctica’s environment, Voronoi-based geometry and AI-assisted lighting design to robotic production and operations (D2RP&O) approach is emphasized. The study proceeded through a series of integrated design and development steps, including activity mapping, spatial concept formulation, parametric modelling in Grasshopper, integration of AI-assisted lighting, detailed fragment design, prototype and material selection, and fabrication planning using 3D printing strategies.

Project result demonstrates how an integrated, human-centred design strategy can transform extreme habitation into a supportive, engaging, and health-promoting environment, offering broader potential implications for future research stations and other extreme living contexts.

Keywords: extreme environment, Antarctica, Voronoi-based design, D2RP&O, cave-like interior, stacked container modules, reconfigurable habitats, biophilic integration, AI-assisted lighting.

1 Introduction

This research investigates the development of a human-centred interior design strategy for the TROLL Norwegian Research Station in Antarctica through the concept of “The Cave Pulse Light Experiment”, which reinterprets reconfigurable stacked container modules as adaptive and responsive living environments that support both physiological and psychological well-being in extreme conditions.

Antarctic research stations present significant challenges to human habitation, including isolation, confinement and prolonged exposure to harsh climatic conditions, all of which can reduce physical activity and negatively impact mental health. Currently, the interiors of the TROLL Research Station largely prioritise functionality and logistics over human experience, providing insufficient support for occupants' overall well-being and engagement with their environment. This highlights the need for research that integrates spatial design, environmental stimuli and human-centred strategies to create compact habitats that actively enhance both physical and mental health.

The central problem addressed by this study is the lack of holistic design approaches capable of transforming confined living systems into environments that actively promote adequate lighting, movement, environmental variation, productivity, daily performance and wellbeing, especially as research missions extend in duration.

For this purpose the project uses voronoi cells. Voronoi cells are forming a pattern when space is methodically subdivided, based on proximity to a number of points. Each of these points creates an area containing all locations closest to it. Subsequently a system of irregular, interconnected cells is covering a chosen surface. These organic patterns can also be observed in nature, inside leaves for example. Being highly adaptable, voronoi structures are ideal for creating complex spatial design configurations.

To address this, the project develops an adaptive interior framework that establishes a cave-like spatial configuration, fostering a sense of protection, immersion and spatial continuity within a confined footprint. The research further explores spaces that encourage physical exercise to support both mental and physical health, including climbing, the integration of plant life as a biophilic element and AI-assisted interactive lighting systems that dynamically respond to human circadian and cardiac rhythms.

The authors' contribution lies in proposing a design-driven framework that rethinks container-based habitats as dynamic, health-oriented and experiential living spaces that go beyond providing basic shelter.

Theoretical Background

1.1 Environmental constraints of Arctic environments

Humans spend approximately 90% of their time indoors [1), making the built environment a critical determinant of human health and well-being. In extreme environments such as the Antarctic, this proportion can increase to nearly a hundred percent during prolonged snowstorms, when occupants may be confined indoors for several consecutive days. Under such conditions, the quality of the interior environment becomes essential in maintaining psychological stability and preventing adverse mental health outcomes. Despite this, many research stations, such as the Troll Station, are primarily designed to meet functional and logistical requirements, often resulting in spaces that are spatially limited, materially overloaded, and lacking in qualitative considerations.

However, a growing body of research indicates that poorly designed environments can induce chronic physiological stress, an especially critical issue in contexts where individuals reside for extended periods, such as year-long research missions. Prolonged activation of the body's stress response contributes to what is known as allostatic load, the cumulative physiological burden of chronic stress, which has been identified as a key factor in the development of neuroinflammation [2]. Neuroinflammation, in turn, is associated with a wide spectrum of neurological and psychiatric conditions, including depression, schizophrenia, autism spectrum disorders, obsessive-compulsive disorder, and neurodegenerative diseases such as Alzheimer's and Parkinson's [3,4].

Given that individuals in such extreme and isolated environments are already known to experience significant psychological strain, these findings underscore the importance of the built environment as more than a neutral backdrop. Instead, it must be understood as an active contributor to either exacerbating or mitigating stress-related health risks. This highlights the relevance of design approaches that explicitly address human needs and well-being, positioning the interior environment as a key factor in supporting the mental and physical health of its occupants.

Expeditioners experience extended periods of darkness in the winter and light in the summer, and they live among snow and ice. The local climate is extremely cold and frequently windy.
In some respects, Antarctic life is very similar to "normal" life as most know it; residents of the stations have completely insulated living and working spaces with private rooms and bathrooms.

People need to be able to live and work with others and develop empathy and tolerance. For a tiny community, where people live near one another for several months, this can occasionally be challenging.

Even though there aren't as many fresh fruits and veggies, the food is comparable to what most would eat in general. Food quantities are determined by the average annual consumption of each individual. That equates to over 780 kg of food and 380 L of liquids per person, including juices, soft drinks, oils, and sauces, that is called "person entitlement".
For the first few months after restocking, fresh vegetables and eggs are accessible. Expeditioners typically consume frozen, tinned, or dry food once the fresh food runs out. Hydroponically grown salad vegetables are added to this. Long-term storage of food requires cautious handling, with older stocks being consumed first [5].

To understand the insufficient qualities of the current troll station, we examined fundamental needs theories. As previously discussed, after Maslow's hierarchy of needs, it becomes evident that even basic physiological needs are difficult to fulfil in Antarctica. The extreme conditions of polar night and polar day disrupt the circadian rhythm, compromising sleep and, consequently, both physical and mental health. Nutrition itself also plays a key role, due to the limited access, which results in only one delivery per year. However, Maslow's model simplifies the higher-level needs, which relate to more nuanced experiential qualities. Therefore, we also consider a more recent framework developed by Pieter Desmet and Steven Fokkinga, who define 13 fundamental needs with 52 sub-needs to better describe a fulfilled life experience [6]. Unlike Maslow, their model excludes survival needs and focuses on experiential and emotional well-being.

Based on the framework in figure X(below), our design focuses on the needs of autonomy, beauty, comfort, fitness and stimulation. Designing with a focus on fundamental human needs offers a holistic approach to improving the well-being of individuals. By addressing not only functional and physiological requirements but also experiential and emotional dimensions, the design fosters a more supportive and resilient living environment. This needs-based approach enhances users' sense of control, engagement, and comfort, while simultaneously promoting physical activity and mental stimulation. As a result, it contributes to improved psychological stability, reduced stress, and an overall higher quality of life, ultimately enabling occupants to better cope with the challenges of isolation and environmental extremes like in the Antarctic context.

Need	Explanation	Sub-needs
AUTONOMY	Being the cause of your own actions and feeling that you can do things your own way. Rather than feeling as though external conditions and other people are the cause of your actions.	**Need for freedom of decision** **Need for individuality** **Need for creative expression** **Need for self-reliance**
BEAUTY	Feeling that the world is a place of elegance, coherence and harmony. Rather than feeling that the world is disharmonious, unappealing or ugly.	**Need for unity and order** **Need for elegance and finesse** **Need for artistic experiences** **Need for natural beauty**
COMFORT	Having an easy, simple, and relaxing life. Rather than experiencing strain, difficulty, or overstimulation.	**Need for peace of mind** **Need for convenience** **Need for simplicity** **Need for overview and structure**
COMMUNITY	Being part of and accepted by a social group or entity that is important to you. Rather than feeling you do not belong anywhere and have no social structure to rely on.	**Need for social harmony** **Need for affiliation (group identity)** **Need for rooting (tradition, culture)** **Need for conformity (fitting in)**
COMPETENCE	Having control over your environment and being able to exercise your skills to master challenges. Rather than feeling that you are incompetent or ineffective.	**Need for knowledge and achievement** **Need for challenge** **Need for environmental control** **Need for skill progression**
FITNESS	Having and using a body that is strong, healthy, and full of energy. Rather than having a body that feels ill, weak or restless.	**Need for nourishment** **Need for health** **Need for energy and strength** **Need for hygiene**
IMPACT	Seeing that your actions or ideas have an impact on the world and contribute to something. Rather than seeing you have no influence and do not contribute to anything.	Need for influence Need for contribution Need for building something Need for legacy
MORALITY	Feeling that the world is a moral place and being able to act in line with your personal values. Rather than feeling that the world is immoral and your actions conflict with your values.	**Need for having guiding principles** **Need for acting virtuously** **Need for a just society** **Need for fulfilling duties**
PURPOSE	Having a clear sense of what makes your life meaningful and valuable. Rather than lacking direction, significance or meaning in your life.	**Need for life goals and direction** **Need for meaningful activity** **Need for personal growth** **Need for spirituality**
RECOGNITION	Getting appreciation for what you do and respect for who you are. Rather than of being disrespected, under appreciated or ignored.	**Need for appreciation** **Need for respect** **Need for status and prestige** **Need for popularity**
RELATEDNESS	Having warm, mutual, trusting relationships with people who you care about. Rather than feeling isolated or unable to make personal connections.	**Need for love and intimacy** **Need for camaraderie** **Need to nurture and care** **Need for emotional support**
SECURITY	Feeling that your conditions and environment keep you safe from harm and threats. Rather than feeling that the world is dangerous, risky or a place of uncertainty.	**Need for physical safety** **Need for financial security** **Need for social stability** **Need for conservation**
STIMULATION	Being mentally and physically stimulated by novel, varied, and relevant impulses and stimuli. Rather than feeling bored, indifferent or apathetic.	**Need for novelty** **Need for variation** **Need for play** **Need for bodily pleasure**

Fig. 1: *Fundamental needs for human-centred design*

1.1.1 Growing greenery in Antarctica

Food production in Antarctic research stations relies heavily on hydroponics systems [7], which allow expeditioners to grow a steady, reliable supply of fresh produce despite the extreme environment outside. In these controlled indoor facilities, crops such as tomatoes, lettuces, cucumbers, capsicums, beans, zucchinis, spinach, snow peas, fennel, coriander, and basil are cultivated year-round, with seedlings regularly germinated to ensure continuous harvests.

Growing herbs such as basil, coriander, and fennel indoors, whether in Antarctica or elsewhere, requires careful management of several key factors. Adequate light is critical, typically provided by LED grow lights that mimic the full spectrum of sunlight and run for 12–16 hours per day. Temperature must be kept stable, generally between 18–24°C, while humidity levels should be balanced to prevent mold or dehydration.

Hydroponic systems also depend on a consistent supply of nutrient-rich water, with precise control of pH (usually 5.5–6.5) and mineral concentrations to support healthy growth. Space is often limited, so compact varieties and vertical growing setups are preferred [8,9,10].

Beyond nutrition, these green spaces serve an important psychological role: during the long, dark winter months when sunlight is scarce and the landscape is dominated by ice and snow, tending for and being around plants offers a valuable mental break and a sense of normality. However, strict environmental controls are essential due to the risk of introducing non-native species which can disrupt the existing ecosystems. There, only approved seeds may be used, with restrictions on certain plant families like brassicas and many herbs, as well as all mushroom cultures, to protect the fragile environment [11,12].

1.2 Light adaptation

Research shows that exposure to daylight-like light and a clear day-night pattern improves sleep, mood, cognition and metabolic health. [13] provide some key findings, suggesting that the increase of illuminance and correlated colour temperature at night are positively associated with melatonin suppression and therefore affect the circadian rhythm. Higher levels of CCT are proven to stimulate positive mood. [13] also prove that higher levels of illuminance are positively correlated with subjective alertness during daytime and increased positive moods during the morning, but with an increase in negative moods during the afternoon.

[14] conducted research investigating the impact of lighting on psychological perception, physiology, and productivity. They state that Illuminance and CCT could significantly influence the feeling of comfort and relaxation of the subjects. Warm CCT and higher illuminance, varying from 3000K (590 lux), made subjects feel more comfortable. Productivity was enhanced above 500 lux. However, the heart rate slightly increased as well in the adjustable lighting mode. The subjects preferred intermediate CCT (4200K) and bright illumination of 500 lux after self-adjustment. Based on these results, [14] propose three different lighting control strategies based on psychology, productivity, circadian rhythm and energy saving. Enhancing productivity, a higher correct answer rate was evident at 4000K. [14] also state that illumination value is the main consideration for a high-productivity lighting control strategy. The evaluation of lighting control strategies based on a healthy light environment provides a proposal for a healthy lighting control strategy in which the experimental results and WELL regulations are combined. The proposal aims to optimize colour temperatures with sufficient values of 150 EML between 09:00 and 13:00 to reduce daytime sleepiness and reduce the value after 20:00 to minimise the eyes' absorption of blue light.

[14] indicate no significant influence of illuminance and CCT on physiological indices and therefore suggest no special CCT or illumination requirements at 13:00 to meet the lighting requirements of daily operations.

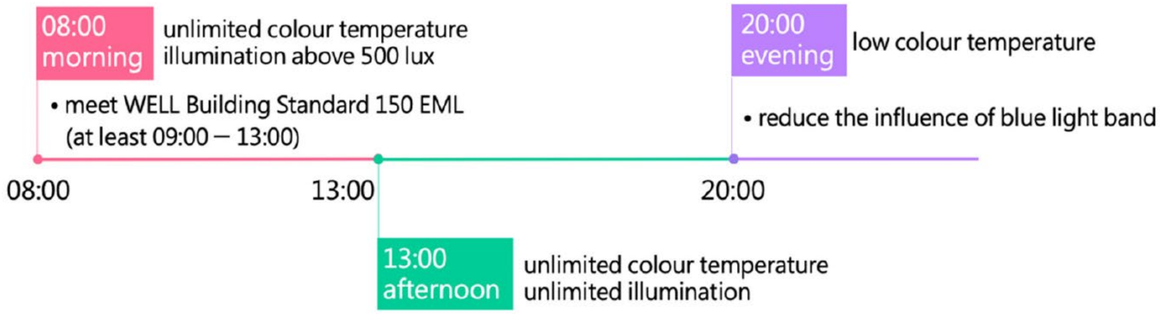


Fig. 2: *Effect of colour temperature and Illuminance on psychology*

1.3 Voronoi structures

Voronoi structures for this project have been created by applying general principles in a way, which served their specific function. First a framework was established, meaning a boundary which represents the overall “design domain”. The chosen boundary was 6m x 2.5m, resembling the footprint of “one” container. The boundary acts as a limit within which the voronoi pattern can be generated.
Then “seed points” have been generated and distributed within this chosen boundary. Seed points can be distributed randomly, resulting in organic, irregular patterns, or even grid-like, resulting in uniform cells, or clustered, where gradients can be observed. In the design, a random distribution has been adopted.

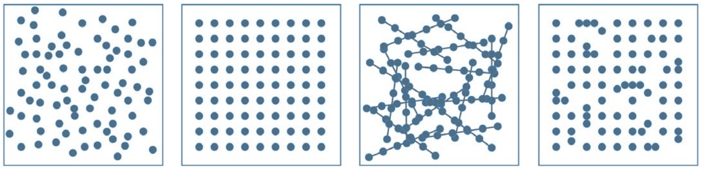


Fig. 3: *Seed point distribution*

After, the voronoi generation process was initiated, where seed points were connected through “delaunay triangulation". “Perpendicular bisectors” were being formed. This was visually forming “2d polygons” thus the 2d voronoi pattern. In this pattern, each cell stands for the area closest to its seed point.

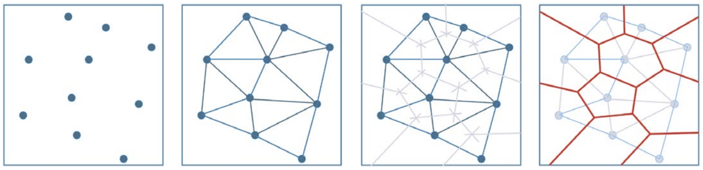


Fig. 4: *General principles for voronoi pattern formation*

The generated voronoi pattern has been trimmed to fit the predefined boundary. Subsequently, spatial differentiations were implemented,, which stand for the functional zoning, inside the container volume. The resulting “sub-boundaries inside the main design domain/boundary, got assigned different “cell densities” based on their function. More seed points result in smaller/denser cells, fewer seed points on the contrary result in larger, sparse cells. In the design, a combination of both have been applied.

Based on this, a concrete geometry has been realised through transforming the 2D voronoi cells into 3D elements - meaning, the 6mx2.5m floorplan with the cell pattern has been extruded 2.5m. Then, “cell thickness” had to be defined. In the design, a constant cell thickness has been chosen, to make the later printing more effective. Then, in specific regions, 3D cells have been subtracted to refine the spatial configuration depending on the prerequisites of specific functions (sleeping, circulation, relaxation, etc.)

Fig. 5: *Extrusion from 2D voronoi cells to 3D geometry*

Finally, this process has been repeated in different spatial units inside the boundaries of the two stacked containers. The effectiveness of this process comes through a number of key controls:
a) Point count = controlling cell size
b) Point distribution = controlling spatial variation
c) Boundary shape = defining the overall spatial margins
d) Cell thickness = controlling structural and visual weight

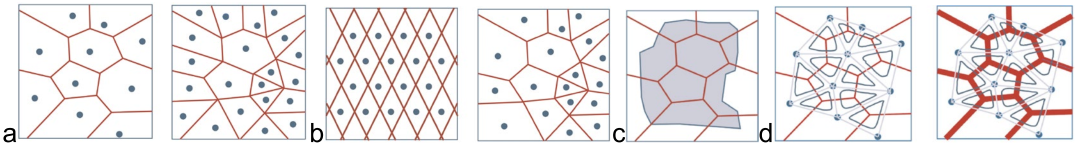


Fig. 6: *Illustration key controls for voronoi creation*

These voronoi creation principles were translated into a computational model using Grasshopper. A parametric script was developed to generate a Voronoi-based geometry, enabling control over the distribution, size, and density of cells. This approach allowed the intentional differentiation of spatial zones according to functional and environmental requirements, ensuring both efficiency and adaptability in the design.

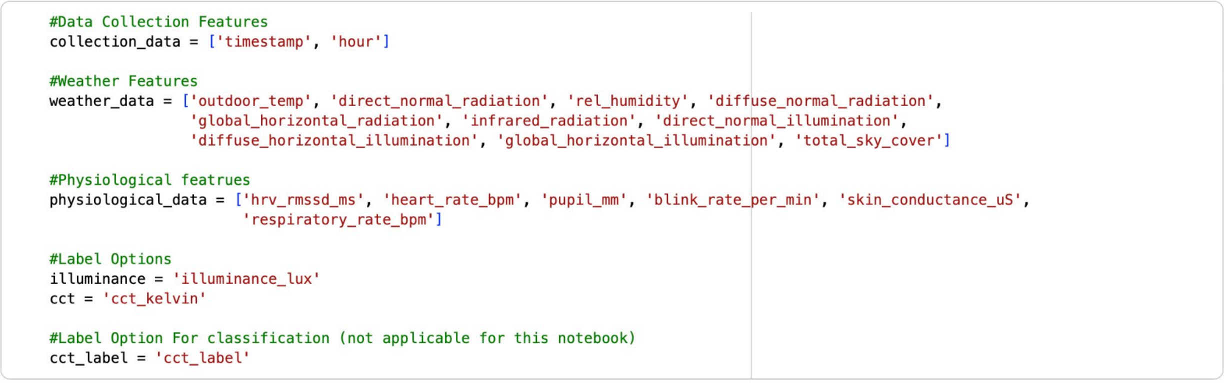
1.3.1 Benefits of Voronoi shape and material use

There are several benefits in applying voronoi based design. It allows for efficient material use and reduces waste material, just like in nature, where cells inside a leaf are structured in the most efficient spatial configuration. In addition, with this cell structure comes high structural strength, since load is distributed effectively over a vast system of cells. With the cells being hollow, structural weight is also reduced and because of the cell’s variability in shape and size, high adaptability can be achieved.

1.4 AI integration

The workshop on *Applying Machine Learning for Lighting Design* [15] by Lisa-Marie Mueller, PhD candidate at TU Delft, provided key insights into the use of data to guide design decisions. An AI-generated dataset

consisting of body, light and weather data was provided to investigate the correlation between different feature values.
The Figure below shows the different features provided:



```
#Data Collection Features
collection_data = ['timestamp', 'hour']

#Weather Features
weather_data = ['outdoor_temp', 'direct_normal_radiation', 'rel_humidity', 'diffuse_normal_radiation',
                'global_horizontal_radiation', 'infrared_radiation', 'direct_normal_illumination',
                'diffuse_horizontal_illumination', 'global_horizontal_illumination', 'total_sky_cover']

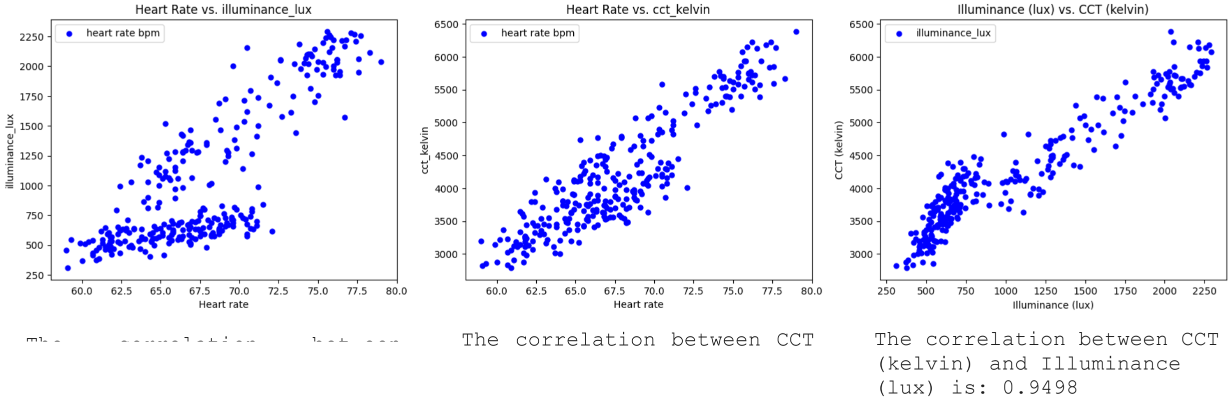
#Physiological featrues
physiological_data = ['hrv_rmssd_ms', 'heart_rate_bpm', 'pupil_mm', 'blink_rate_per_min', 'skin_conductance_uS',
                      'respiratory_rate_bpm']

#Label Options
illuminance = 'illuminance_lux'
cct = 'cct_kelvin'

#Label Option For classification (not applicable for this notebook)
cct_label = 'cct_label'
```

Fig. 7: Provided Features

The normalised data shows a high correlation of 0,81 between illuminance (lux) and the heart rate (bpm). An even higher correlation of 0.91 was found between the correlated colour temperature (kelvin) and the heart rate, pointing out that higher colour temperatures, in the form of blue tones, increase heart rate and lower colour temperatures, meaning warmer tones, decrease heart rates.
Reviewing the correlation between correlated colour temperature and Illuminance, we can conclude that there is a nearly linear relationship between these two features, with a high correlation factor of 0.95.



```
The correlation between CCT
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```
The correlation between CCT
(kelvin) and Illuminance
(lux) is: 0.9498
```

Fig. 8: *Python Script Lisa-Marie Mueller*

Taking a look at the circadian rhythm and the change of heart rate and illuminance over time, we can see that the graph shows two colliding paths. These results mirror those of the previous findings and further support the reliance of heart rate on illuminance. Both heart rate and illuminance clearly vary over the day. There are discernible patterns, suggesting periodical cycles. Illuminance, as expected, shows fluctuations that likely correspond to a daily light cycle, with higher values during the day and lower values during the night. The heart rate also exhibits changes over time, indicating periods of higher and lower activity during the day. Through visually identifying when peaks in both trends align, the graph shows how physical activity is enhanced during daytime, as with light in a biological rhythm. This emphasises the connectivity between both features.

Looking at the average heart rate variation over the day, a peak is visible during daytime activities showing higher heart rates. The average correlated colour temperature during daytime also shows the balance between higher colour temperatures during daytime (brighter colours) and lower colour temperatures during night- and eveningtime (warmer colours).

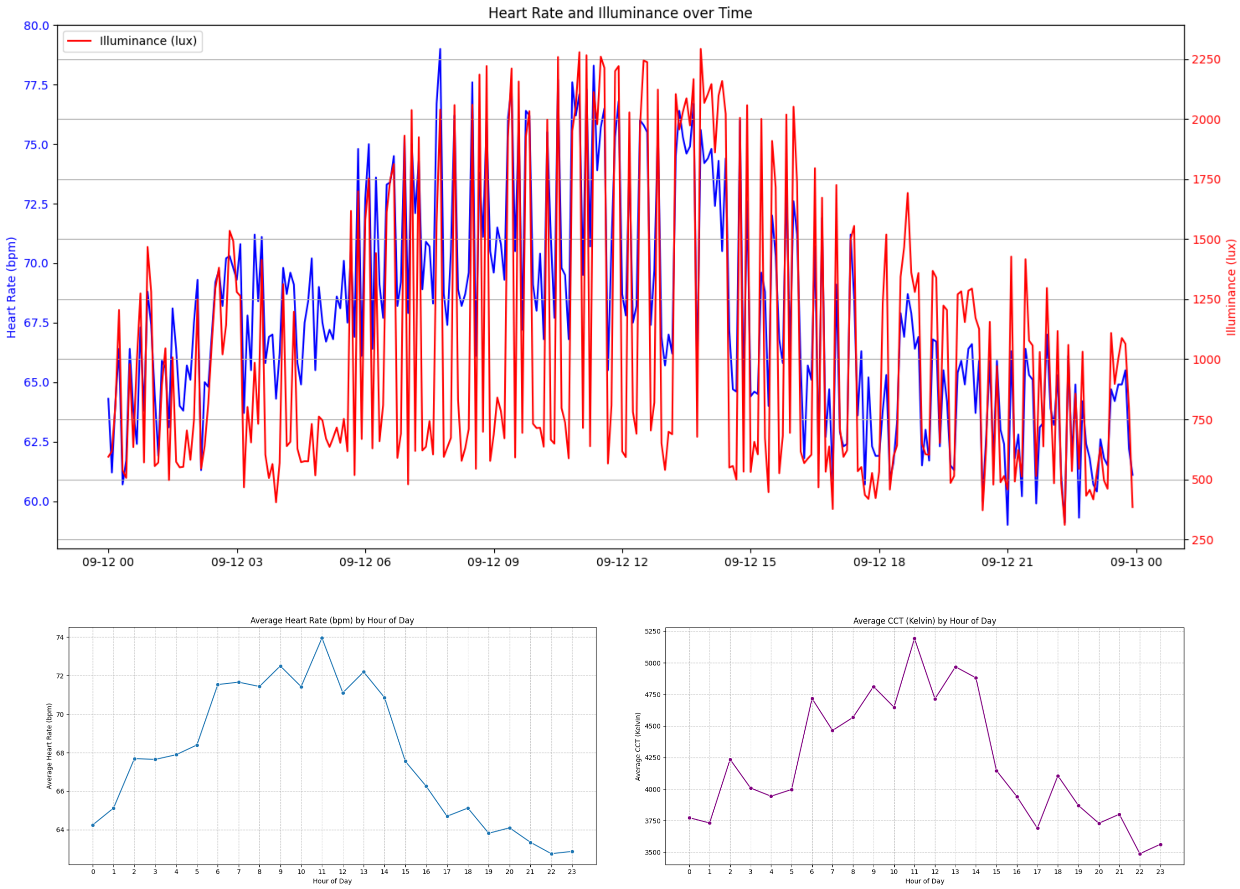


Fig. 9: *Functional Division Volumes*

These findings show a high correlation between heart rates on light. The linear correlation of heart rate and correlated colour temperature suggests both features rely on each other and influence one another. This leads to the conclusion that heart rates can be regulated through light adaptation, whilst the illuminance and correlated colour temperature change over the course of the day.

2 Research Methodology

An initial research phase was conducted to define the environmental constraints of Antarctic research stations, focusing on extreme climatic conditions, isolation, confinement, and limited natural light, all of which significantly affect human health and performance. In parallel, design to robotic production and operation approaches were investigated, particularly Voronoi-based spatial systems, due to their adaptability and efficiency in subdividing space. Existing studies on parametric design and artificial intelligence in architecture were reviewed to establish a theoretical framework for the subsequent design development.

2.1 User Requirements and Activity Mapping

The second phase identified the key parameters required to design the container-based living unit. This included mapping user activities, defining essential functions such as sleeping, working, exercising, and social interaction and identifying which functions may overlap. Particular attention was given to the relationship between spatial configuration and human wellbeing, with a focus on lighting strategies to support circadian rhythms in environments with limited daylight exposure. The analytical outcomes of this phase established the following spatial and functional requirements for the project: stacked volume and spatial generosity, environmental security, functional zoning, spatial continuity, biophilic integration, personalization of space and personal retreat.

2.2 Spatial concept development

Based on the identified requirements, a design concept was developed to organise functions within a constrained container volume. The proposal aimed to create a flexible and reconfigurable interior where multiple activities could coexist efficiently. Functional zones were defined while maintaining spatial continuity, allowing adaptability to different user needs over time.

2.3 Parametric Modelling and Voronoi Generation

The design was translated into a computational model using Grasshopper. A parametric script was developed to generate a Voronoi-based geometry, enabling control over the distribution, size, and density of cells. This approach allowed the intentional differentiation of spatial zones according to functional and environmental requirements, ensuring both efficiency and adaptability in the design.

2.4 AI-Assisted Lighting Integration

An AI-based approach was incorporated to optimise the lighting conditions within the generated geometry. The system was used to simulate and adjust illumination levels across the Voronoi cells, aiming to enhance visual comfort and support users' circadian cycles. This phase focused on integrating environmental performance with spatial design.

2.5 Detailed Components Development

Selected elements of the project were further developed at a detailed level to test their functionality and spatial efficiency. These included foldable ceiling-mounted beds designed to optimise limited space and a minimal Voronoi-based module conceived as a multifunctional element. This module can operate as seating, a climbing step or a plant container, demonstrating the adaptability and multi-purpose potential of the system.

2.6 Prototype and Material Selection and Fabrication Strategy

Finally, one component was selected for further development according to 3D printing requirements. This step enabled the evaluation of the design at a prototypical scale and its potential for real-world application.

3 Design Development

3.1 Initial Design Concept

The initial concept was shaped by a set of guiding ideas about what the container should provide. Early in the process, the decision was made to use two stacked containers rather than a single unit, increasing both vertical space and overall volume to better support the well-being of the four occupants who were intended to inhabit the container in the beginning.

Voronoi cells were incorporated as multifunctional elements, serving as climbing holds, storage units and glove boxes. A foldable net was also introduced, designed to function flexibly as additional storage and as a hangout area. From the outset, it was considered essential that each researcher have access to private space, in addition to shared communal areas. Finally, lighting was identified as a key strategy for enhancing the overall health and comfort of the inhabitants.

3.2 Pre-Midterm Design Development

The design process began with activity mapping, which helped define the essential functions the container needed to accommodate. Early ideas included a “Voronoi column” as a thermal chimney and the introduction of an airlock or buffer zone arranged in a horizontal configuration. At this stage, stacking was already considered a key spatial strategy.

Voronoi geometry was introduced as a central design tool. The container was first divided into volumetric regions based on the functions identified through activity mapping. A Voronoi script was then applied to the surfaces of these volumes, generating multifunctional elements such as walls that could be used for storage, seating, working and socialising. This phase established the foundation for combining spatial organisation with a responsive geometric system.

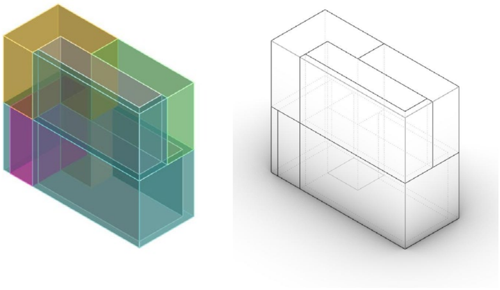


Fig. 10: *Functional Division Volumes*

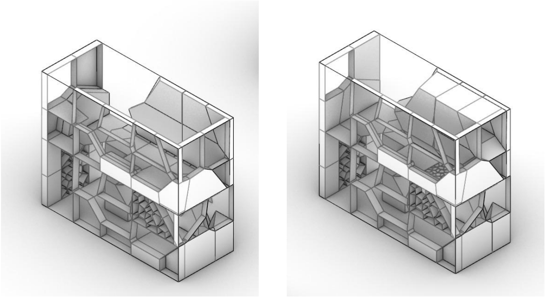
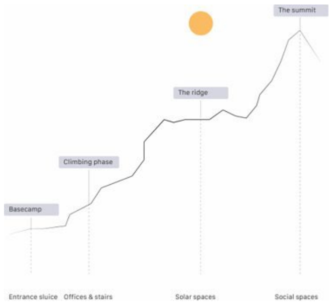
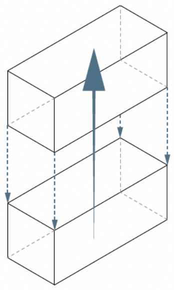


Fig. 11: *Isometric Voronoi-based Design View*

3.3 Midterm Design Proposal

The concept then evolved into *“Polar Ascend,”* inspired by the idea of a mountain expedition. The design aimed to allow working, resting and socialising to coexist within a continuous spatial experience, structured as a sequence of “stages” similar to ascending a mountain.





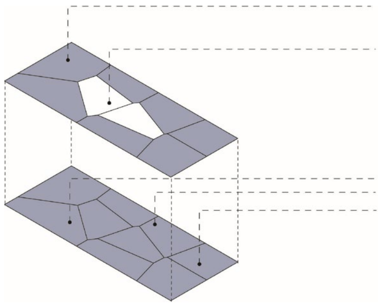


Fig. 12: *Polar Ascend Diagram* **Fig. 13:** *Stacking Diagram* **Fig. 14:** *Voronoi-based Floor Division Diagram*

The stacked configuration and horizontal array were maintained, while the internal zoning became more defined. Spaces were organised into areas for working, eating, climbing and sleeping on the ground floor, alongside social hubs, a relaxation cave and a central void with a net on the upper level.

Voronoi geometry was further explored by applying it to the floor plan according to the zoning layout. These cells were then extruded into volumes, with Voronoi patterns subtracted from them. However, at this stage, the process remained randomised, as there was no control over the placement of the Voronoi seed points. The selected fragment for further development was a Voronoi cell designed for storage, emphasising its multifunctional potential.

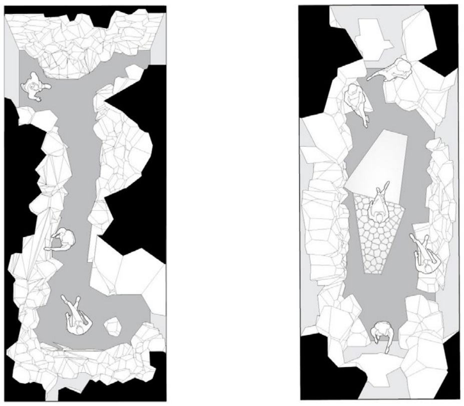


Fig. 15: *Upper and Lower Floorplans*

3.4 Post-Midterm Design Development

After the midterm presentation, the concept shifted from *“Polar Ascend”* to *“The Cave Pulse Light Experiment,”* marking a move toward a more immersive and cohesive spatial identity. The idea of the cave emphasised enclosure, continuity and a more organic relationship between spaces.

Fig. 16: *The Cave Pulse Light Experiment Diagram*

At this stage, the use of Voronoi geometry became more intentional. Instead of relying on random generation, the placement of seed points was controlled to align with specific design decisions. This allowed for variation in cell density: larger cells accommodated functions such as cooking and working niches, while smaller, denser cells were used to support climbing surfaces and storage units (see Voronoi structures section of chapter 2.3).

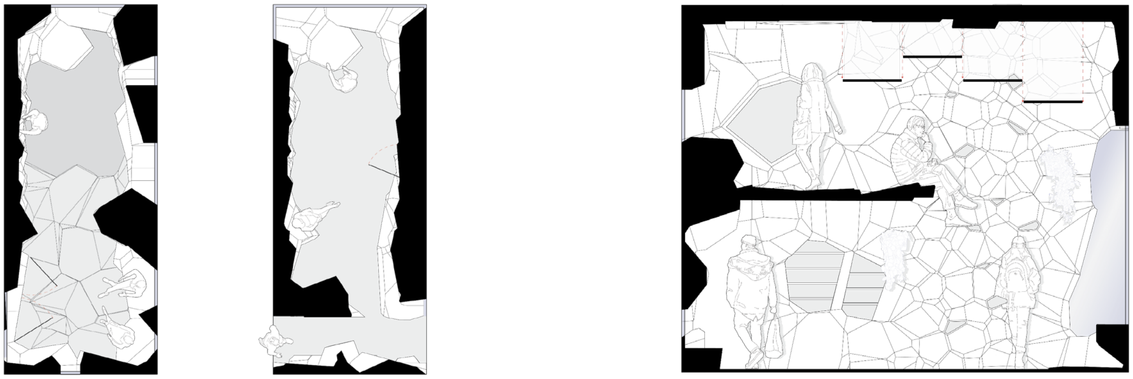


Fig. 17 & 18: *Upper and Lower Floorplans and Longitudinal Section*

Spatial organisation also evolved, with the introduction of a double-height area and the relocation of sleeping spaces to the upper level. The beds at this point were designed as foldable elements integrated into the ceiling, allowing flexibility depending on the users’ needs. The design fragment selected for prototyping was updated to a Voronoi cell incorporating both plant integration and lighting.

Despite these improvements, a conflict remained between the orthogonal geometry of the container and the Voronoi system, which characterised previous developments. The subdivision of surfaces into rectangular bands to control cell density created a clash between the two geometries. Additionally, the spatial quality did not yet fully achieve the intended cave-like atmosphere, as transitions between walls, floors and ceilings lacked continuity, and the foldable bed system was not fully aligned with the cave concept.

4 Final Design Solutions

4.1 Final Design

The final design resolved the tension between geometric systems by fully embracing Voronoi logic. Instead of dividing surfaces into straight strips, density variations were generated using Voronoi-based subdivisions, resulting in a more coherent and unified geometry.

The spatial experience was further refined to enhance the cave-like quality. Beds were carved directly from the walls and floor, reinforcing the sense of inhabiting a continuous, sculpted interior rather than occupying a fitted container. Floors and ceilings were also more seamlessly integrated with the walls, strengthening the overall sense of continuity of the Voronoi-based geometry.

At the same time, the project scope was adjusted to accommodate three researchers instead of four, allowing for a more generous and resolved spatial configuration.

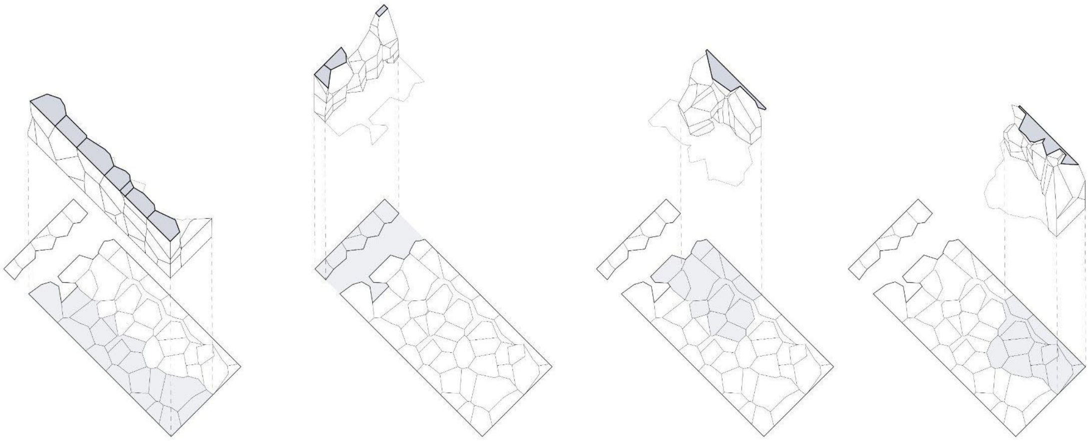


Fig. 19: *Lower Floorplan Spatial Configuration*

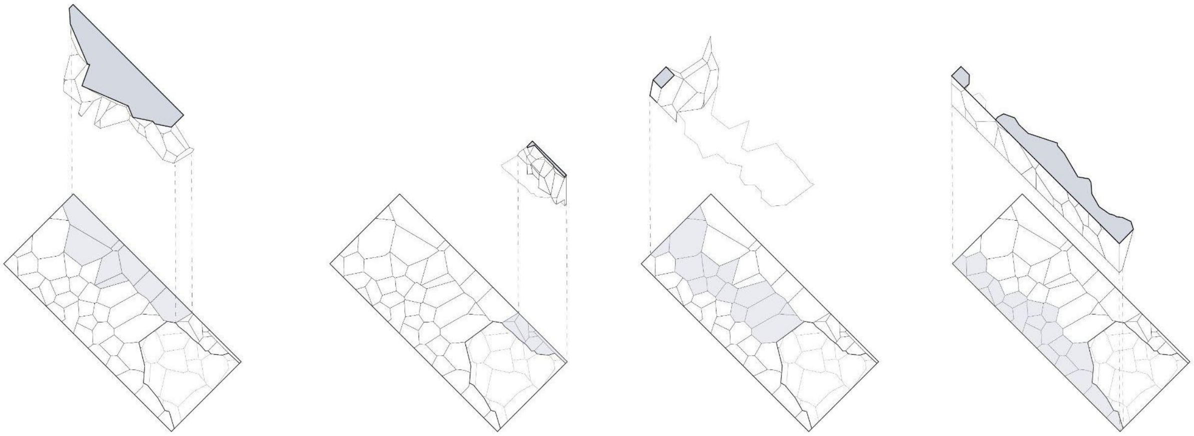


Fig. 20: *Upper Floorplan Spatial Configuration*

Fig. 21: *Upper and Lower Floorplans*

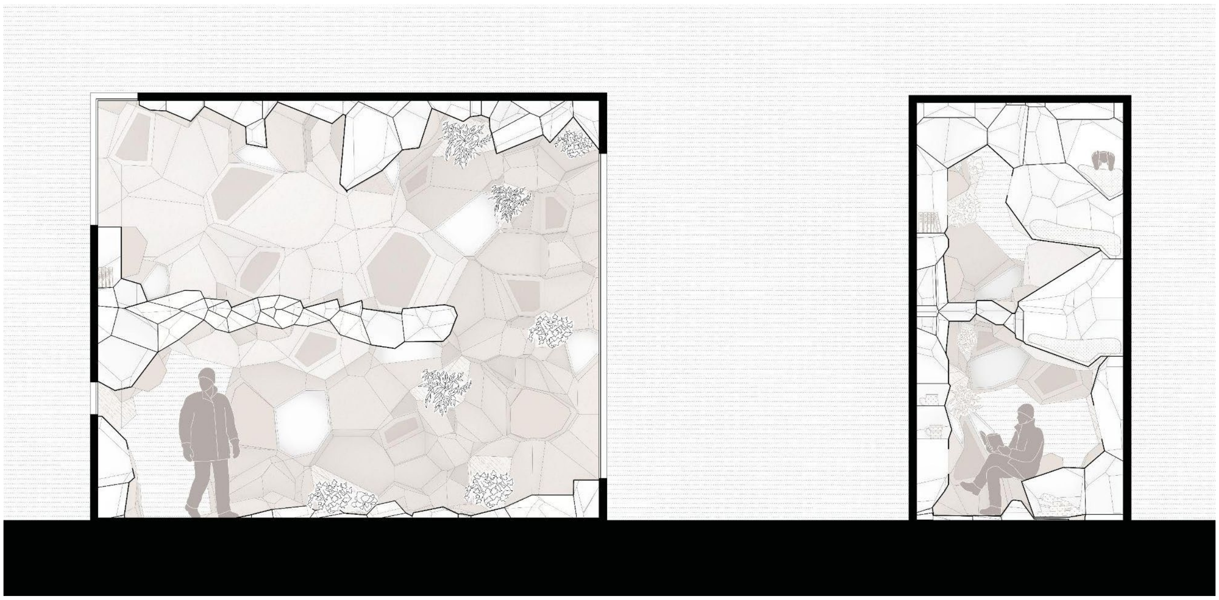


Fig. 22: *Longitudinal and Cross Sections*

4.2 AI Integration

Based on the analysis that provided the correlation between colour temperature, illuminance and heartrate the design used these features integrated into an adaptable concept. To improve the circadian rhythm during polar seasons, an adaptive lighting strategy could be used to define a daily rhythm and improve human health, as suggested in the theoretical background.

To create a daily rhythm, an adaptive system was set up, based on the difference between the expected heart rate and the perceived heart rate.

ΔH= *expected heart rate-perceived heart rate*

The expected heart rate is linked to the correlated colour temperature and illuminance of an average in the Netherlands. Based on the difference to the perceived heartrate, the colour temperature would be decreased or increased, to stabilise the researcher's heart rate according to the expected beats per minute belonging to that time of the day.

This concept was set up into a Python script that uses a Bluetooth connection to connect the heart rate data to a Grasshopper script that can adapt the colour temperature according to the disbalance. For retrieving the data, a Polar H10 Heart rate device was used that communicates through a BLE low-energy wireless protocol, which makes real-time physiological monitoring possible. To handle the communication in Python, the library Bleak [16] is used as an asynchronous, cross-platform BLE client that allows Python to connect to devices like the Polar H10, subscribe to their datastreams and receive updates in real-time. The Polar H10 holds a Media Access Control unique identifier that is assigned to network interfaces for communication within a network segment. Using this address and the HR characteristic UUID, it would be possible to retrieve human data and adapt the correlated colour temperature to the expected heart rate.

While Grasshopper cannot retrieve colour temperatures, a translation library created by Tamal-Sen, to translate colour temperatures into RGB codes can be imported from GitHub [17]. This part of the script converts the colour temperature to RGB colours that can be used and visualised through Grasshopper in Rhino.
Finally, a WebSocket can be set up for Grasshopper to import the live heart rate data, allowing Grasshopper to update lighting parameters dynamically using the Bengesht plugin in Grasshopper [18].

However, this script is fully applicable using real-time input. Due to privacy restrictions in using biomedical data, this script was not used for simulating the digital twin of the light simulation. In order to showcase the design concept, a fictitious heartbeat in Grasshopper was simulated. This simulated heartbeat can be increased and decreased, resulting in adaptable changes in colour temperature based on the findings. Its application is demonstrated within the lighting script section of chapter 5.2.2.

4.3 Grasshopper script

4.3.1 Geometry

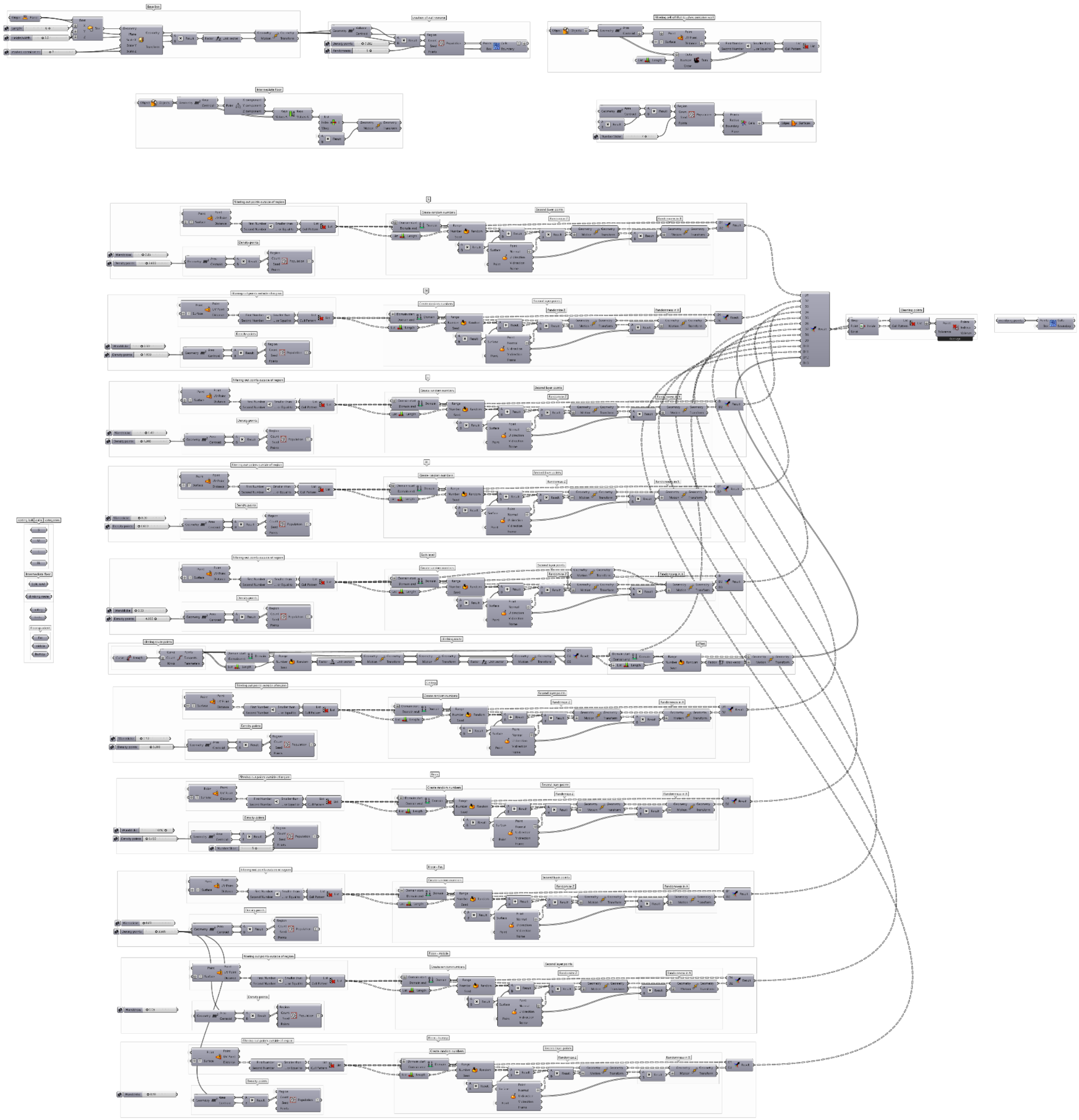


Fig. 23: *Grasshopper Script - Geometry generation*

The parametric workflow developed in Grasshopper serves to generate and control the spatial organisation and formal language of the interior environment based on a Voronoi system. In a first step, a base volume is defined according to the standardized dimensions of a shipping container, which is subsequently duplicated vertically to represent the stacked configuration of two containers. This establishes the primary spatial boundary for all further operations.

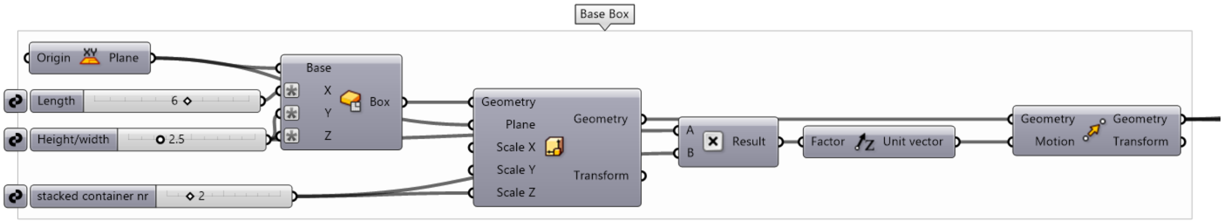


Fig. 24: *Grasshopper Script - Container creation*

Within this defined volume, a three-dimensional Voronoi system is generated. The initial Voronoi cells are intersected with the container geometry, and all cell faces that coincide with or extend beyond the outer shell are removed to maintain a clear structural boundary. An intermediate floor slab is then introduced, onto which the Voronoi logic is also applied, ensuring spatial continuity between levels.

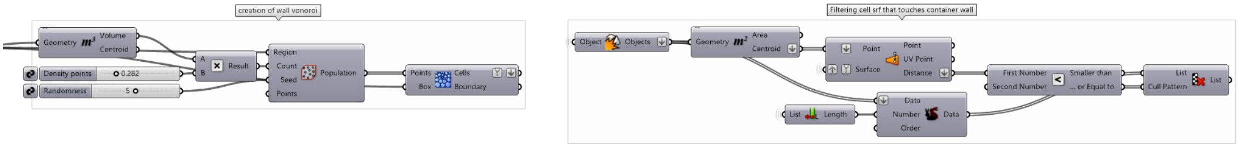


Fig. 25: *Grasshopper Script - Creating a 3d voronoi and filtering for surfaces adjacent to container*

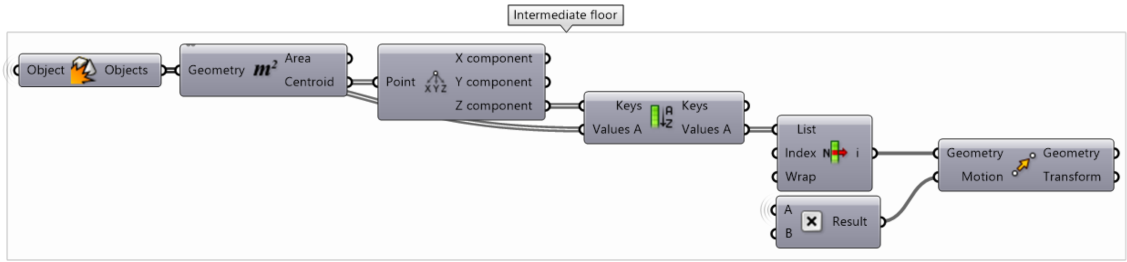


Fig. 26: *Grasshopper Script - Creating a 2d voronoi for the intermediate floor*

A critical step in the process is the strategic distribution of points across selected Voronoi surfaces, as these points determine the scale and differentiation of the resulting cells. Varying point densities are assigned according to functional requirements: areas intended for rest, such as sleeping cells, receive a lower point density to produce larger, more enclosed volumes, whereas zones requiring interaction, most notably the climbing wall, are assigned a higher density to generate smaller, more articulated geometries suitable for grip and movement. Additional points are introduced along predefined climbing routes to further enhance this functionality.

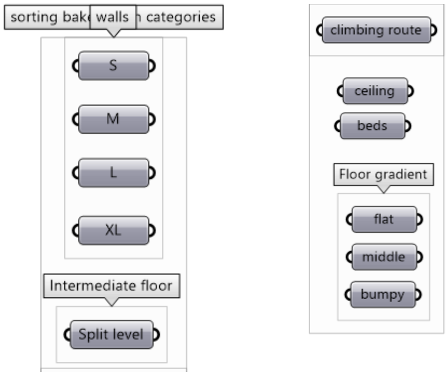


Fig. 27: *Grasshopper Script - Selecting surfaces for different densities*

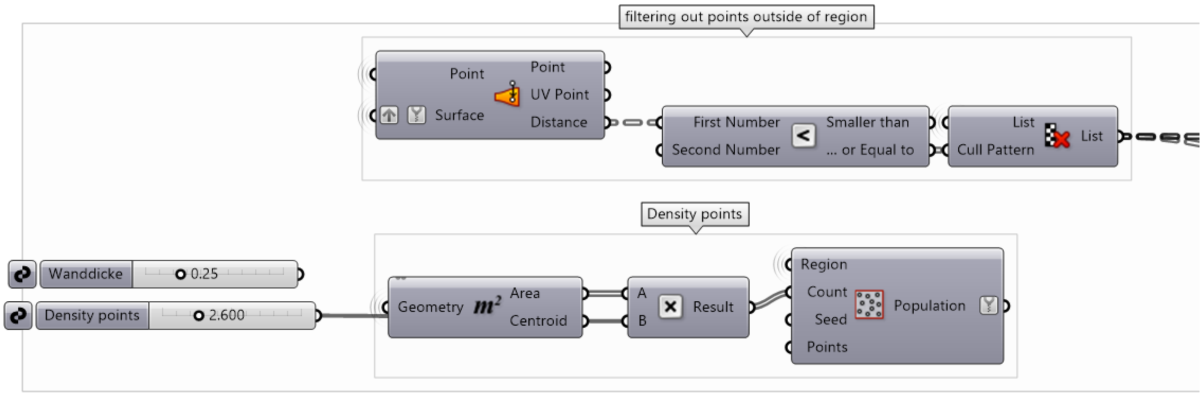


Fig. 28: *Grasshopper Script - Applying different densities based on function*

These points are then offset into the interior volume and subjected to controlled randomisation, primarily along the vertical and lateral axes. This manipulation allows for the calibration of wall thickness and spatial depth within the Voronoi structure. Subsequently, all generated points are filtered to ensure they remain within the container boundaries, then, if necessary, manually adjusted, before being used as input for the final three-dimensional Voronoi generation, which produces the overall spatial framework.

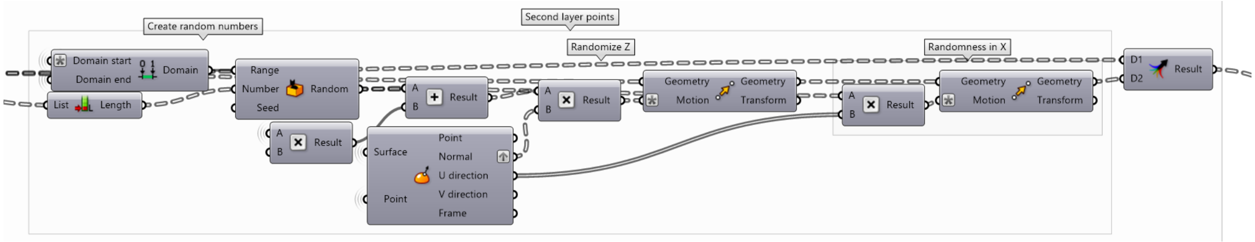


Fig. 29: *Grasshopper Script - Randomise offset points for thickness of walls*

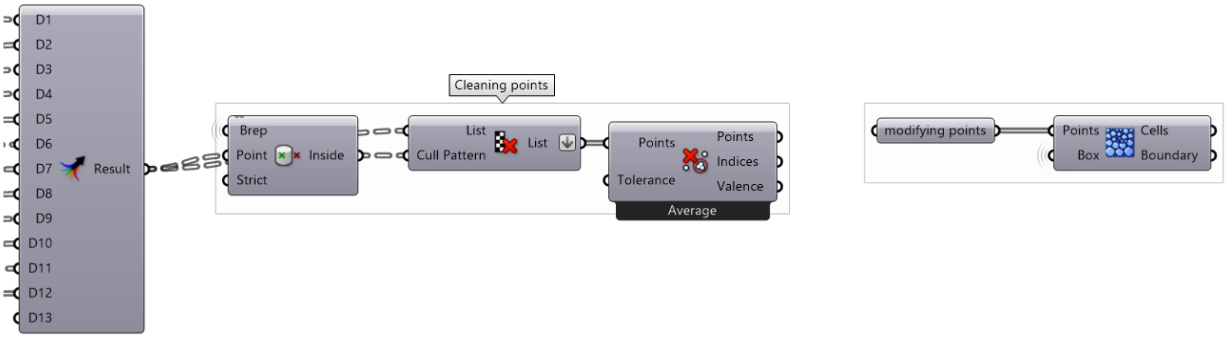


Fig. 30: *Grasshopper Script - Filtering points and manually modifying before creating 3d voronoi*

In the final stage, selected internal cells are manually removed or adapted to accommodate specific programmatic elements. This allows the integration of functional features such as lighting systems, planting zones, storage spaces, and climbing surfaces. Through this combination of algorithmic control and manual refinement, the script enables a highly differentiated and responsive interior that aligns with the experiential and functional objectives of the design.

4.3.2 Lighting

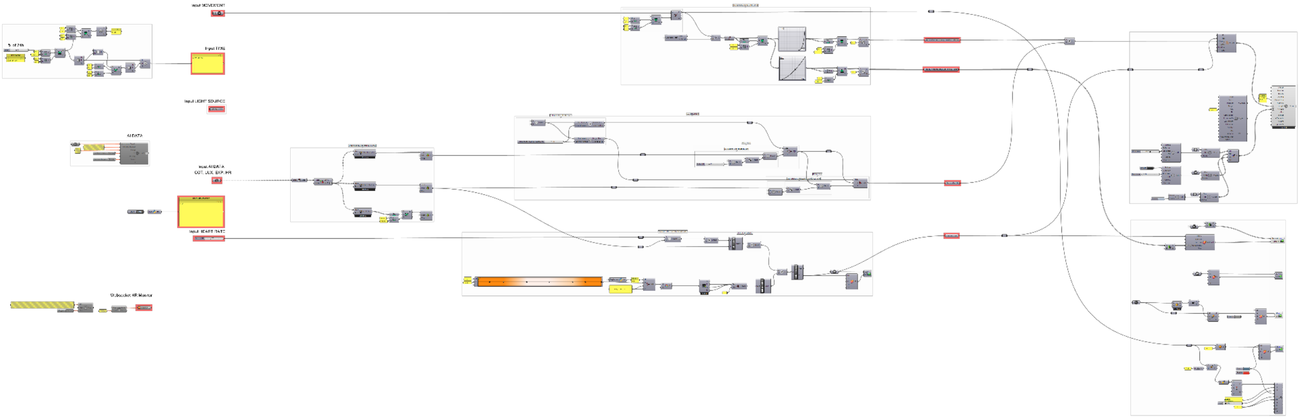


Fig. 31: *Grasshopper Script - Adaptive Lighting*

The Grasshopper definition simulates an adaptive lighting system in which the light environment changes in response to temporal, spatial, and physiological data. Instead of relying on a fixed lighting schedule, the script combines predefined reference values with occupant-related and AI-generated inputs to produce a responsive lighting condition that adapts to the current situation inside the space.

Fig. 32: *Grasshopper Script Lighting - Input Parameters*

The system is based on an external Excel dataset containing timestamp, heart rate, illuminance in lux, and correlated colour temperature in Kelvin. This dataset provides the temporal structure of the script, as each timestamp corresponds to a predefined lighting state. The values were generated using AI-based data derived from a workshop at TU Delft led by PhD student Lisa-Marie Mueller [15] (see chapter 2.4). Within Grasshopper, these imported values are separated into individual data streams so that the parameters can be processed independently. This allows the script to isolate target illuminance, target CCT, and reference physiological values for later comparison.

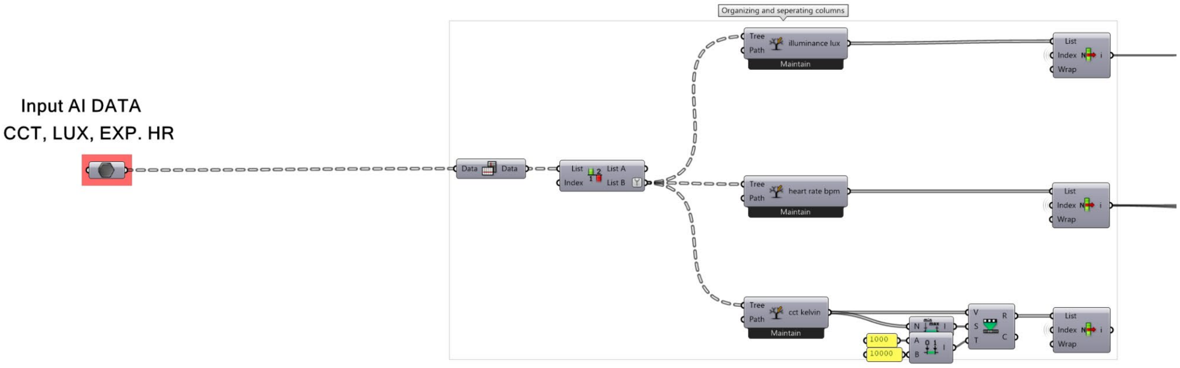


Fig. 33: *Grasshopper Script Lighting - AI Data Structure*

A key part of the definition is the integration of spatial information. The occupant's position within the research container influences how the lighting system responds. Rather than adjusting the entire space uniformly, the script localises the effect according to the proximity between the user and the lighting panels. Within the Grasshopper definition, this behaviour is abstracted through a point moving along a reparameterised curve. The curve serves as a simplified representation of the occupant's path through the container, while the time slider controls the point's position along this path.

The resulting distance values are further processed through a graph mapper, which allows the relationship between proximity and light output to be non-linear. This enables amplification of the effect near the user, producing a strong local response, while maintaining a controlled and gradual falloff toward more distant panels.

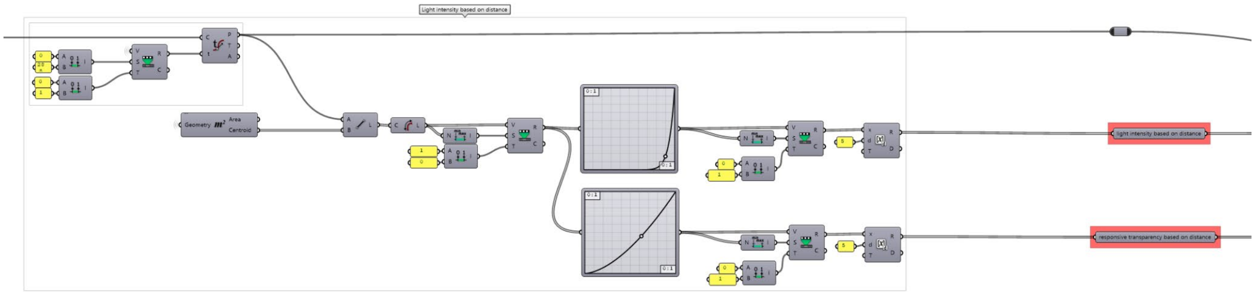


Fig. 34: *Grasshopper Script Lighting - Distance-based mapping of user position*

The physiological layer is based on heart rate. Within the script, heart rate can be provided manually through a slider, simulated through a Python script that cycles values from 30 to 190 bpm in intervals of 400 milliseconds, or potentially integrated as live data via a WebSocket connection. The value is then compared with a predefined reference from the dataset. This difference is evaluated through a tolerance threshold and a scaling factor, which determine whether the deviation is significant and how strong the resulting lighting response should be.

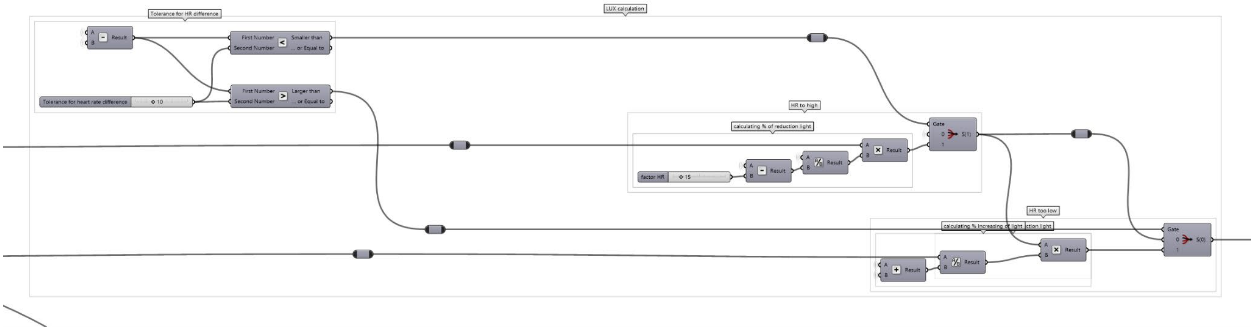
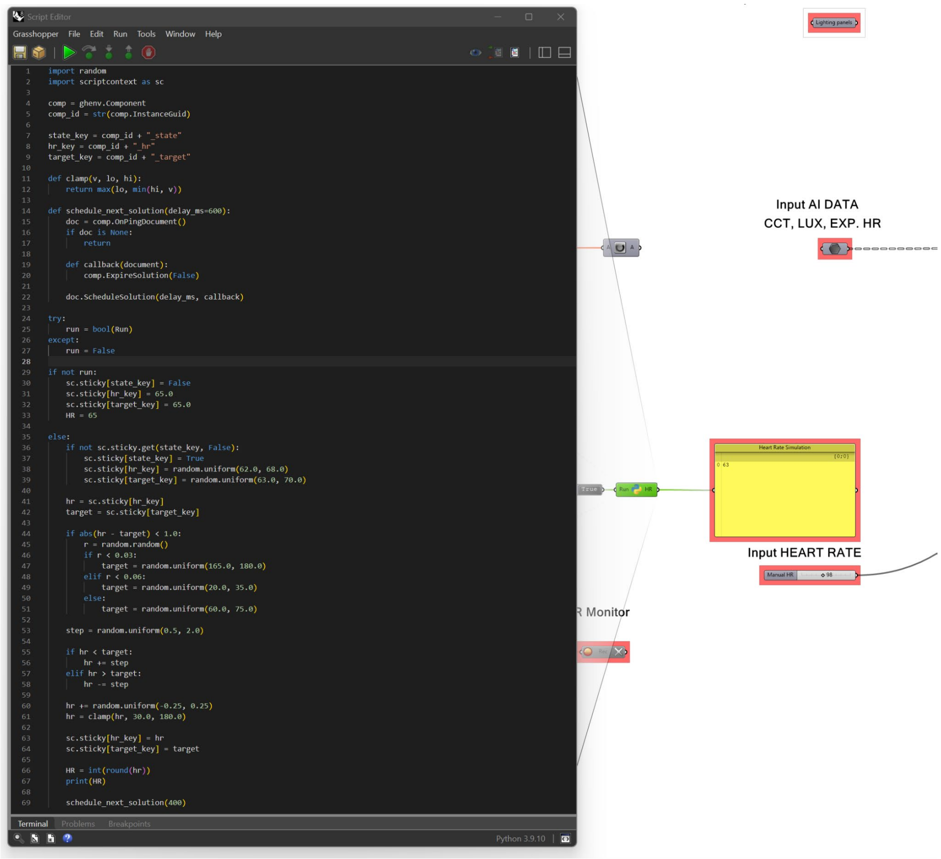


Fig. 35: *Grasshopper Script Lighting - Calculation tolerance threshold*



```python
import random
import scriptcontext as sc

comp = ghenv.Component
comp_id = str(comp.InstanceGuid)

state_key = comp_id + "_state"
hr_key = comp_id + "_hr"
target_key = comp_id + "_target"

def clamp(v, lo, hi):
    return max(lo, min(hi, v))

def schedule_next_solution(delay_ms=600):
    doc = comp.OnPingDocument()
    if doc is None:
        return

    def callback(document):
        comp.ExpireSolution(False)

    doc.ScheduleSolution(delay_ms, callback)

try:
    run = bool(Run)
except:
    run = False

if not run:
    sc.sticky[state_key] = False
    sc.sticky[hr_key] = 65.0
    sc.sticky[target_key] = 65.0
    HR = 65

else:
    if not sc.sticky.get(state_key, False):
        sc.sticky[state_key] = True
        sc.sticky[hr_key] = random.uniform(62.0, 68.0)
        sc.sticky[target_key] = random.uniform(63.0, 70.0)

    hr = sc.sticky[hr_key]
    target = sc.sticky[target_key]

    if abs(hr - target) < 1.0:
        r = random.random()
        if r < 0.03:
            target = random.uniform(165.0, 180.0)
        elif r < 0.06:
            target = random.uniform(20.0, 35.0)
        else:
            target = random.uniform(60.0, 75.0)

    step = random.uniform(0.5, 2.0)

    if hr < target:
        hr += step
    elif hr > target:
        hr -= step

    hr += random.uniform(-0.25, 0.25)
    hr = clamp(hr, 30.0, 180.0)

    sc.sticky[hr_key] = hr
    sc.sticky[target_key] = target

    HR = int(round(hr))
    print(HR)

    schedule_next_solution(400)
```

Fig. 36: *Grasshopper Script Lighting - Python heart rate simulation*

In the final setup, the colour temperature values were not derived from the AI-generated dataset, as these outputs proved unreliable and produced inaccurate results. Instead, predefined CCT values, based on the research by [14], as described in chapter 2.2, were implemented as a stable reference framework. These values are structured according to circadian principles, with lower CCT levels in the morning and evening hours and higher CCT levels during core working hours to create a more stimulating environment.

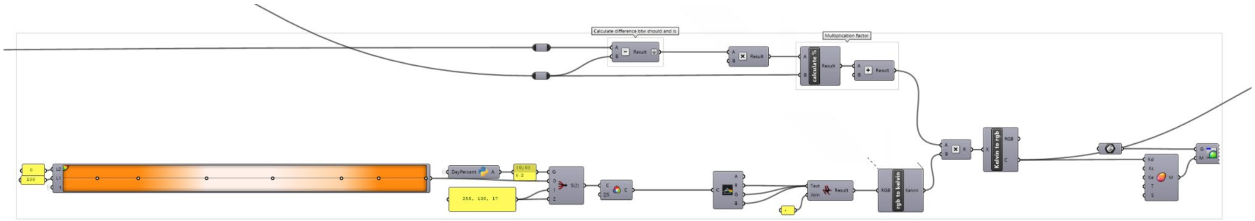
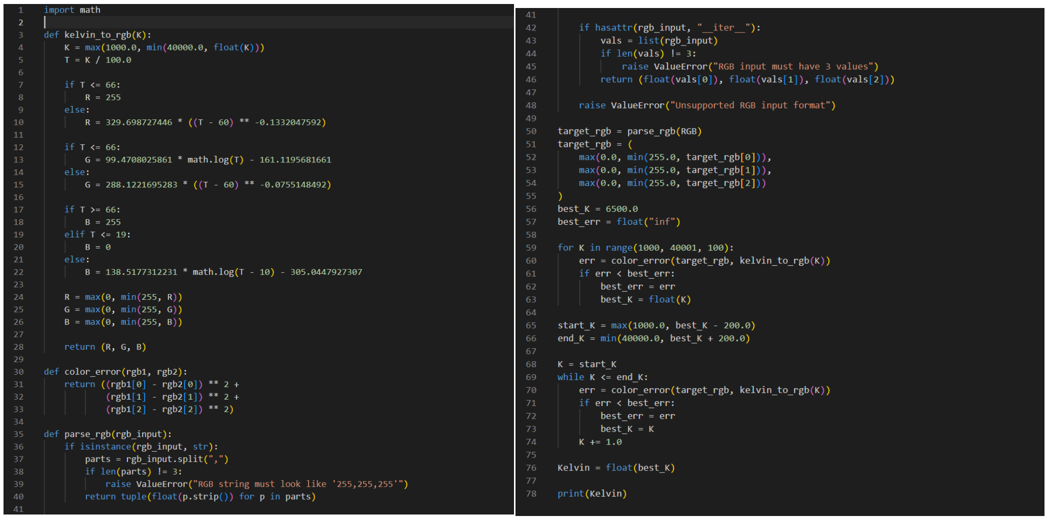


Fig. 37: *Grasshopper Script Lighting - Heart Rate–Driven colour Temperature Adjustment*

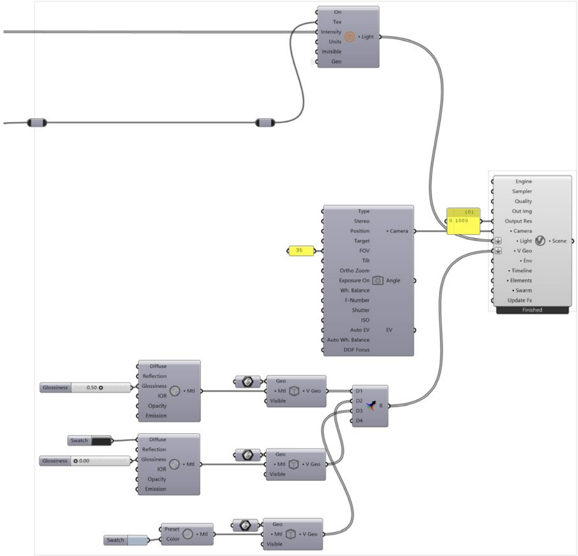
The relationship between heart rate and colour temperature forms the central concept of the system. In this model, an increased heart rate leads to a warmer light condition, while a lower heart rate results in a cooler light condition. The lighting, therefore, operates as an environmental parameter that seeks to balance the user's physiological state through atmospheric modification of the space. Within the Grasshopper definition, this is implemented by comparing the AI-based expected heart rate with the measured heart rate and translating the resulting deviation (*ΔH= expected heart rate - perceived heart rate)* into a multiplication factor that modifies the target colour temperature. For visualisation, RGB values are first converted into CCT data, adjusted through this factor, and then converted back into RGB values using Python [17].



```python
import math

def kelvin_to_rgb(K):
    K = max(1000.0, min(40000.0, float(K)))
    T = K / 100.0

    if T <= 66:
        R = 255
    else:
        R = 329.698727446 * ((T - 60) ** -0.1332047592)

    if T <= 66:
        G = 99.4708025861 * math.log(T) - 161.1195681661
    else:
        G = 288.1221695283 * ((T - 60) ** -0.0755148492)

    if T >= 66:
        B = 255
    elif T <= 19:
        B = 0
    else:
        B = 138.5177312231 * math.log(T - 10) - 305.0447927307

    R = max(0, min(255, R))
    G = max(0, min(255, G))
    B = max(0, min(255, B))

    return (R, G, B)

def color_error(rgb1, rgb2):
    return ((rgb1[0] - rgb2[0]) ** 2 +
            (rgb1[1] - rgb2[1]) ** 2 +
            (rgb1[2] - rgb2[2]) ** 2)

def parse_rgb(rgb_input):
    if isinstance(rgb_input, str):
        parts = rgb_input.split(",")
        if len(parts) != 3:
            raise ValueError("RGB string must look like '255,255,255'")
        return tuple(float(p.strip()) for p in parts)

    if hasattr(rgb_input, "__iter__"):
        vals = list(rgb_input)
        if len(vals) != 3:
            raise ValueError("RGB input must have 3 values")
        return (float(vals[0]), float(vals[1]), float(vals[2]))

    raise ValueError("Unsupported RGB input format")

target_rgb = parse_rgb(RGB)
target_rgb = (
    max(0.0, min(255.0, target_rgb[0])),
    max(0.0, min(255.0, target_rgb[1])),
    max(0.0, min(255.0, target_rgb[2]))
)
best_K = 6500.0
best_err = float("inf")

for K in range(1000, 40001, 100):
    err = color_error(target_rgb, kelvin_to_rgb(K))
    if err < best_err:
        best_err = err
        best_K = float(K)

start_K = max(1000.0, best_K - 200.0)
end_K = min(40000.0, best_K + 200.0)

K = start_K
while K <= end_K:
    err = color_error(target_rgb, kelvin_to_rgb(K))
    if err < best_err:
        best_err = err
        best_K = K
    K += 1.0

Kelvin = float(best_K)

print(Kelvin)
```

Fig. 38: *Grasshopper Script Lighting - Tamal-sen/colourTemperatureToRGB*

In the current model, this relationship is shown in a simplified way in the Rhino preview through changing panel transparency, local activation, and the conversion of CCT values into RGB. The lighting effect is further represented through Rhino and Chaos V-Ray mesh lights, which also respond through localised activation and RGB-based colour output. The conversion of Kelvin-based CCT values into RGB was implemented through a Python script. In this way, the project visualises not only the resulting lighting effect but also the underlying logic of the system, showing how brightness, colour temperature, and spatial activation interact within the simulation.



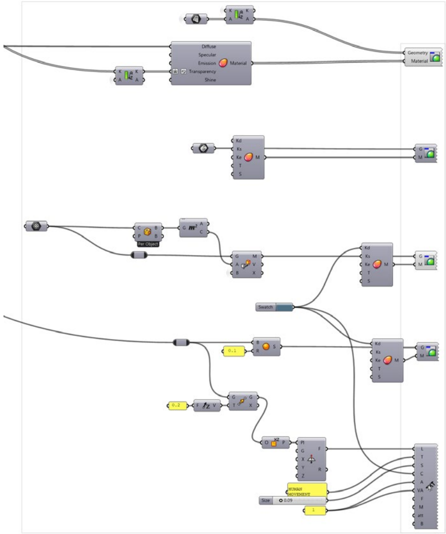


Fig. 39: *Grasshopper Script Lighting - Visualisation using Chaos V-Ray & Rhino Preview*

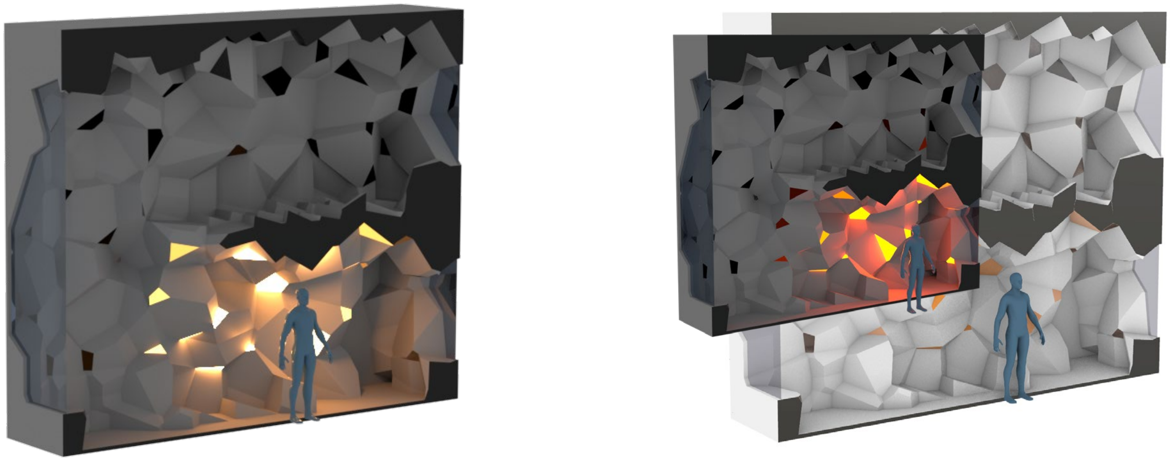
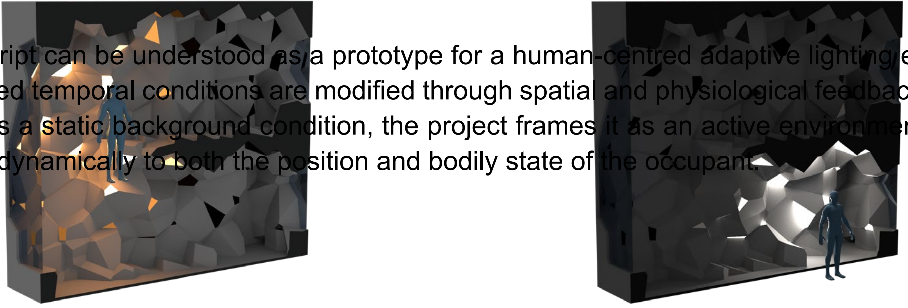


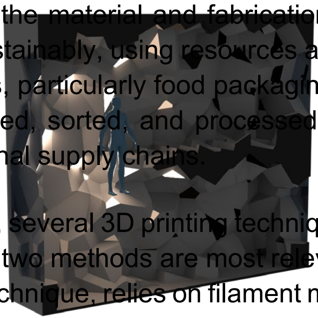
Fig. 40: *Visualisation using Chaos V-Ray & Rhino Preview*



Overall, the script can be understood as a prototype for a human-centred adaptive lighting environment in which scheduled temporal conditions are modified through spatial and physiological feedback. Rather than treating light as a static background condition, the project frames it as an active environmental parameter that responds dynamically to both the position and bodily state of the occupant.

20:00 **12:00**

HR: 130 bpm ~1000K HR: 130 bpm ~1000K



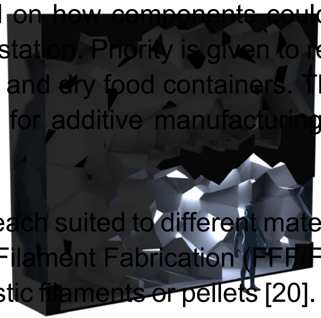


Fig. 41: *Matrix: Responsive Lighting (CCT) depending on Daytime, Spatial Data & Heart Rate*

4.3.3 Printing and material use

In developing the material and fabrication strategy, we focused on how components could be produced locally and sustainably, using resources already available at the station. Priority is given to reusing existing waste streams, particularly food packaging such as bottles, tins, and dry food containers. These materials can be collected, sorted, and processed into usable feedstock for additive manufacturing, reducing the need for external supply chains.

To enable this, several 3D printing techniques were considered, each suited to different material conditions. Among these, two methods are most relevant [19]. First, Fused Filament Fabrication (FFF/FDM), the most widely used technique, relies on filament made from recycled plastic filaments or pellets [20]. Second, fused particle or pellet fabrication allows for direct printing from shredded or pelletized waste, making it particularly suitable for in-situ recycling processes and reducing the need for intermediate material processing.

A range of thermoplastics commonly found in packaging waste can be reused in these systems, including PLA, ABS, PET/PETG and polypropylene (PP). With appropriate processing and the addition of stabilisers, these recycled materials can achieve properties close to those of virgin plastics. Furthermore, material performance can be enhanced through the incorporation of composites and fillers derived from other wastes or biomass, such as ceramic particles, glass fibres, carbon fibres, or natural fibres like wood and agricultural residues. These combinations can improve strength, durability, and overall material behaviour. However, due to the limited accessibility and availability of materials at the Troll station, these options should be considered with caution.

In our specific context, materials such as PET/PETG, polypropylene, polystyrene, PLA, and PVC are particularly relevant, as they are widely used in food packaging and are therefore readily available. Their established use in food-related applications also suggests suitability for interior environments. However, a key limitation of recycled plastics is material degradation over multiple cycles, often requiring the addition of a proportion of virgin material to maintain flexibility and prevent brittleness.

Given these considerations, pellet-based printing emerges as the most viable approach, as pellets can be directly produced from shredded packaging waste and fed into the printing system with minimal processing. While the production of bioplastics from food waste is theoretically possible, in this context, such resources are likely too limited and are more effectively reused in biological cycles, for example, as nutrients for plant growth.

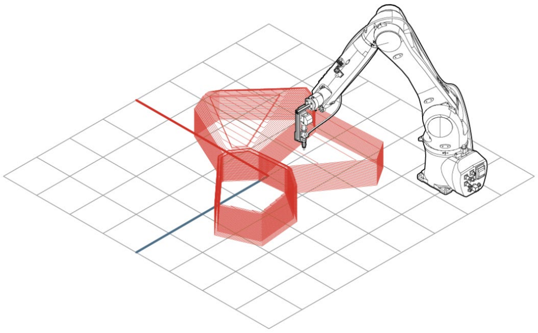


Fig. 42: *Scheme: 3D Printing Voronoi Geometry*

4.3.4 Visualisation

In visualising the project, our goal was to communicate the impact of dynamic inputs, such as heart rate, time of day, and user location, generated through Grasshopper, which continuously influence the lighting conditions. While translating the geometry into AR or VR environments is technically feasible using tools like Fologram or Mindesk, and even allows for interactive control through sliders, these platforms cannot currently simulate or customize lighting conditions beyond basic material previews. Conversely, traditional renderings enable accurate representation of lighting atmospheres but do not capture the immersive and interactive qualities of AR/VR, particularly the user's movement through space. As a result, we adopted a hybrid approach: presenting the parametric system and its dynamic behaviour through a video-based code preview, while complementing it with static renderings that effectively convey the intended lighting scenarios. For this use case, we also experimented with AI-based rendering workflows, such as Nano Banana, to explore whether they could support the visualization of dynamic lighting atmospheres.

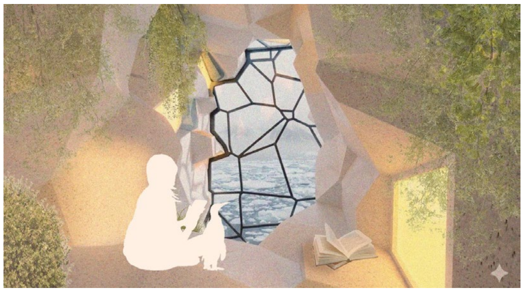


Fig. 43: *AI Lighting explorative renders*

4.3.5 Fragment

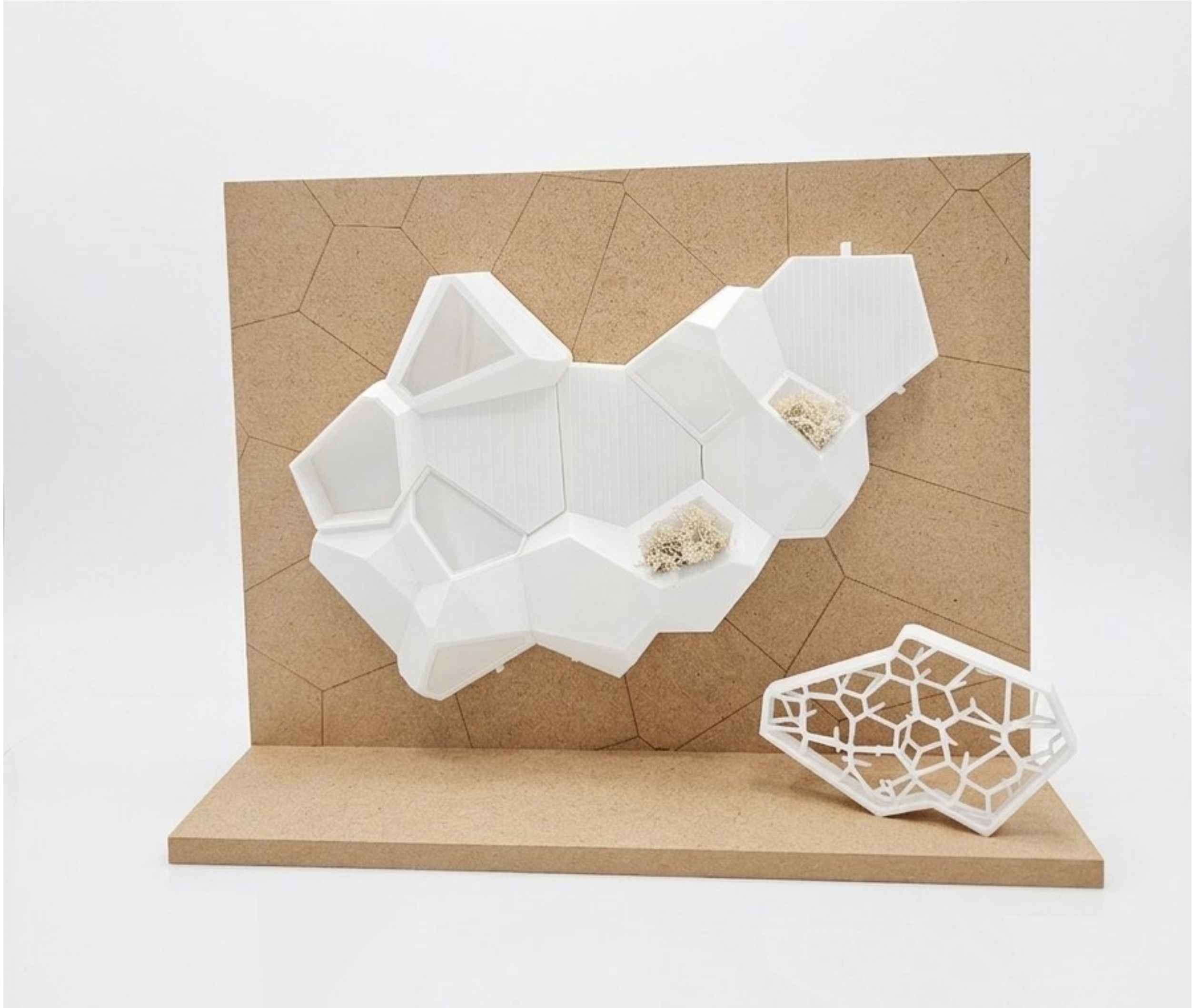


Fig. 44: *Physical Fragment*

Within the fragment, the transition of the design proposal from the digital to the analog is explored through both diagrammatic studies and a physical model. Different cell configurations, including lighting integration, hydroponic planting pots, and storage units, are combined into groups of three and mounted on a backboard. This arrangement tests how individual units can form larger spatial constellations while maintaining a coherent geometric logic. The connection clips make use of the geometric properties of the Voronoi cell and are positioned orthogonally to the parallel shells, allowing the different constellations to be assembled and fixed to the supporting surface.

The accompanying diagrams illustrate this process on two levels. On the one hand, they describe the spatial organization of the fragment and the relationship between the mounted elements, the backboard, and the underlying geometric framework. On the other hand, they begin to outline a possible fabrication logic by linking the formal characteristics of the cells to methods of assembly and production.

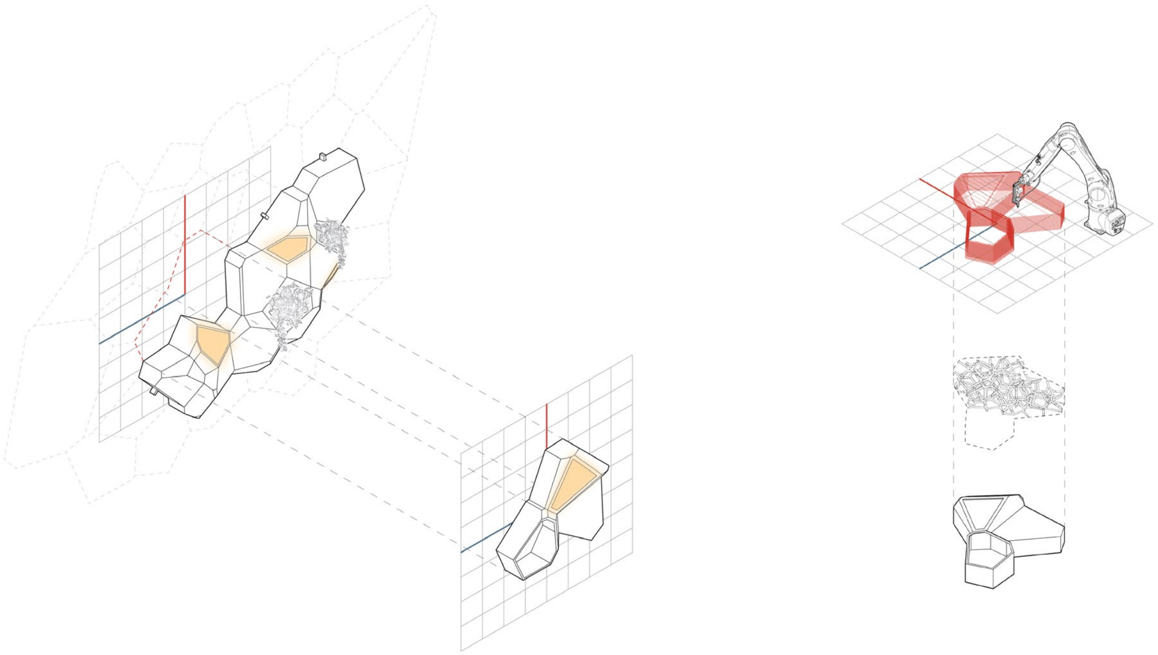


Fig. 45: Diagram Digital Fragment *& Print Process*

The fragment itself was produced as a first physical prototype using a Bambu Lab A1 Mini, printed in PLA with a 0.4 mm nozzle. As such, it should be understood primarily as a proof of concept. It allows the spatial qualities, scale, connection details, and material behavior of the design to be evaluated in physical form. At the same time, the prototype reveals practical questions of tolerance, stability, and assembly that are less evident in the digital model.

Beyond the small-scale prototype, the project also points toward a different fabrication approach for a larger architectural application. While the printed model was produced through conventional desktop 3D printing, the proposed design anticipates the use of robotic fabrication, for example with a KUKA robotic arm.

In addition, the fragment serves as an initial exploration of the next step in the design process, namely the development of a Voronoi-based infill pattern. As indicated in the diagrams, this strategy could translate the geometric logic of the outer shell into the interior of the printed elements, reducing material usage while preserving structural continuity with the overall design language. Future research could focus on the structural optimisation of this infill system within Rhino Grasshopper, using Karamba3D as a simulation and analysis tool.

5 Conclusions

In “Cave Pulse Light Experiment” reconfigurable container modules are transformed into adaptive living environments that respond to fundamental human needs while addressing the challenges of isolation, confinement, and environmental stress. At its core, the design is trying to restore disrupted physiological conditions by integrating intelligent lighting systems that support circadian rhythm regulation, mitigating health issues associated with prolonged indoor exposure and extreme climate conditions. The design emerged from an extensive needs and requirements analysis, which helped in creating key design considerations such as autonomy, comfort, fitness, stimulation, and beauty i.e. aesthetics.

Autonomy is fostered through individualised systems that adapt to users’ biometric data, daily activities, and personal preferences, alongside spatial features such as privacy screens and highly personalised living cells. The space stimulates the occupant with interactive lighting, adaptable elements, natural features, and varied spatial experiences, supporting both mental and physical well-being and encouraging interaction with and within the space. The spatial and aesthetic strategy further enhances well-being through a coherent formal language inspired by the sculptural qualities of ice formations. This approach is expressed through a consistent Voronoi-based geometry, the integration of natural elements, and framed views of the surrounding landscape, strengthening the occupants’ connection to nature.

Comfort is achieved through spatial hierarchy, where intimate niches and cocoon-like sleeping areas coexist with larger gallery spaces and double-height volumes. Fitness is encouraged through the incorporation of a climbing wall embedded within the ice-like forms, as well as a generally playful interior that promotes movement and interaction. The project acknowledges that social dynamics in shared spaces can hardly be controlled, but can be meaningfully supported. By creating environments that are both interactive and adaptable, the design enables a balance between individualisation and collective experience, fostering opportunities for social interaction while respecting personal boundaries.

Overall, the “Cave Pulse Light Experiment” demonstrates how an integrated, human-centred design strategy can transform extreme habitation into a supportive, engaging, and health-promoting environment, offering broader potential implications for future research stations and other extreme living contexts.

5.1 Study Limitations

The "Cave Pulse Light Experiment" (CPLX) identifies several critical study limitations that influenced the research methodology and final design outcomes. These constraints can be broadly understood through the lens of data privacy, technical execution, and environmental regulations.

Data and Methodological Constraints

A primary limitation involves the restriction on using authentic physiological data. Due to privacy regulations regarding the handling of biomedical information, real-time heart rate data could not be integrated into the digital twin simulation. Consequently, the research relied on a fictitious, simulated heartbeat within the Grasshopper environment to demonstrate the responsive lighting design. Additionally, the reliability of emerging technologies presented a significant challenge; it was observed that AI-generated dataset outputs for correlated color temperature (CCT) were frequently inaccurate. To ensure experimental stability, the study opted to utilize predefined reference values derived from established scientific literature rather than relying on inconsistent AI-driven data.

Technical and Simulation Boundaries

The research was further constrained by a technical disconnect between various visualization and design platforms. While augmented and virtual reality tools (such as Fologram and Mindesk) allow for interactive user control, these platforms currently lack the capacity to accurately simulate or customize complex lighting conditions beyond basic previews. Conversely, although traditional rendering software can represent accurate lighting atmospheres, it is unable to capture the immersive, interactive nature of a user’s movement through the space.

Furthermore, a notable research gap exists regarding the integrated support for dynamic light intensity and color temperature transitions within real-time rendering programs. While parametric environments like Grasshopper allow for the logical mapping of lighting data, existing visualization engines often fail to bridge the gap between data-driven lighting logic and high-fidelity, interactive visual output. This necessitated a fragmented workflow, as the software lacks the native ability to retrieve color temperatures directly, requiring external translation libraries to convert CCT values into RGB codes for visualization.

Environmental and Spatial Limitations

The physical and regulatory environment of Antarctica imposed several rigid constraints on the project:

Biosecurity and Resource Demands: Strict international biosecurity protocols prohibit the introduction of non-native species, which severely limits the variety of plants available for biophilic design. Moreover, the maintenance of indoor greenery is limited by high energy requirements for constant climate control and the need for specialized technical oversight to monitor plant health in isolated conditions. Despite these challenges, indoor herb cultivation remains highly efficient, producing fresh, aromatic crops in places where traditional agriculture would be impossible.

Spatial and Scope Constraints: The project was strictly bound by the dimensions of standardized shipping containers (6m x 2.5m). This fixed spatial footprint forced a reduction in the initial project scope from four researchers to three to ensure a habitable and resolved spatial configuration.

Contextual Isolation: The extreme polar conditions mean that occupants may be confined indoors for several consecutive days during snowstorms, making the psychological impact of the interior environment a critical but difficult-to-measure variable within the timeframe of the study.

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Image References

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Diagram source not specified in the caption

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