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Design of a modular system for the implementation of green roofs and passive ventilation on a building cover

Bachelor End Project
Industrial Design Engineering and Product Development

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ABSTRACT

Abstract

Design of a system for the implementation of green roofs on buildings that initially lack them, with the aim of combating the urban heat island effect both within the building and in its surroundings. Designed based on biomimicry and biodesign principles, in addition to the advantages of a conventional green roof, this system adapts the strategy used by prairie dogs, which is based on Bernoulli's principle, to create a cold air current that circulates beneath the green layer and above the roof surface, helping to disperse the heat emitted from this surface. The system has been developed with sustainability and environmental cooperation values in mind. Among its secondary functions, it incorporates the collection, storage, and management of rainwater, which will be used to supply, as much as possible, the plants within the system, and any excess can be directed to other systems. Another of its functions is to provide a habitat for urban ecosystem species, which are increasingly affected by the lack of green spaces.

Key words

Green roof; living roof; modular system; passive ventilation; Bernoulli; urban heat island.

Resumen

Diseño de un sistema para la implementación de techos verdes en las cubiertas de edificios que carecen inicialmente de ellos, con el objetivo de luchar contra el efecto de isla de calor urbano, tanto dentro del edificio como en su entorno. Diseñado en base a los criterios de la biomímesis y el biodiseño, además de las ventajas de un techo verde convencional, este sistema adapta la estrategia usada por los perritos de las praderas, que a su vez se fundamenta en el principio de Bernoulli, para crear una corriente de aire frío que circula por debajo de la capa verde y sobre la superficie de la cubierta, ayudando a dispersar el calor que se emite en esta superficie. El sistema se ha desarrollado en base a valores de sostenibilidad y cooperación con el medio. Entre sus funciones secundarias se incorpora la recogida, almacenamiento y gestión del agua de lluvia que será utilizada para suplir, en la medida de lo posible, a las plantas que habitan el sistema, y el posible exceso puede ser dirigido a otros sistemas. Otra de sus funciones es proveer de un hábitat a aquellas especies de animales del ecosistema urbano, a las que la carencia de espacios verdes afecta cada día más y más.

Palabras clave

Techo verde; cubierta ajardinada; techo vivo; sistema modular; ventilación pasiva; bernoulli; isla de calor urbana

REPORT

1. Object

1.1. Challenge

Climate change has changed this earth. It has had great impact on the entire wide world, including us, our buildings and our urban environments. One of its effects has been the rising temperatures. This problem will be the challenge for this case study.

Buildings absorb more heat during the day than they can emit during the night. This contributes to the Urban Heat Island Effect, also referred to as UHIE. This problem has caused urban areas to become uncomfortable for its residents, especially during the hot summer months. These residents can experience difficulties with sleeping and are more likely to experience heat-related illness. This problem has even resulted in a 12% death rate rise in 2014. Less disturbing consequences of this problem are worse air quality and increase in energy costs for all the AC units and other devices used.

In The Hague stands the main THUAS building. Within, temperatures can rise up to 25 degrees Celsius, especially in the Strip side of the building. This building and the surrounding urban area will be the case study in this search for a solution.

Nature, with its evolutionary capabilities and it's experience with weather conditions (a little more than we do) can help to solve this challenge. With all that experience come strategies, abilities and mechanisms that have evolved to thrive in fluctuating weather conditions like the ones we face with this Urban Heat challenge. These strategies, abilities and mechanisms will be researched and analyzed. All that useful information will be 'naturally processed' and formed into a product. This solution can come in any size or shape and will be the next step forward to solve the rising temperatures in buildings and urban areas.

1.2. Urban Heat Island Effect

The urban heat island (UHI) effect is a phenomenon characterized by significantly elevated temperatures within urban areas compared to their rural surroundings. This temperature difference arises from several interconnected factors:

Firstly, the built environment of cities, consisting of densely packed buildings, roads, and other infrastructure, absorbs and stores heat from the sun throughout the day. Surfaces such as asphalt and concrete have low albedo values, meaning they absorb rather than reflect solar radiation, contributing to the heat buildup.

Additionally, human activities within urban areas, such as transportation, industrial processes, and energy consumption for heating and cooling, release heat into the surroundings, further intensifying the UHI effect.

Furthermore, the removal of vegetation during urbanization diminishes the cooling effect of plants through processes like evapotranspiration, where plants release water vapor into the atmosphere, cooling the air. This reduction in greenery exacerbates the UHI effect.

The layout and geometry of urban structures also play a role. Tall buildings can create urban canyons that trap heat and hinder airflow, leading to localized pockets of higher temperatures within cities.

The intensity of the UHI effect varies depending on factors such as geographical location, weather conditions, and urban morphology. For example, cities in warmer climates or those experiencing calm weather conditions with clear skies may exhibit more pronounced UHI effects.

Addressing the UHI effect requires multifaceted strategies. Increasing green spaces, such as parks and urban forests, can help mitigate heat buildup by providing shade and promoting evapotranspiration. Improving urban design to incorporate features like green roofs and permeable surfaces can also reduce heat absorption. Additionally, measures to reduce anthropogenic heat emissions, such as promoting energy-efficient building practices and sustainable transportation, are essential in combating the UHI effect and creating more resilient and livable urban environments.

1.3. Client

Our client is Jacco Bruil and THUAS mission zero. Jacco Bruil is doing research on urban heat, partially on the THUAS campus. He asked us to come up with a product solution that can be added to the existing campus but could later on be applied to other buildings. The product has to be something that can be added to the building, preferably, or can be integrated into the building with minor changes. The product solution can also be something that is being integrated in the buildings environment. In this case minor changes can be done.

1.4. Team

"Hello everyone, we are Anton, Rens and Luc, a diverse team of three individuals from different countries and fields of study. Our unique backgrounds and shared passion for nature drives our collaboration. With combined interests and expertise, we are motivated to learn, apply our knowledge, and design innovative solutions. Our project is inspired by our fascination with nature's organisms and our commitment to sustainability. Together, we aim to create a product that embodies our dedication to environmental stewardship and innovation."

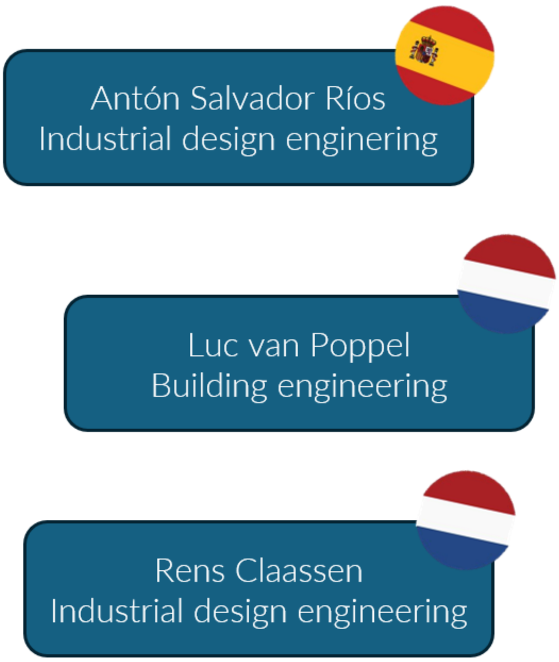


Figure 1. Team members

1.5. Stakeholders

To get insight in who the stakeholders of this document are we made a stakeholder analysis. In this we included primary, secondary and tertiary stakeholders. To us it felt like some stakeholders didn't completely fit in a specific layer so we put them in between the layers.

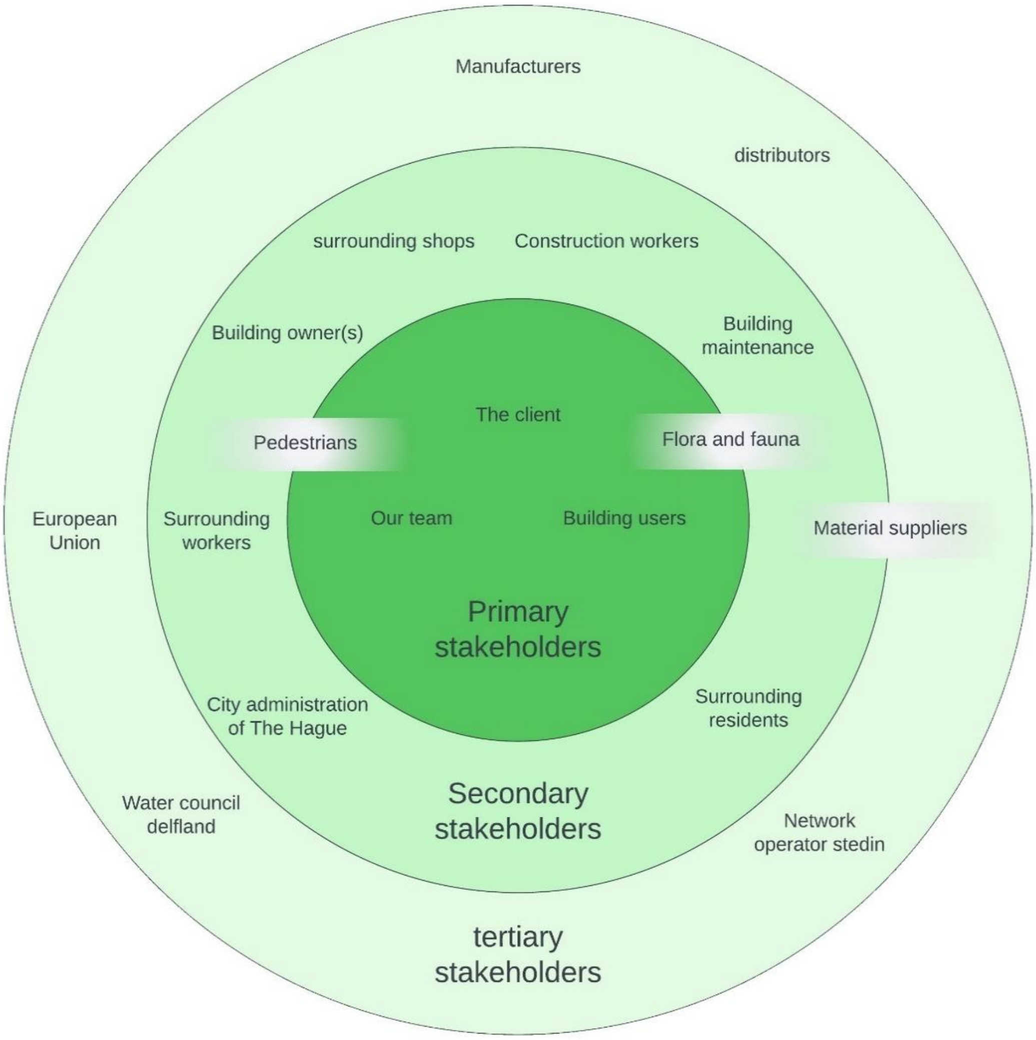


Figure 2. Stakeholders

Client: benefits from a product solution that helps cool the THUAS campus during hot summers.

Building users: employees of the THUAS campus and students but also users of buildings the solution could be applied to. They want to keep on using the building during hot summers in the same way they do now.

Pedestrians: people that use the surrounding of the building(s), they want to continue using the surrounding in the same way they did before without any disadvantages from either urban heat or our solution.

Flora and fauna: The nature surrounding the building(s) should be provided the right environment to thrive because they also help with cooling down the building and its environment.

Building owner(s): Building owners have to invest in the solution and also benefit from the solution

Surrounding shops: Surrounding shops shouldn't be affected by the future solution in a negative way and preferrable in a positive way if possible

Construction workers: construction workers need to install our solution to the building. The solution should be able to be installed as easy and safe as possible.

Building maintenance: Building maintenance should be able to keep doing their regular maintenance work without having negative effects from our solution, but also maintenance on our solution should be as easy and efficient as possible.

Surrounding residents & surrounding workers: surrounding residents want to benefit from the fact that the whole area is able to cool down better, but they also don't want our solution to be negatively affecting their building(s).

City administration of The Hague: Our solution should be within the regulations of the city administration. The city administration also benefits from the building getting less hot in the summer, this way the whole area would need less cooling.

Manufacturers: Manufacturers benefit from our product and should be able to produce it. It's also preferable to have a product that can be manufactured by a single manufacturer or just a small group of manufacturers.

Distributors: Distributors prefer a product that can be distributed and handled easily.

Material suppliers: preferably suppliers that supply some kind of waste product that can be reused. The product should also be beneficial to the supplier so it should not exceed the limits of the supplier.

Network operators & water councils: They have a part in the product solution because the product might be hooked up to the network and use its resources, but the product could also provide resources back to the network.

European Union: European Union is involved with their laws, but also it supplies grants on new project that help with sustainable development goals.

2. Subjects to consider

2.1. Research questions

To start the research for this project we first came up with a list of research questions we wanted to be answered. After we did that list we linked the types of research to the questions. From that point we did all the research that was needed to come up with this design brief. After doing the research we added all the conclusions to the research questions. In the table below you can read all of the research questions with their conclusions.

Research question	***Type of research***	***Conclusion***
What kind of solutions are there currently on the market?	Desk research: current solutions and competition	**Ventilation and Evaporation Cooling Solutions:** Current solutions predominantly operate on a large scale, utilizing passageways for air circulation and ponds/fountains for evaporation. There's a need to explore methods for creating cooler air and implementing ventilation in buildings without significant structural modifications. **Sun Protection Solutions:** Existing strategies focus on shade and light reflection, often employing lighter colors for albedo effect and various forms of shading, including natural, static, and dynamic products. There's an opportunity to develop dynamic product solutions that incorporate natural shading elements adaptable to changing conditions. **Cooling with Water Solutions:** While many industrial solutions utilize water for cooling, the project emphasizes solutions inspired by nature's principles. Focus should be on collecting and retaining water, particularly in urban environments where water acquisition poses challenges, offering potential opportunities for innovation.
What solutions does nature have on regulating heat? And how are they doing this? • *What solutions does nature have in the category of ventilation and evaporation?* • *What solutions does nature have in the category of water and evaporation?* • *What solutions does nature have in the category of protection from the sun?*	NTS	The summary of this research question can be found a bit further on the in the list with mechanisms and ADP's below relevant functions in nature.

How does nature shade?	NTS	In the NTS's in appendix C and the divided research in appendix B will show how nature shades.
How does nature adapt behavior?	NTS	For this life principle, the NTS's in Appendix C give different ways of doing so. Also next to the researched organisms we've learned about a lot of different organisms and their strategies to adapt behavior, this will be shown in the context of this document.
Who are the stakeholders? And what are their preferences and needs?	Stakeholder analysis	The following is the list of the stakeholders: - Client - Building users - Pedestrians - Flora and fauna - Building owner(s) - Construction workers - Building maintenance - Surrounding residents & surrounding workers - City administration of The Hague - Manufacturers - Distributors - Material suppliers - Network operators & water councils - European Union
What kind of regulations are relevant to our project? • *What can be changed/added in urban environments?* • *What systems can be implemented in a building?*		In this project, regulations and ethical considerations are paramount, particularly in the context of building design. The 'building bible,' known as 'bouwbesluit,' serves as a comprehensive guide, outlining mandatory rules updated in 2012. Compliance with these regulations is essential to avoid legal complications. Additionally, ethical concerns such as environmental impact, neighboring buildings' welfare, and aesthetics cannot be overlooked. For instance, considerations may include potential light pollution or unsightly appearances from nearby structures. Various regulations and concerns address aspects like environmental impact assessment, energy efficiency, noise and light pollution control, safety standards, and community engagement. These regulations aim to balance the benefits of building systems like cooling systems while mitigating negative impacts on the environment and community well-being. Consulting with experts, stakeholders, and regulatory bodies throughout the process ensures comprehensive adherence to relevant factors. Additionally, other regulations may involve maintaining the building's original function and context, incorporating diverse organism strategies, and considering time frames for product functionality.

Where could we intervene with our design?	Interview client	We are allowed to make minor changes to the building and its surroundings but no big reshaping or planning. It could be on the inside or outside and preferably is an addition
What resources might our design produce / share?	Interview client	Depends on the product, it could use water and power from outside if necessary but preferably it's self-sustaining
What does the current heat situation look like? Which elements of the city/buildings are contributing to urban heat? What are the ones that have more impact?	Desk research: current heat situation/Jacco's data	The current situation in The Hage doesn't look very good. In the THUAS building, temperatures can rise up to 25 degrees which is an uncomfortable place for the students and teachers. This happens in other buildings in The Hague too and it's something that needs a solution asap. More information about the current situation can be found in the following chapter; Context.
What are easily available materials or waste materials in the Netherlands or in the building that can be used?	desk research	The choice of materials for the product is driven by its intended function, location, and environmental impact. Factors such as durability, transparency, and seasonal use play significant roles in determining the most suitable materials. Local availability and sustainability considerations often guide material selection, with a preference for options with low or zero impact on the environment. Stakeholder preferences and client requirements may influence decisions, leading to the avoidance of certain materials like plastic. Potential materials include wood sourced from old furniture or construction sites, salvaged bricks and masonry, and repurposed metal or glass. Additionally, textiles, concrete, tiles, and electrical components can be creatively sourced and repurposed to reduce waste and promote sustainability. By utilizing these materials, not only are costs potentially minimized, but also a contribution is made towards a more sustainable manufacturing process. However, it's crucial to ensure that the chosen materials are suitable for the product's intended use and meet any necessary safety or regulatory standards.

Table 1. Research questions

2.2. Legal Framework

For this project, the case study is a building. Within the building environment, many regulations are enforced. There's even a so called 'building bible' with all the rules you will need to follow when designing a building, this is actually called 'bouwbesluit', last changed and updated in 2012.

When designing a product for the THUAS building the rules from this 'bible' will need to be followed to not make anything illegal. Next to that, there are many, more ethical regulations that cannot be overlooked during this project. For example, maybe there are residential buildings or shops nearby the THUAS building that will face consequences. The product could reflect light in their directions, maybe the product will be on the façade and look hideous from the outside, then surrounding buildings have to look at that.

This is a list of regulations and possible concerns for the product:

1. **Environmental Impact Assessment (EIA):**
Require a comprehensive assessment of the environmental impact of the cooling system, including its effects on local microclimates, biodiversity, and air quality.
2. **Building Codes and Zoning Regulations:**
Ensure compliance with local building codes and zoning regulations related to construction, height, setback requirements, and land use.
3. **Energy Efficiency Standards:**
Mandate that the cooling system meets specific energy efficiency standards to minimize energy consumption and reduce greenhouse gas emissions.
4. **Noise Regulations:**
Establish limits on noise levels generated by the cooling system to mitigate potential disturbances to nearby residents and businesses.
5. **Light Pollution Control:**
Implement measures to minimize light pollution from the cooling system, especially if it includes lighting elements, to preserve the night sky and reduce impacts on nocturnal wildlife.
6. **Heat Island Mitigation:**
Require the implementation of measures to mitigate heat island effects, such as using reflective materials, green roofs, or incorporating vegetation into the design.
7. **Air Quality Monitoring and Control:**
Monitor and control emissions from the cooling system to ensure compliance with air quality standards and protect public health.
8. **Water Usage Restrictions:**
Set limits on water usage for the cooling system, promoting water conservation and efficiency in its operation.
9. **Safety Standards:**
Establish safety standards to prevent accidents or injuries related to the installation, operation, and maintenance of the cooling system.
10. **Accessibility Requirements:**
Ensure that the cooling system is accessible to all individuals, including those with disabilities, in compliance with accessibility guidelines and regulations.
11. **Public Health Considerations:**
Assess potential impacts on public health, such as heat-related illnesses or vector-borne diseases and implement measures to mitigate risks.
12. **Community Engagement and Consultation:**
Require developers to engage with local communities and stakeholders to gather input, address concerns, and ensure that the cooling system's design and implementation align with community needs and priorities.

13. **Long-Term Maintenance and Monitoring:**

Establish requirements for long-term maintenance and monitoring of the cooling system to ensure its continued effectiveness and safety over time.

14. **Emergency Preparedness and Response:**

Develop contingency plans and protocols for emergencies, such as power outages or extreme weather events, to minimize disruptions and ensure the safety of occupants and the surrounding environment.

15. **Compliance and Enforcement Mechanisms:**

Implement mechanisms for monitoring compliance with regulations and enforcing corrective actions or penalties for non-compliance.

These regulations and considerations aim to balance the benefits of the cooling system with potential impacts on the environment, neighboring buildings, and the well-being of individuals within the community. It's essential to consult with relevant experts, stakeholders, and regulatory authorities throughout the planning and implementation process to ensure that all relevant factors are adequately addressed.

Other regulations might be:

1. Establishing existing systems in building
2. Keeping original function of the product in mind
3. Keeping original context of the product in mind
4. Using multiple organism strategies, mechanisms or systems
5. Establishing possible ecosystems that could be of interest
6. Establishing possible time frames when the product is needed/functional

2.3. Urban Heat Island in Den Haag

From the Urban Heat Research (Appendix A), we subtract a set of conclusions.

Urban Heat Island (UHI) refers to the phenomenon of cities having higher temperatures than the surrounding rural areas, because of the absorption of the urban structures. In The Hague the difference between the city and surrounding rural areas is approximately 2ºC.

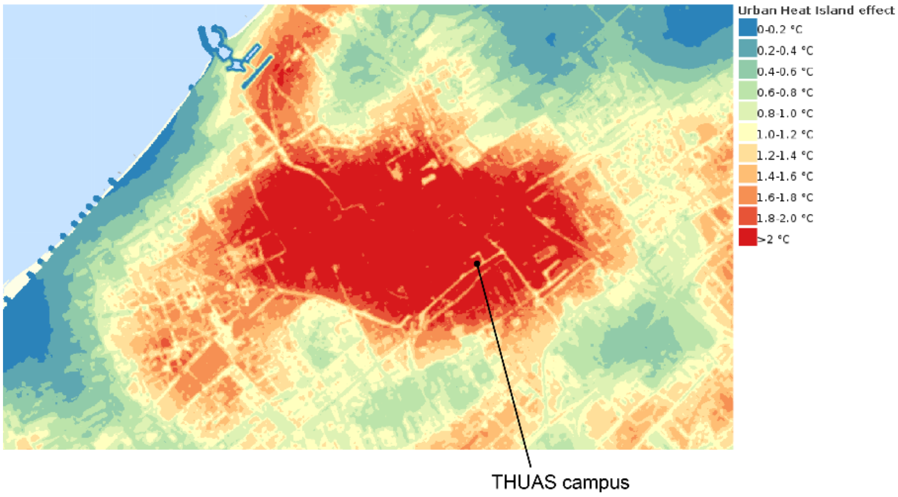


Figure 3. UHI effect in The Hague (Klimaateffectatlas, n.d.)

The urban heat causes which our solution could relate to are the following:

- Urban Greenery
- Urban Surface Water
- Properties of urban materials
- Anthropogenic heat

The area of study is all the THUAS main campus, represented in the following image.

Figure 4. Area of interest for the project (Neerland in 3D, n.d.)

We can intervene either in the building, on the exterior of the building or the surrounding environment.

If we act on the surrounding environment this image of the PET shows us where the areas of more interest could be (the darkest ones).

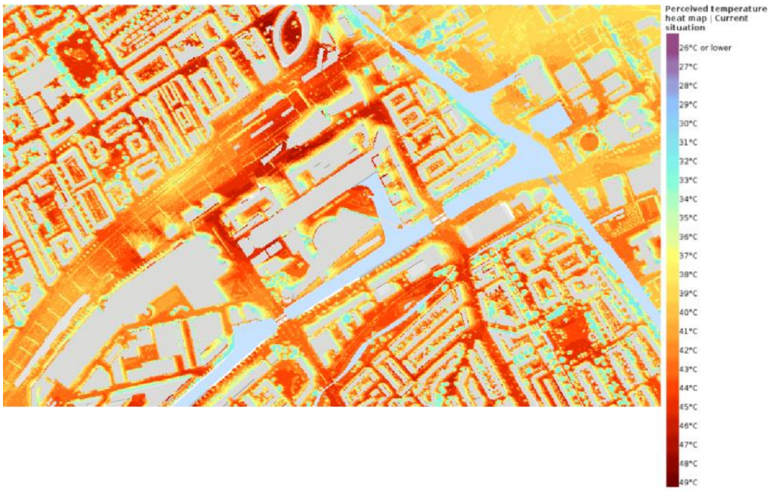


Figure 5. PET around the THUAS campus (Klinaateffectatlas, n.d.)

If we act in the building, the following graph shows that our solution shouldn't be active all year, but only the months of summer (from June to October approximately) where the day temperature actually goes up the comfort temperature, so it gives us a temporality. The rest of the year it could be inactive or fulfil other functions

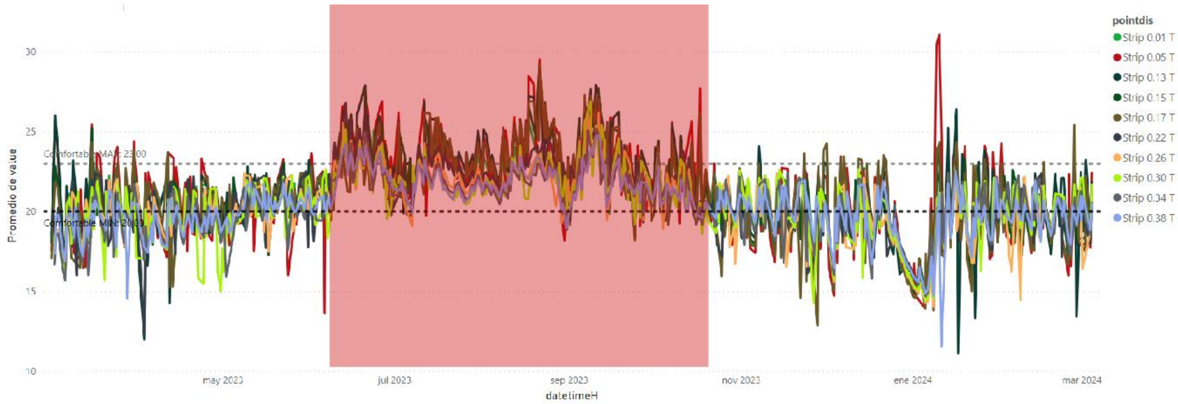


Figure 6. Temperatures inside the THUAS building (Facility Management Living lab, n.d.)

2.4. Relevant functions in Nature

According to the biomimicry design methodology, referencing nature is a big part of it. Several functions performed by living organisms can be useful for the topic of the project, such as the following:

Protect from temperature

Protect from light

Maintain homeostasis

Protect from loss of liquids

Regulate temperature

Transform/Convert energy

With these functions in mind, a biobrainstorm (whose results can be found in the appendix) was conducted. From it, it was noticed that nature's methods to manage high temperatures could be grouped in three big groups: ventilation, water and sun protection. According to this classification an the interest of their strategies three organisms were selected by each member of the group to make a Nature Technology Summary (NTS). The results of that research can be fount in the following tables.

The NTS's made by the author can be found in the appendix.

Ventilation cooling principles

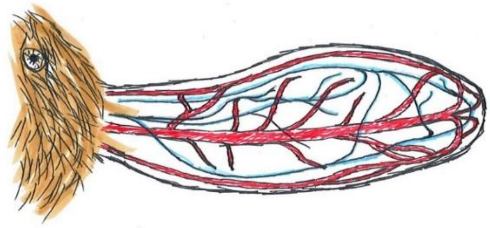
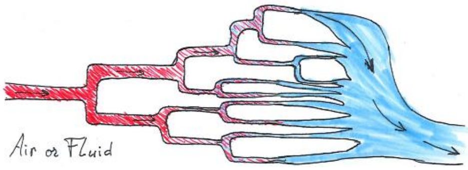
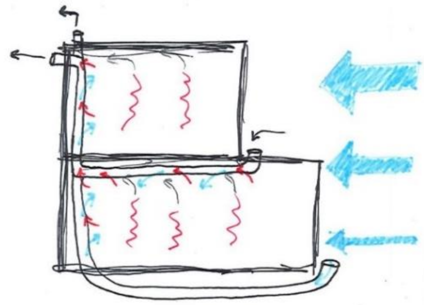
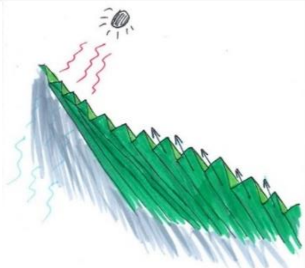
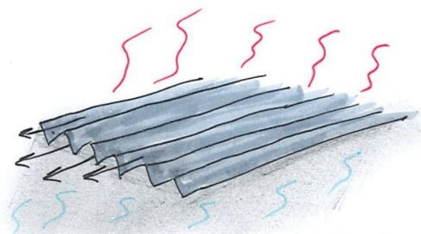
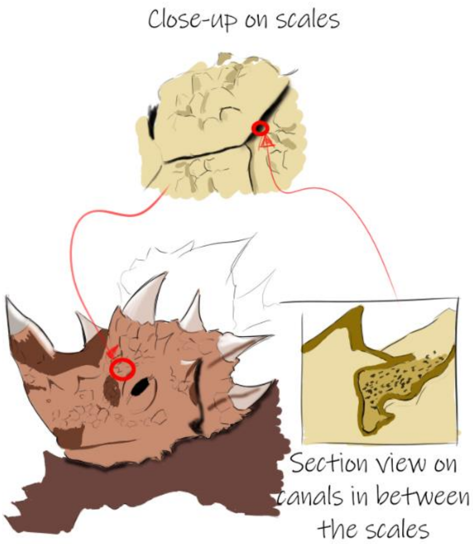
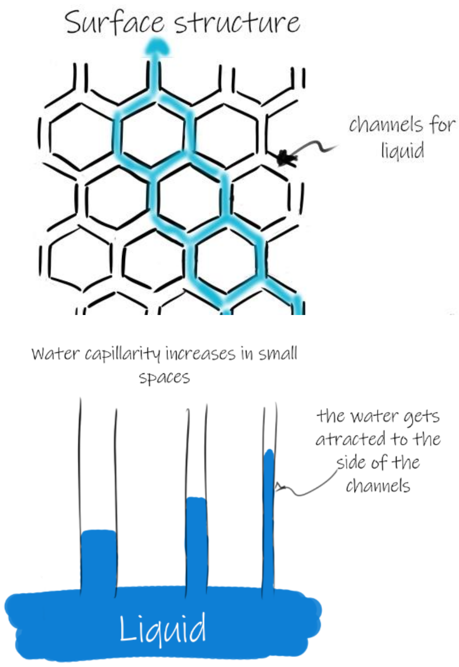
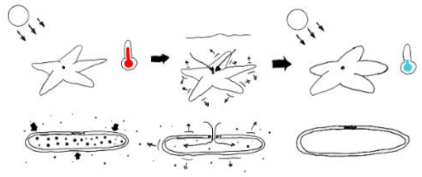
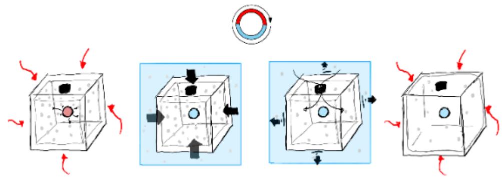
Organism	BDP	ADP
Jack rabbit (by Luc van Poppel)		
	The mechanism in a jackrabbit's ears works through a process of thermoregulation involving increased blood flow and efficient heat transfer. When the jackrabbit's body temperature rises, its blood vessels dilate, allowing more blood to flow through its large ears. As warm blood circulates through the extensive network of blood vessels in the ears, heat is transferred to the surrounding air through convection and radiation. The jackrabbit's ears provide a significant surface area for heat exchange, facilitating the efficient dissipation of excess heat from the body. This process helps the jackrabbit regulate its body temperature, preventing overheating and allowing it to thrive in diverse environmental conditions.	High temperature fluid flows through a spread out circulatory network with an increased surface area, closer to lower temperature environment, here the fluid can radiate heat to its environment. This is to lower the fluids temperature which lowers the entire unit's core temperature.
Prairie dog (by Luc van Poppel)		
	The prairie dog's cooling mechanism involves constructing burrows with multiple entrances at different heights. When wind encounters the higher entrance first, it accelerates, creating higher air pressure. This pressure difference induces airflow through the burrow system, as air moves from areas of high pressure to low pressure. As air flows through the burrow, it carries away heat, providing natural ventilation and cooling for the prairie dog colony underground. This airflow also replenishes oxygen levels, ensuring a comfortable environment, particularly during hot weather conditions.	Tunnels/tubes with alternating heights create a vacuum effect which cools the interior of a structure.
Fan palm (by Luc van Poppel)		
	The fan palm employs a sophisticated cooling strategy in hot environments, utilizing a combination of anatomical, physiological, and structural adaptations. Its large, fan-shaped leaves provide shade and surface area for heat dissipation, while specialized leaf structures minimize heat retention and promote efficient transpiration. Internally, the palm features intricate vascular systems and air spaces within its tissues, facilitating convective heat transfer. Through these mechanisms, the palm effectively regulates its temperature, mitigating heat stress and optimizing its ability to thrive in hot and arid climates.	Thin surfaces keep thermal capacity of the unit low. These structured surfaces guide surrounding air through the surface to transport off thermal energy.

Table 2. Ventilation cooling principles

Water cooling principles

<table>
<tr><th>Organism</th><th>BDP</th><th>ADP</th></tr>
<tr><td rowspan="2">Thorny devil (by Rens Claasen)</td><td>
</td><td>
</td></tr>
<tr><td>The thorny devil's skin, covered with scales and channels, absorbs water rapidly. These channels, featuring protrusions found only on the skin's bottom, absorb water within seconds. Microstructures resembling scales cover the channels, with narrower subchannels on the dorsal skin. Capillary action, driven by adhesive and cohesive forces, facilitates water transport up the channels. Liquids are drawn into minute openings, ascending through thin tubes due to intermolecular forces. The unique structure allows the thorny devil to absorb water from puddles or moist sand efficiently.</td><td>A surface consisting of hexagonal shapes that have channels in between these hexagonal shapes. Within these channels there can be found a similar structure of protrusions with again channels in between them. The diameter of these channels is small enough to facilitate capillary action. Capillary action is a phenomenon where liquids travel vertically or horizontally due to adhesive and cohesive forces. The speed and saturation rate of these so-called capillary channels are determined by the type of fluid that runs through them and the structure, width and surface of the channels.</td></tr>
<tr><td rowspan="2">Pisaster Ochraceus</td><td></td><td></td></tr>
<tr><td>To avoid heating up during low tides with high air temperatures, when P. ochraeus experiences a high temperature during a low tide, it releases metabolites that cause a difference in osmotic pressure between the inside of its coelomic cavity and the sea water in the next high tide. This causes the madreporite to pump a certain amount (dependent on the experienced temperature and the temperature of the water) of cold water inside the body of the starfish, rising its body mass, so that the next low tide it will take more time to heat up.
When the temperature during low tides becomes moderate again, the process reverses and the starfish releases the excess fluid.</td><td>To avoid heating up during high heat stress short term cyclic situations, when this cycles starting to happen are detected, emit a response that cause a calculated imbalance between the system and the surrounding medium in the next low temperature part of the cycle, so that during this time the surrounding (cooler) medium will be pumped into the system until this imbalance is solved, thus increasing the net mass of the system and making it harder to heat up during the next high temperature part of the cycle.</td></tr>
</table>

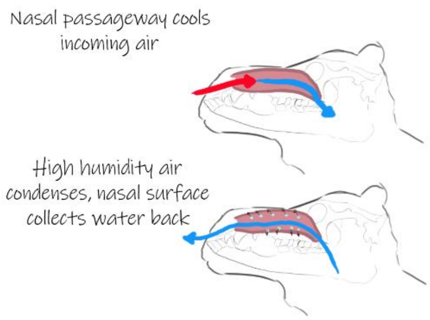
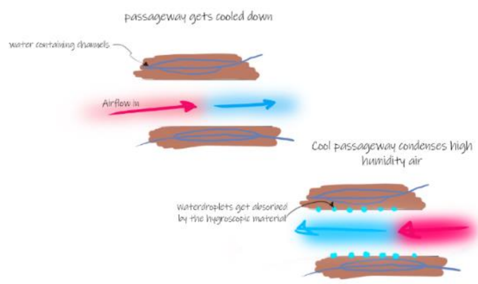
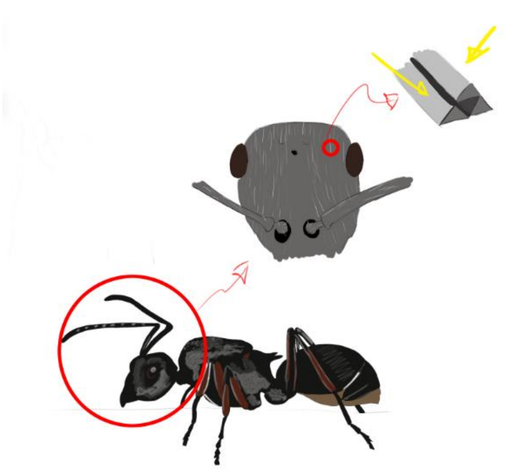
Dromedary camel (by Rens Claasen)		
	The camel employs a sophisticated cooling mechanism in its nose and respiratory system to regulate body temperature and minimize water loss through evaporation. At night, it inhales cool air, exchanging heat with the extensive nasal surface. Upon exhaling, warm, humid air condenses on the now cooler nasal surfaces. What sets camels apart is their hygroscopic nasal surface, capable of absorbing water from exhaled air thanks to its large surface area exceeding 1000 cm2, far greater than humans'. During the day, camels prioritize cooling their brains by redirecting blood flow. When temperatures rise, the facial artery constricts, and angular veins dilate, redirecting cooler blood towards the brain. This intricate strategy ensures efficient temperature regulation, unique to camels.	Cool air passing through a passageway that exchanges heat to the cool air, then the air is heated up and increases in humidity to cool a certain element. Then the air is passed through the same passageway which has cooled down by the cool air that passes through, and the hot air condenses against the surface of the passageway, which is covered by a hygroscopic material. The water is then circulated back into the element that needs to be cooled.

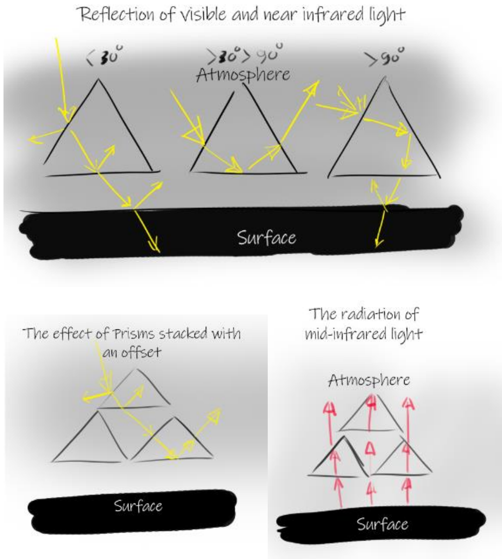
Table 3. Water cooling principles

Sun protection principles

Organism	BDP	ADP

Saharan silver ant (by Rens Claasen)

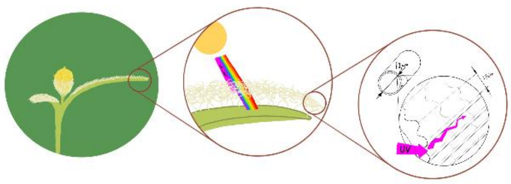


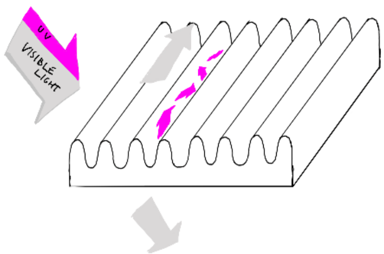


Saharan Silver ants employ specialized hairs to combat extreme heat. These prism-shaped hairs reflect a significant portion of incident light and aid in heat dissipation, crucial for survival in temperatures exceeding 70°C. Positioned atop stones or dry vegetation during foraging, the ants experience substantially cooler rest spots. Their hair structure facilitates light reflection through stacking, enhancing reflectivity, especially beyond 30° angles. However, beyond 90°, reflectivity decreases, impacting total internal reflection. Additionally, in the mid-infrared range, the hairs' reduced reflectivity enhances emissivity, enabling efficient heat dissipation through radiative heat transfer. This adaptation allows the ants to manage body temperatures that peak at around 50°C during foraging, ensuring survival in the scorching desert environment.

Visible and near infrared light gets reflected inside prism shaped strands, this way the surface underneath the strands gets hit less by the wavelengths of visible and near infrared light. For these prisms to work optimally it is important that the light hits these prisms in a certain angle. The angle in which the light starts reflecting significantly starts at 30° and ends at 90°. In order to make sure the least amount of light hits the surface underneath the prism shaped strands are stacked on top of each other with an offset of half a strand width. This way the light that is able to pass through one strand, goes into the next strand and gets reflected.
The prism shaped strands reflect less light in the mid-infrared range, around 8 μm. The surface underneath the prism shaped strands radiates light in the 6 to 16 μm range. This way the surface underneath the prism shaped strands is able to radiate heat back to the surrounding surface.

Alpine Edelweiss





To protect its living cells from the harmful effects of the UV radiation, the Alpine Edelweiss have developed a protective layer of filaments over its sun-facing surface.
These filaments are transparent, but have a special structure composed of a series of fibers close in size to the wavelength range of UV radiation. Thanks to this size-closedness it is able to reflect incising, specific frequencies of UV rays and channel them along the spaces in between the fibers, also charging them with the energy of the rays close in frequency, and dissipating all of it by circulating it in between the fibers. This way the UV rays don't reach the living cells of the plant, whereas the rest of the visible range of frequencies does.

To obstruct specifically the UV part of the spectrum to pass through, use a transparent structure of a planar slab bearing a grating-like surface corrugation (with a protrusion width close to the UV range of frequencies) to reflect specific frequencies on light in between the protrusions, charge them with the energy of those rays close in frequency, and dissipate all of their energy by conducting then along the channel, while allowing other frequencies of light to pass through.

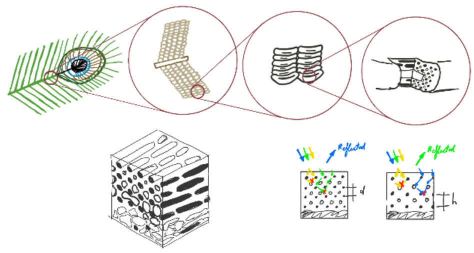
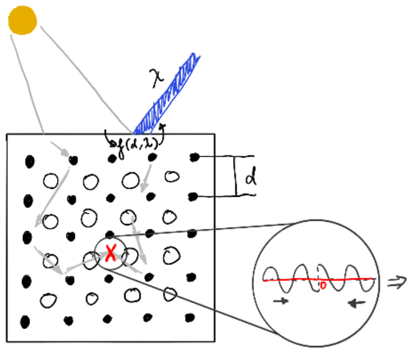
Indian peacock		
	To create striking colors and catch the attention of females, the male Indian peacock have developed feathers with a special structure that reflects the light of specific wavelengths. The feathers are composed by barbs that are at the same time composed by tiny structures called barbules. This barbules have a structure of a 2D quasi-square and several layers lattice of melanin in a matrix of keratin, and airholes in the middle of each square lattice. This structure acts as photonic crystals. That means that light scattered from each particle interferes in some directions with each other and radiates secondary emission in others, being that directions a function of the wavelength and the distance between layers. That means that some wavelengths are "trapped", and others are reflected.	To reflect specific wavelengths of light, use a 2D square lattice with a distance between vertices on the order of the light wavelength, to "trap" certain wavelengths in the lattice and reflect others (change the distance between vertices to change reflected wavelength).

Table 4. Sun protection principles

2.5. Life's principles

In this section we analyze the different life principles, and how our solution could relate to them.

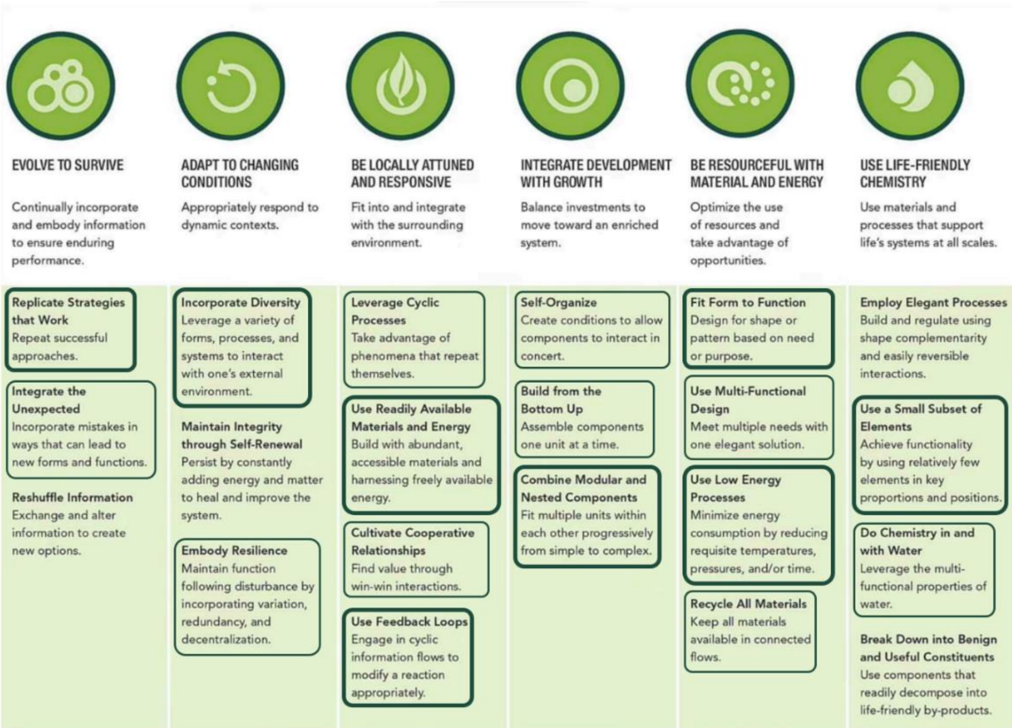


Figure 7. Relevant Life's principles (Biomimicry 3.8, s.f.)

Thick marked sub-principles will be main focus.

Evolve to survive	Existing and successful solutions exist already, and can be taken as a reference. Look at apparently failed strategies (in organisms or products) that could be applied with success in a different context.
Changing conditions	Climate change will have effect on weather conditions in The Hague and will have consequences on how the building needs to be protected. Summers will get hotter and sunlight will get stronger. Strong storms may happen in the future.
Attuned and responsive	Using feedback loops and available materials a solution will form according to it's surroundings and will not be redundant.
Integrate development	A solution using elements that would be installed and later develop on their own become something bigger, more functional A modular solution that could reach a higher scale when putting a lot of units together would be ideal, achieving its function that way
Be resourceful	Using passive processes or even producing energy itself thanks to mechanisms like reflection, passive ventilation or evaporation. Being able to cool or heat as necessary, and maybe add mor functions to it. Reducing fabrication energy costs. Being able to recycle or give some value to its components at the end of life
Life friendly chemistry	Manufacturing parts of carbon/bio based chemistry. Use coatings, paints... that have water as a solvent. Using biodegradable materials.

Table 5. Relevant Life's Principles

2.6. Sustainable development goals

Figure 8. Relevant SDG's (United Nations, s.f.)

We have selected the sustainable development goals that our solution needs to be related to, and we explain why in this section.

3. Good Health and well-being
"Ensure healthy lives and promote wellbeing for all ages"
To reduce the health risks related to UHI effect.

4. Quality education
"Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all"
To have comfortable temperatures in the THUAS campus during the summer.

6. Clean water and sanitation
"Ensure availability and sustainable management of water and sanitation for all"
Ensure that used water is not contaminated or wasted in its use, and try to reuse it if possible.

7. Affordable and clean energy
"Ensure access to affordable, reliable, sustainable and modern energy for all"
Be either efficient, self-sufficient or even produce energy for something else in a sustainable way.

8. Decent work and economic growth
"Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all"
To ensure and promote decent working conditions, If installed in a building or environment where people work.

9. Industry, innovation and structure
"Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation"
To be resilient and innovative, as an part of the city infrastructure.

11. Sustainable cities and communities
"Make cities and human settlements inclusive, safe, resilient and sustainable"
Make the city more inclusive and safe to the people with less resources, the vulnerable people and the elder people.

12. Responsible consumption and production
"Ensure sustainable consumption and production patterns"

To be sustainably produced, have a long life span and a non-harmful end of life.

13. Climate Action
"Take urgent action to combat climate change and its impacts"
Help against climate change by reducing the absorbed heat and also the energy consumption.

15. Life on land
"Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"
To respect and take the other lifeforms of the urban ecosystem lives into account.

17. Partnership for the goals
"Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development"
As a solution that involves a broad set of sustainable development goals, it could be part of the partnership.

2.7. Vision

"Our vision is to create a sustainable cooling solution for urban buildings and its environment inspired by nature's principles. By utilizing waste materials and fostering surrounding ecosystems, we aim to combat urban heat while nurturing the environment and promoting sustainability."

2.8. List of requirements

Nr.	*Requirement*	*Source*	*Priority*
1	Include strategies from NTS's	Life's principle: Replicate strategies that work NTS's	Must
2	It is a product in the building, outside of the building or its environment.	Client	Must
3	The solution improves the temperature comfort in the building	Client SDG's: Climate Action	Must
4	When using water the solution must not the pollute the water	SDG's: Clean water and sanitation	Must
5	The solution needs to have another function besides cooling the building	Life's principle: Use multi-functional design	Must
6	Production of the solution should be sustainably made.	SDG's: Climate action	Must
7	Adjust to the legal requirements within the "bouwbesluit"	Desk research: Wat kind of regulations are relevant to our project	Must
8	It must be able to work during the summer months and not during the rest of the year, or work in another way	Life's principle – Adapt to changing conditions. Desk research – Urban heat situation. Client	Must
9	The solution is energy efficient	Client	Must
10	The product should only include a subset of 8 elements maximum	Life's principle - Use a small subset of elements	Must

11	The solutions aesthetics should be attractive, and it can't have negative consequences to surrounding buildings.	Stakeholder analysis	Must
12	If the solution is producing a waste material it needs to be able to be reused readily somewhere else	Life principle's: leverage cyclic processes	Must
13	It is an addition to the building with no modification	Client	Should
14	It is compatible with any kind of building	Client	Should
15	The product should use the smallest possible subset of chemical elements	Life's principle - Use a small subset of elements	Should
16	The solution is passive or self sufficient	Life's principle: Low energy process	Should
17	The solution should have an afterlife purpose	SDG's: responsible consumption and production Life's principles - Recycle all materials	Should
18	The solution is on the topic of greenery, surface water, take advantage of the properties of different urban materials/shapes or anthropogenic heat	Urban Heat Research	Should
19	Maintenance on the solution is made easy	Stakeholder analysis	Should
20	The solutions effectiveness can be measured	Stakeholder analysis	Should
21	The solution produces energy for other appliances	Life's principle: Cultivate cooperative relationships	Could
22	The solution detects and reacts by itself when it's needed and the way is needed	Stakeholders Life's principle - Be Locally Attuned and Responsible	Could
23	The solution could share resources with other components or systems in the surrounding	SDG's: Partnership for the goals	Could
24	The solution is modular	Life's principle – Integrate development with growth	Could
25	The solution provides housing or resources in some way to organisms	Life's principle – cultivate cooperative relationships Life's principle – Integrate development with growth	Could
26	The solution reduces direct or indirect the cost of cooling or heating the building and its surroundings	Stakeholders analysis SDG's: affordable and clean energy	Could
27	Only use locally sourced materials	Desk research: What are easily available materials or waste materials in the Netherlands or in the building that can be used? Life's principle – use readily available materials	Could

29	Only use reused materials	Desk research: What are easily available materials or waste materials in the Netherlands or in the building that can be used? Life's principle – use readily available materials	Could

Table 6. List of requirements

3. Proposed alternatives for the solution

3.1. Concepts

From the ideation process, the concepts that made it to the first converging process were the following:

A. **Ventilating Tiles:** That would use the ventilation principles to cool themselves during the day.
B. **Reactive Shading:** That would shade or not in response to the climate conditions.

1. **Camel Green Roof Subsurface**: A subsurface for a green roof that would help water it by absorbing moisture from the air.
2. **Silver Ants Pergola/Roof:** A horizontal system to reflect the incidental light based on the mechanism of the Saharan Silver Ants.
3. **Roof Shadow/Birdnesting/Water-cooling modules**. A series of modules of different heights that would create currents of air with a combination of shadows and Bernoulli effect, cool water passively for refrigeration and also host several organisms of the cities ecosystem.
4. **Rainwater collection lattice with an overflow:** A water collection system for the rain season that helps collect water for later cooling uses in the hot season.
5. **Water passive cooling system:** A system that would cool water on the parts of the building that would be in the shadow.
6. **Pavement with irrigation:** A pavement that would absorb water during the rain season and then use it on summer days to cool itself.
7. **Prairie dog pavement and street lighting:** A pavement system that would emulate prairie dog burrows by having channels under it were passive airflow would take place, cooling it.
8. **Starfish Roof:** That would inflate and deflate creating an extra insulation layer only during the day.
9. **Fan Palm Façade:** That would cover the entire façade and have ventilation from the inside of the building running through it to cool the air.
10. **Fan Palm Evapotranspiration Parasol:** A parasol for public spaces that would use fan palm mechanism to cool the surface below, as a forest does.
11. **Plants in vents:** Somehow implementing vegetation inside/in the entrances of the ventilation system to cool the air inside it by evapotranspiration.
12. **Thorny Devil Pavement:** A pavement that uses the thorny devil mechanism to extend water over itself and then evaporate it, thus cooling it.
13. **Fan Palm Pavement:** A pavement that casts shadow over itself creating small air currents that cool it.
14. **Thorny Devil Roof/Vertical Garden Tiles:** A system that uses the thorny devil mechanism to water a vertical or roof garden.
15. **Jackrabbit Cooling Balloon:** A system that would deliver the air from the vent system to a higher (and cooler) part of the atmosphere and back into the building.
16. **Silver Ants Façade/Sunscreen:** A vertical system to reflect the incidental light based on the mechanism of the Saharan Silver Ants.
17. **Fan Palm Screens:** That would direct the air over a water basin with plants to cool it before guiding it over the façade.
18. **Camel vent that collects water:** A module for installing in the exit of the vent system that collects the moisture of the air for later use as a refrigerant.
19. **Rainwater collection façade system whose parts turn in summer to perform evapotranspiration:** With parts with two sides that flip in between seasons. One side collects water, other uses it to cool by evapotranspiration.
20. **Green sunscreen water collector façade element:** A sunscreen element implementing plants that could cover or not the façade depending on the seasons. Also, it would collect water in the plants themselves.
21. **Movable sunscreen system for the pavement area:** It would use the principles of the fan palm.

3.2. Ideas

From the previous list, as it is explained in the next section, seven were selected for further development: A, 1, 3, 4, 17, 19 and 20.

After an interview with the client and the combination of several of the façade options it was cut to the three next in this section.

All the ideas were developed with inputs from every member of the team, but each would have a person in charge.

3.2.1. Green wave roof element

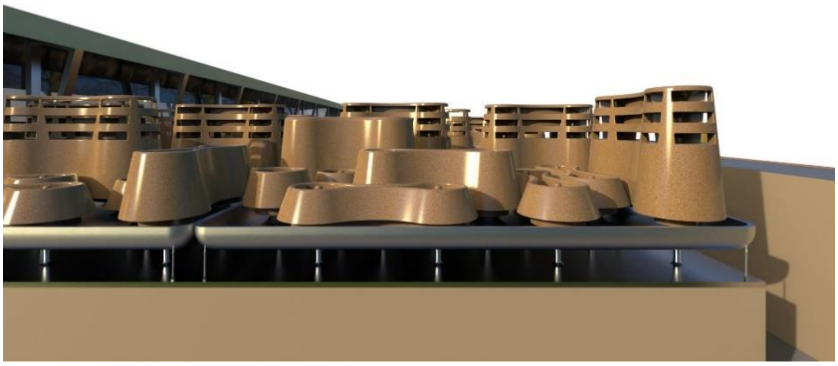


Figure 9. Green wave

Green wave is concept number 3 further developed, with Rens Claasen in charge. As the concept it is based on, it would collect water during rain; use air, shade and evapotranspiration to cool down, and also house plants and animals, as explained in the graphics below.

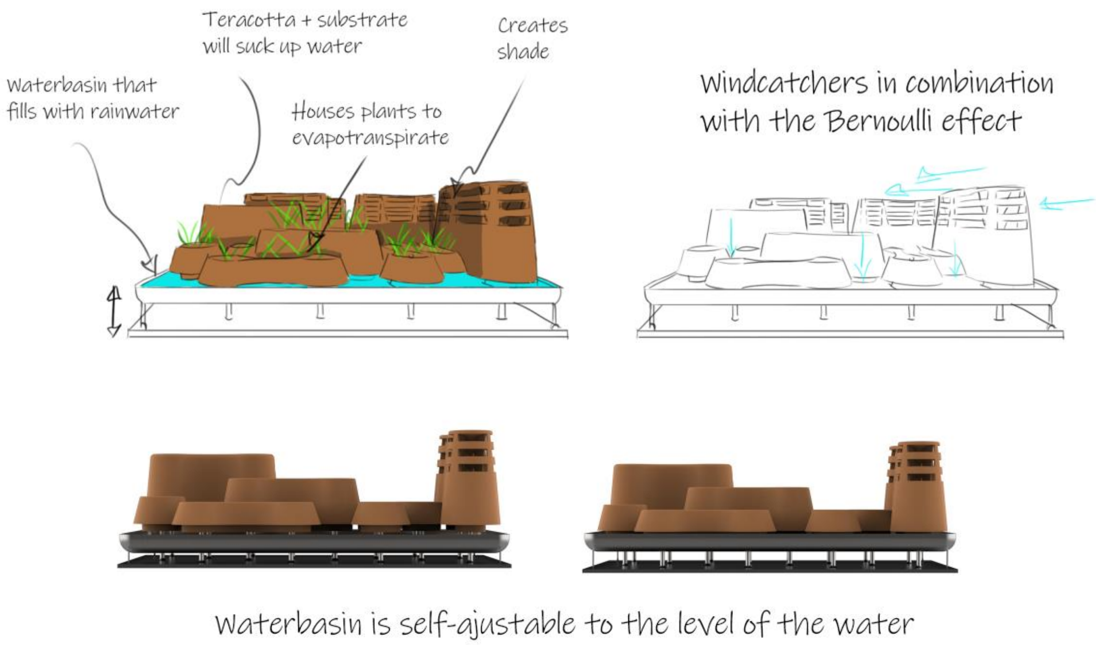


Figure 10. Green wave working principles

It is composed of several modules, that are interchangeable, allowing to customize a roof to the needs of a client. These modules are all stackable.

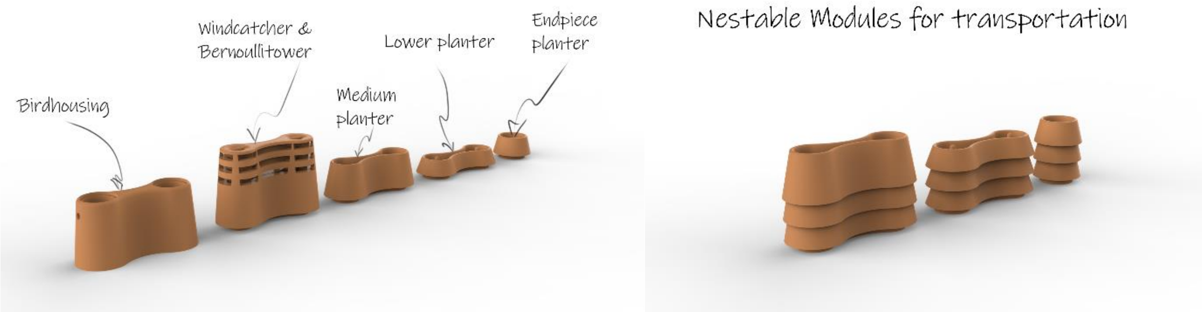


Figure 11. Green wave modules

3.2.2. BioBreeze

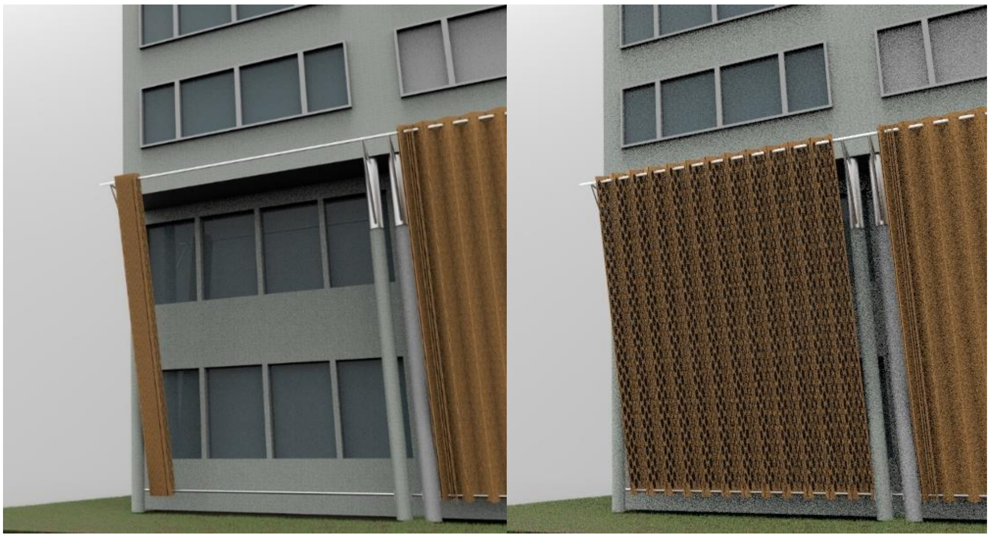


Figure 12. Bio Breeze

BioBreeze is concept 17 further developed, with Luc van Poppel in charge. It would use the fan palm principles to guide the air that would go against the façade downwards, over a basin/pond of water which would cool the air. Once cooled it would continue its way along the surface of the building taking heat from it.

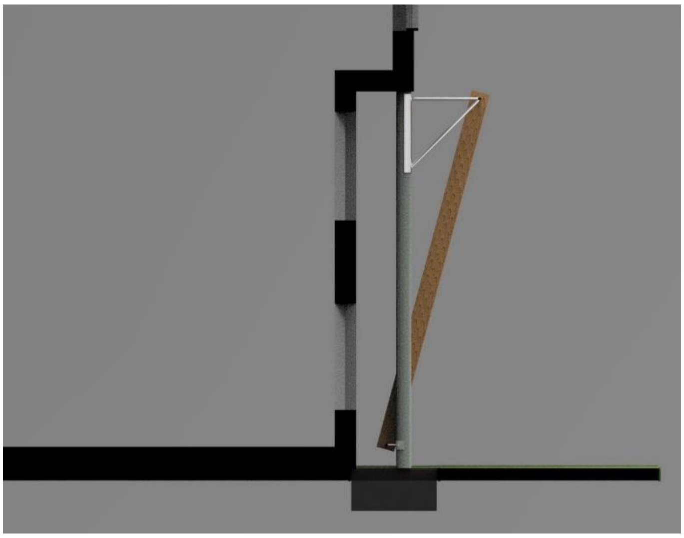


Figure 13. Bio Breeze assembly

The sunscreens would be a bamboo structure guided along an aluminum rail, only using pillars as mounting points. It would fold up automatically during less hot/sunny days, and its pond Invites wildlife and greenery to live there.

3.2.3. Green Blinds

Figure 14. Green Blinds

Green Blinds are concepts 4, 19 and 20 combined and further developed, with Antón Salvador in charge. It is a lattice system that would cover the façade and windows during hot days with plants, effectively shading and cooling them, without stopping all the light, that would be filtered by the plants.

It would be a modular system, able to adapt to any façade and window height, composed of a small subset of elements.

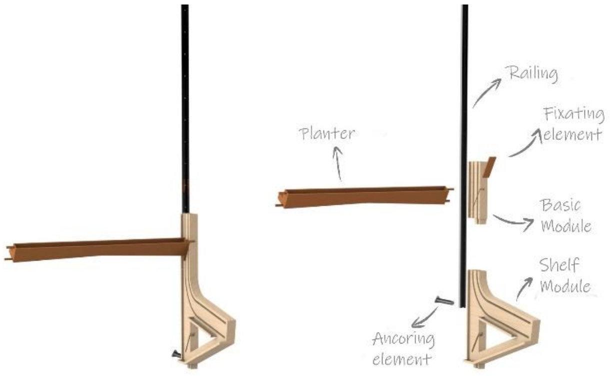


Figure 15. Green Blinds parts

Added to the benefits of the shading, when the plants would be up they would form a continuous layer, hampering the exchange of air, thus promoting the appearance of an upwards current along the surface of the building due to the Bernoulli effect that could cool it.

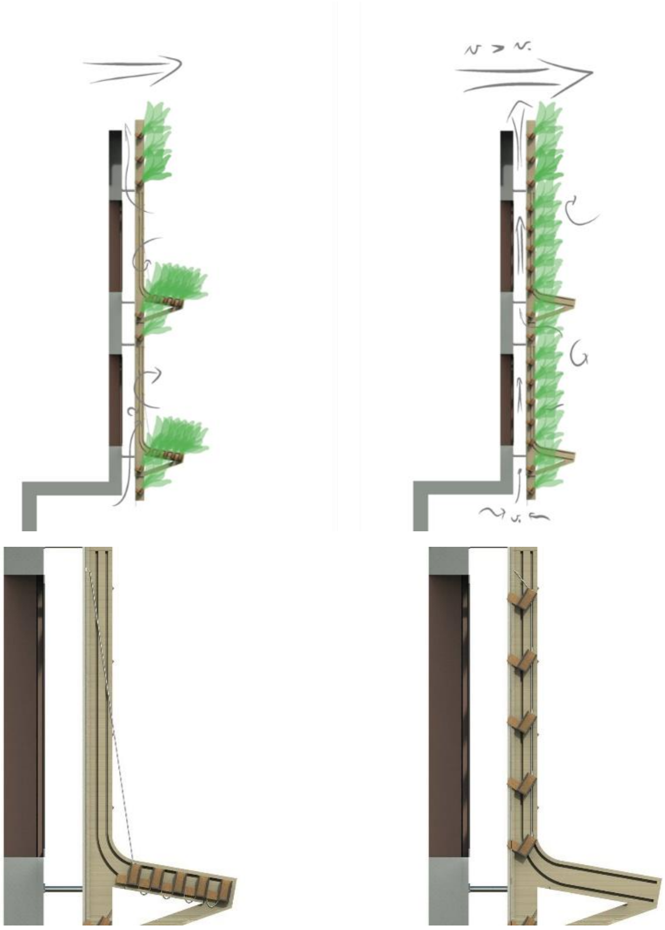


Figure 16. Green Blinds working principles

Its final function would be water collection, during rain season it would store water in the plants themselves, but the excess water could be gathered and guided along the railing for containment for other uses, such as watering the plants in the later hot season.

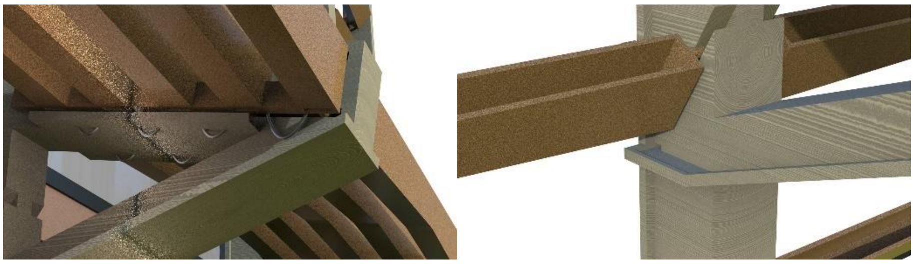


Figure 17. Green Blinds water collection

4. Decision Criteria

4.1. Selection of the criteria

The selection of the criteria was based on the should's and could's of the list of requirements, looking for the idea that would fulfill it better. They are the following.

C1	It is an addition to the building with no modification
C2	It is compatible with any kind of building
C3	The product should use the smallest possible subset of chemical elements
C4	The solution is passive or self sufficient
C5	The solution should have an afterlife purpose
C6	The solution is on the topic of greenery, surface water, take advantage of the properties of different urban materials/shapes or anthropogenic heat
C7	Maintenance on the solution is made easy
C8	The solutions effectiveness can be measured
C9	The solution produces energy for other appliances
C10	The solution detects and reacts by itself when it's needed, and the way is needed
C11	The solution could share resources with other components or systems in the surrounding
C12	The solution is modular
C13	The solution provides housing or resources in some way to organisms
C14	The solution reduces direct or indirect the cost of cooling or heating the building and its surroundings
C15	Only use locally sourced materials
C16	Only use reused materials

Table 7. Decision criteria

4.2. C-Boxes

The following image shows the different criteria used for the selection of the concepts to further develop. The below C-Box shows the average of the other four. The concepts selected are the ones in the green quadrant.

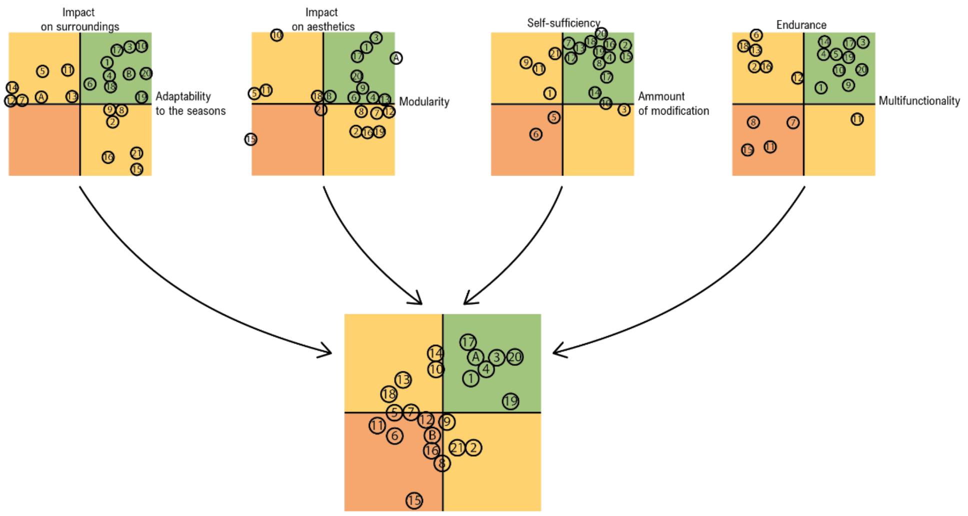


Figure 18. C-Boxes of the first converging process

4.3. Weight assignment for the different criteria

The following table shows the weight assigned to each criterion by direct assignment, with values on the Saaty scale.

Criterion	Weight (Saaty scale)
C1	5
C2	7
C3	5
C4	5
C5	7
C6	9
C7	9
C8	7
C9	3
C10	3
C11	5
C12	5
C13	3
C14	7
C15	1
C16	3

Table 8. Weight of each decision criterion

4.4. Review of the different alternatives for each criterion

The alternatives were graded for each criterion in a scale of 1 to 5, being 5 the best compliance with that criterion and 1 the worst.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Green wave	4	5	3	4	4	4	4	3	2	3	4	5	5	3	3	3
Green Blinds	1	3	2	2	2	4	3	4	2	3	3	4	4	3	3	3
Bio Breeze	3	2	3	4	2	3	3	4	2	3	3	4	2	3	3	3

Table 9. Score of the different alternatives for each criterion

4.5. Selection of the best alternative

The selection of the best alternative was made with the help of a weighted objectives.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	Σλj eij	Winning order
λj (Saaty)	5	7	5	5	7	9	9	7	3	3	5	5	3	7	1	3		
Green wave	4	5	3	4	4	4	4	3	2	3	4	5	5	3	3	3	319	1
Green blinds	1	3	2	2	2	4	3	4	2	3	3	4	4	3	3	3	246	3
Bio Breeze	3	2	3	4	2	3	3	4	2	3	3	4	2	3	3	3	249	2

Table 10. Weighted objectives

By this method it was determined that Green Wave was the idea that best suited the project.

5. Reason for the adopted solution

Once having analyzed all the alternatives according to the selected criteria, as explained in section 4.5, it was determined that the optimal solution for the client request was the first option, Green wave, and so it was presented to the client. He gave the green light for detail design.

Figure 19. Green wave final design

6. Detailed description of the adopted solution

6.1. Working mechanism

The product works when its modules are spread across the entire surface of the roof of a building, creating a layer over it, which is made easy by the variety of modules.

Figure 20. Green Wave set up

The product not only prevents the heating of the building produced by the incidental sunlight, but also actively cooling it by absorbing the heat released from the roof and helping disperse it in the surrounding air. To do that, it uses the difference in height between one of its modules, the wind catcher, and the gaps between the bases of the other modules. When the wind blows over the surface, it goes faster by the top of the windcatcher than it does by the base of the modules, effectively creating a difference in air pressure. This causes the stagnant air in the base to be sucked downwards into the layer under the planters and run over the water that transfer the heat from the building to the moving air, and then exit through the windcatcher back into the atmosphere, releasing the heat there.

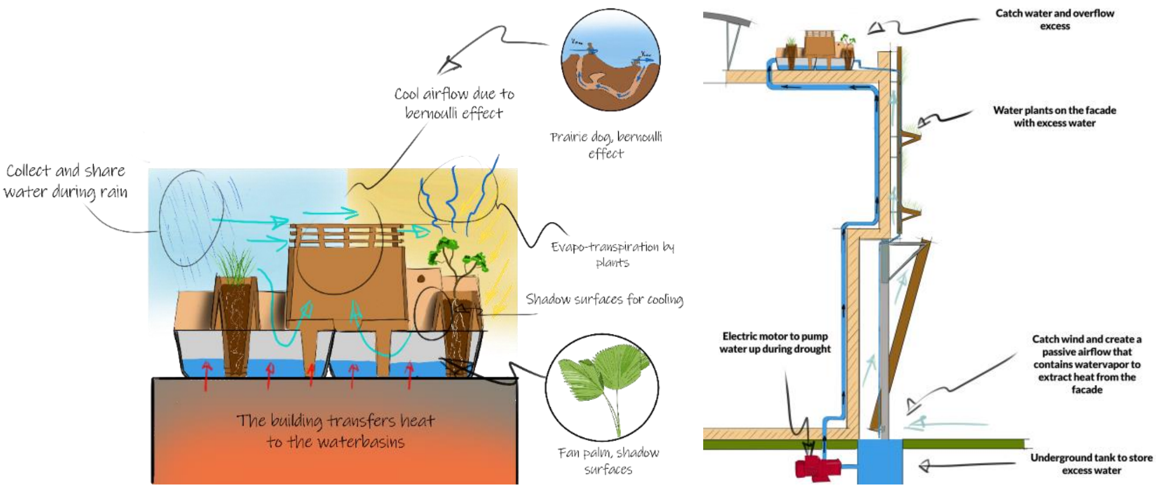


Figure 21. Green wave working mechanism

If the other ideas were to be developed in the future, all of them could work together, enhancing each other's capabilities, like an ecosystem.

6.2. Description of the pieces

<table>
<tr><td>Name</td><td rowspan="10"></td></tr>
<tr><td>Basin</td></tr>
<tr><td>Use</td></tr>
<tr><td>Structural base of the product. All the modules are placed in it.
Collecting and containing water, that will be cooled by the airflow.</td></tr>
<tr><td>Raw material</td></tr>
<tr><td>Zinc:
Malleable
Resistant once formed
Light
100% Reciclable
Highly resistant to corrosion</td></tr>
<tr><td>Manufacturing process</td></tr>
<tr><td>Punching and blanking
Deep Drawing</td></tr>
</table>

Table 11. Piece 1 - Basin

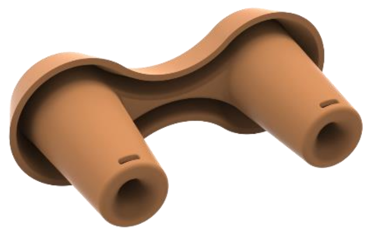
Name	 
Low Planter	
Use	
Base planter, for plants without big need for root space. Containing the substrate and absorbing the water upwards from the basin. In between the gaps they leave, air will flow. Fit with the basin poles.	
Raw material	
Red Terracotta: Malleable Water absorption Nature friendly	
Manufacturing process	
Rehumectation Press Molding Drying Firing	

Table 12. Piece 2 – Low planter

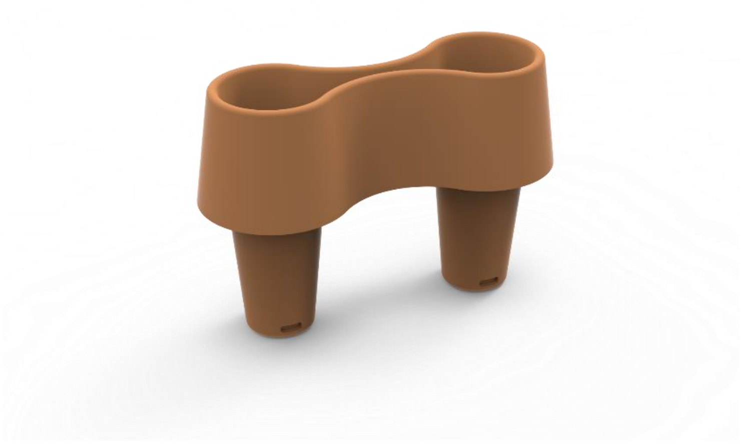
Name	
Medium Planter	
Use	
Bigger planter, for plants with medium need for root space. Containing the substrate and absorbing the water upwards from the basin. Shades other lower modules. In between the gaps they leave, air will flow. Fit with the basin poles.	
Raw material	
Red Terracotta: Malleable Water absorption Nature friendly	
Manufacturing process	
Rehumectation Press Molding Drying Firing	

Table 13. Piece 3 – Medium planter

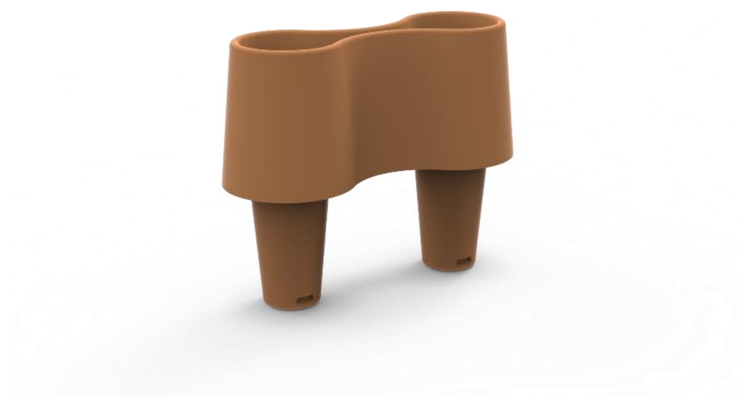
<table>
<tr><td>Name</td><td rowspan="8"></td></tr>
<tr><td>High Planter</td></tr>
<tr><td>Use</td></tr>
<tr><td>Biggest planter, for plants with need for a lot of root space.
Containing the substrate and absorbing the water upwards from the basin.
Shades other lower modules.
In between the gaps they leave, air will flow.
Fit with the basin poles.</td></tr>
<tr><td>Raw material</td></tr>
<tr><td>Red Terracotta:
Malleable
Water absorption
Nature friendly</td></tr>
<tr><td>Manufacturing process</td></tr>
<tr><td>Rehumectation
Press Molding
Drying
Firing</td></tr>
</table>

Table 14. Piece 4 – High planter

Name
Individual Planter
Use
Allows to fill in gaps left by the dual modules in the ends of a set up. Small planter, for plants without big need for root space. Containing the substrate and absorbing the water upwards from the basin. In between the gaps they leave, air will flow. Fit with the basin poles.
Raw material
Red Terracotta: Malleable Water absorption Nature friendly
Manufacturing process
Rehumectation Press Molding Drying Firing

Table 15. Piece 5 – Individual planter

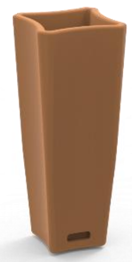
Name	
Inter Planter	
Use	
Fit in the gaps between modules. Blocks air to be sucked in too close to the windcatcher, forcing a longer path. Small planter, for plants without big need for root space. Containing the substrate and absorbing the water upwards from the basin.	
Raw material	
Red Terracotta: Malleable Water absorption Nature friendly	
Manufacturing process	
Rehumectation Press Molding Drying Firing	

Table 16. Piece 6 – Inter planter

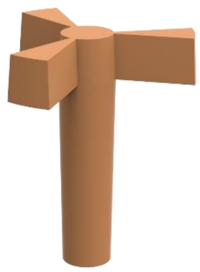
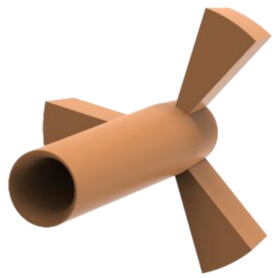
Name	 
Support	
Use	
Placing of both the Bird nest and the Windcatcher on the basin, guarantying stability of the modules. Fit with the basin poles.	
Raw material	
Red Terracotta: Malleable Water absorption Nature friendly	
Manufacturing process	
Rehumectation Press Molding Drying Firing	

Table 17. Piece 7 – Support

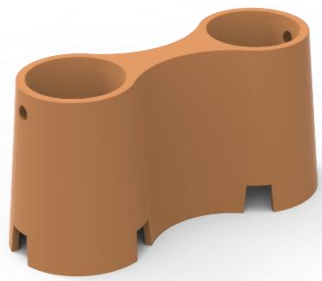
Name	
Bird nest Body	
Use	
Provides housing for city wildlife. Shades other lower modules. In between the gaps they leave, air will flow. Fit with the support.	
Raw material	
Red Terracotta: Malleable Water absorption Nature friendly	
Manufacturing process	
Rehumectation Press Molding Drying Firing	

Table 18. Piece 8.1 – Bird nest

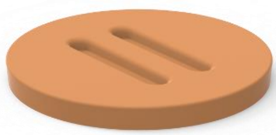
Name	
Bird nest Lid	
Use	
Allows access into the Bird nest in case it is needed.	
Raw material	
Red Terracotta: Malleable Water absorption Nature friendly	
Manufacturing process	
Rehumectation Press Molding Drying Firing	

Table 19. Piece 8.2 – Bird nest lid

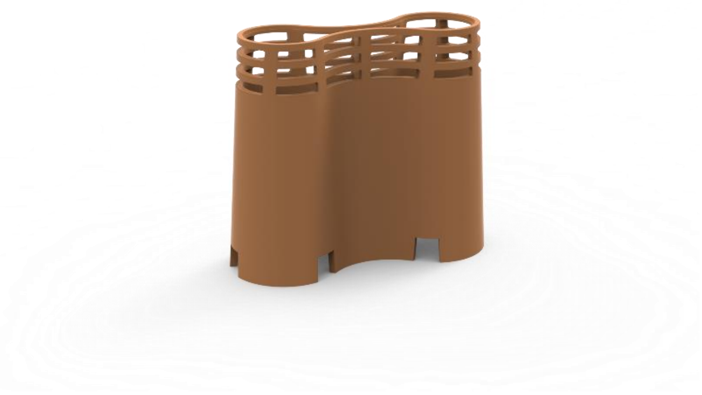
Name	
Windcatcher Body	
Use	
Creates passages for air to flow from the below layer straight to the top of the ensemble. Catches wind in combination with the insert. Shades other lower modules. In between the gaps they leave, air will flow. Fit with the support.	
Raw material	
Red Terracotta: Malleable Water absorption Nature friendly	
Manufacturing process	
Rehumectation Press Molding Drying Firing	

Table 20. Piece 9.1 – Windcatcher

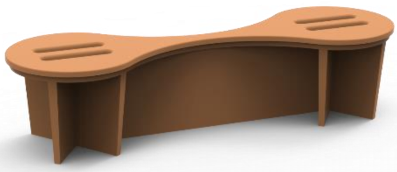
<table>
<tr><td>Name</td><td rowspan="10"></td></tr>
<tr><td>Windcatcher Insert</td></tr>
<tr><td>Use</td></tr>
<tr><td>Fits in the windcatcher. Guides the wind blowing against the top of the windcatcher downwards on the side of the wind, while separating it from the ascending airflow by the Bernoulli effect.</td></tr>
<tr><td>Raw material</td></tr>
<tr><td>Red Terracotta:
Malleable
Water absorption
Nature friendly</td></tr>
<tr><td>Manufacturing process</td></tr>
<tr><td>Rehumectation
Press Molding
Drying
Firing</td></tr>
</table>

Table 21. Piece 9.2 – Windcatcher insert

BID SPECIFICATIONS

1. Object and scope of the bid

Climate change has changed this earth. It has had great impact on the entire wide world, including us, our buildings and our urban environments. One of its effects has been the rising temperatures. This problem will be the challenge for this case study.

Buildings absorb more heat during the day than they can emit during the night. This contributes to the Urban Heat Island Effect, also referred to as UHIE. This problem has caused urban areas to become uncomfortable for its residents, especially during the hot summer months. These residents can experience difficulties with sleeping and are more likely to experience heat-related illness. This problem has even resulted in a 12% death rate rise in 2014. Less disturbing consequences of this problem are worse air quality and increase in energy costs for all the AC units and other devices used.

In The Hague stands the main THUAS building. Within, temperatures can rise up to 25 degrees Celsius, especially in the Strip side of the building. This building and the surrounding urban area will be the case study in this search for a solution.

Nature, with its evolutionary capabilities and its experience with weather conditions (a little more than we do) can help to solve this challenge. With all that experience come strategies, abilities and mechanisms that have evolved to thrive in fluctuating weather conditions like the ones we face with this Urban Heat challenge. These strategies, abilities and mechanisms will be researched and analyzed. All that useful information will be ‘naturally processed’ and formed into a product. This solution can come in any size or shape and will be the next step forward to solve the rising temperatures in buildings and urban areas.

From these premisea the design of a modular system for the implementation of a green roof is proposed, with added cooling functions.

2. General regulations

Environmental Impact Assessment (EIA): Require a comprehensive assessment of the environmental impact of the cooling system, including its effects on local microclimates, biodiversity, and air quality.
Building Codes and Zoning Regulations: Ensure compliance with local building codes and zoning regulations related to construction, height, setback requirements, and land use.
Energy Efficiency Standards: Mandate that the cooling system meets specific energy efficiency standards to minimize energy consumption and reduce greenhouse gas emissions.
Noise Regulations: Establish limits on noise levels generated by the cooling system to mitigate potential disturbances to nearby residents and businesses.
Light Pollution Control: Implement measures to minimize light pollution from the cooling system, especially if it includes lighting elements, to preserve the night sky and reduce impacts on nocturnal wildlife.
Heat Island Mitigation: Require the implementation of measures to mitigate heat island effects, such as using reflective materials, green roofs, or incorporating vegetation into the design.
Air Quality Monitoring and Control: Monitor and control emissions from the cooling system to ensure compliance with air quality standards and protect public health.
Water Usage Restrictions: Set limits on water usage for the cooling system, promoting water conservation and efficiency in its operation.
Safety Standards: Establish safety standards to prevent accidents or injuries related to the installation, operation, and maintenance of the cooling system.
Accessibility Requirements: Ensure that the cooling system is accessible to all individuals, including those with disabilities, in compliance with accessibility guidelines and regulations.
Public Health Considerations: Assess potential impacts on public health, such as heat-related illnesses or vector-borne diseases and implement measures to mitigate risks.
Community Engagement and Consultation: Require developers to engage with local communities and stakeholders to gather input, address concerns, and ensure that the cooling system's design and implementation align with community needs and priorities.
Long-Term Maintenance and Monitoring: Establish requirements for long-term maintenance and monitoring of the cooling system to ensure its continued effectiveness and safety over time.
Emergency Preparedness and Response: Develop contingency plans and protocols for emergencies, such as power outages or extreme weather events, to minimize disruptions and ensure the safety of occupants and the surrounding environment.
Compliance and Enforcement Mechanisms: Implement mechanisms for monitoring compliance with regulations and enforcing corrective actions or penalties for non-compliance.

3. Technical conditions

3.1. Materials: Characteristics and supply

Name	Zinc
Shape and size	Sheet metal: 3mm thickness 1340mm width
Supplier	elZinc
Commercial name	elZinc Wide
Physical properties	Density: 7,2 kg/dm3 Melting point: 420ºC Recrystallization temperature: min. 300ºC Coefficient of linear expansion: 0,022 mm/m/ºC In the direction of rolling: Yield strength elasticity 0,2 %: min. 110 N/mm2 Tensile strength (Rm): min. 150 N/mm2 Breaking elongation (A50): min. 40% Vickers hardness (HV3): min. 45
Chemical composition	Zinc: Zn 99,995 (Z1 as per DIN EN 1179) Pe, Fe, Cd, Sn, Mn, Mg: Zn 99,995 (Z1 as per DIN EN 1179) Copper: 0,08 – 0,2% Titanium: 0,07 – 0,12% Aluminium: max. 0,015%
Supply conditions	One coil per pallet, weighting about 1000 kg each. Each coil should have 35 m of length.

Table 22. Characteristics and supply of zinc

Name	Red Terracotta
Shape and size	Clay dust
Supplier	Scarva pottery supplies
Commercial name	Scarva Raw Materials Fireclay RM1078
Physical properties	Moisture absorption – 6.8% Minus No.200 sieve size – 87% Loss of ignition – 10.6% Specific gravity – 2.66 Loss of ignition – 7.4% Liquid limit – 35% Plastic limit – 19% Plasticity index – 16% Drawing shrinkage – 4.8% Fired shrinkage – 16.2% Maximum dry density – 1.83 Mg/m cube. Optimum moisture content – 12.3% Shear strength – 180 KN per metre square The angle of internal friction – 29.6 degree Ultrasonic pulse velocity – 2.1 km/s Uniaxial compressive strength – 22 MPa
Chemical composition	45.9% alumina and 54.1 percent silica
Supply conditions	Bags of 25 kg

Table 23. Characteristics and supply of red terracotta

3.2. Technical conditions of manufacturing and assembly

3.2.1. Basin

Punching and blanking

The first step is cutting the sheet from the coil to the adequate dimensions for the following step.

According to Thompson (2010):

> "The operation is the same whether it is carried out on a turret punch, punch press or fly press. It is possible to punch a single hole, multiple holes simultaneously, or many holes with the same punch. In stage 1, the workpiece is loaded onto the roller bed. In stage 2, the stripper and die clamp the workpiece. The hardened punch stamps through it, causing the metal to fracture between the circumferences of the punch and die. The die is slightly larger than the punch to allow for roll over and burr caused by the shearing process. The offset is determined by the type and thickness of material and ranges from 0.25 mm to 0.75 mm (0.01- 0.03 in.). Therefore, the sides of the hole are not exactly perpendicular to the face. Once cut, the punch retracts and the stripper ensures that the metal comes free. Either the punched material or the surrounding material is scrap, depending on whether it is a punching or blanking operation. In both cases the scrap is collected and recycled. Dedicated tooling may be made up of many punches joined together. They operate simultaneously in a punch press. Complex and intricate shapes are more easily achieved with these tools such as in the Alessi case study."

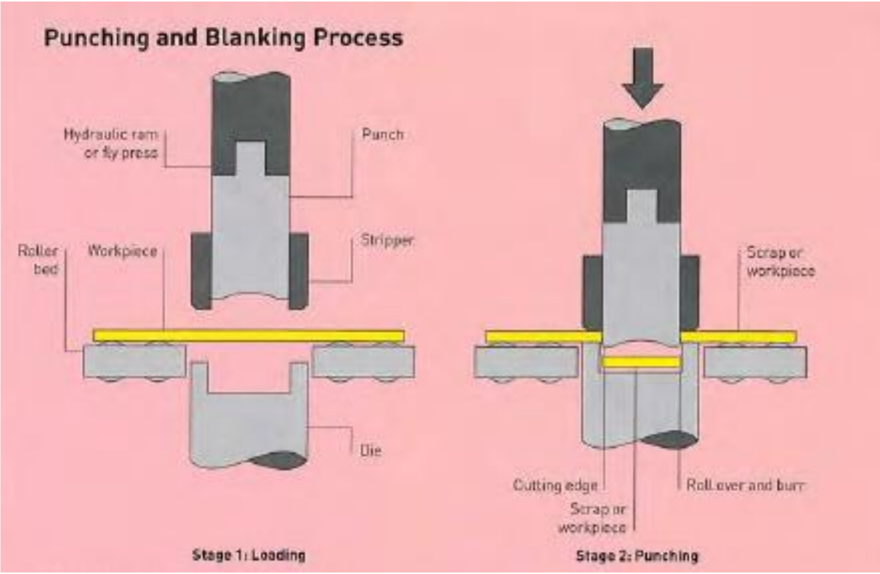


Figure 22. Punching and blanking process (Thompson, 2010)

This process, although more complex due to the shape of the basin, is in essence what will take place after the metal sheet has been cut to the desired pre-shape.

Deep drawing

According to Thompson (2010):

> "The deep drawing process is carried out in different ways - the method of process being determined by the complexity of the shape, depth of draw, material and thickness. In stage 1, a sheet metal blank is loaded into the hydraulic press and clamped into the blank holder. In stage 2, as the blank holder progresses downwards the material flows over the sides of the lower die to form a symmetrical cup shape. In stage 3, the punch forces the material through the lower die in the opposite direction. The metal flows over the edge of the lower die to take the shape of the punch. In stage U, the part is ejected."

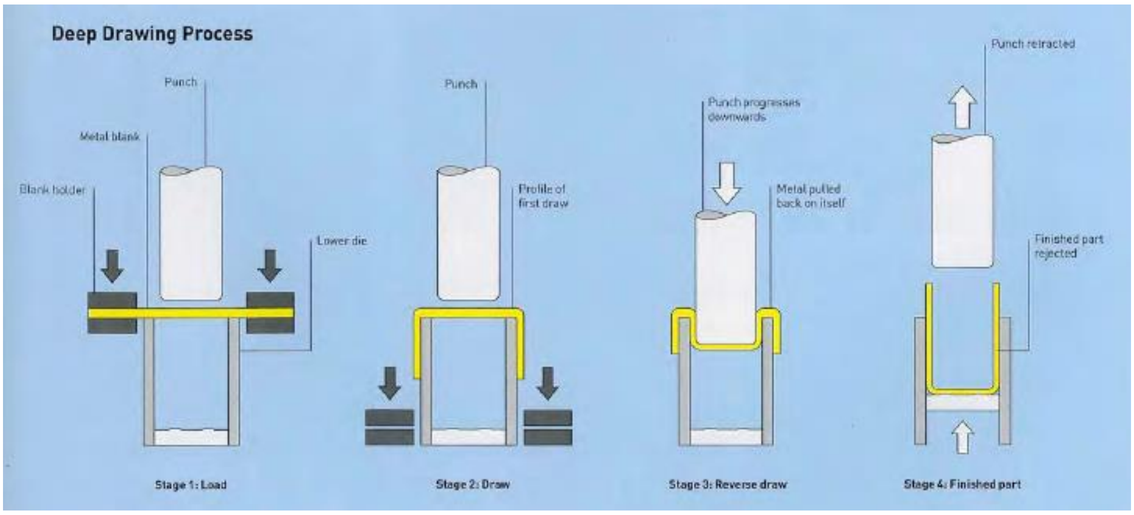


Figure 23. Deep Drawing process (Thompson, 2010)

This process, although more complex due to the shape of the basin, is in essence what will take place after the metal sheet has been cut to the desired pre-shape.

3.2.2. Terracotta pieces

Rehumectation

The first step is transforming the clay dust in something malleable. For that it needs to be mixed with water again.

Press Molding

After that the product can already be shaped. For that press molding is used.

The first step is cutting the sheet from the coil to the adequate dimensions for the following step.

According to Thompson (2010):

> "This is an automated process that forms parts by hydraulic action. Each product will be identical and manufactured to fixed tolerances. The molds are typically made of plaster, although these have a limited lifespan. The die castings can be made to accommodate either 1 large part or several smaller objects. In stage 1, a charge of mixed clay is loaded into the lower mold. In stage 2, the upper and lower molds are brought together at pressures from 69 N/cm2 to 276 N/cm21100-A00 psi). The pressure is evenly distributed across molds and through the clay, which produces even and uniform parts. During the pressing cycle the warm plaster molds draw moisture from the clay, to accelerate the hardening process. The perimeters of each mold cavity on the upper and lower section come together to cut the excess flash from the clay part. The ram pressing process is more rapid that jiggering and can produce up to 6 cycles every minute. Once the pressing cycle is complete, the molds separate and the parts are instantly released by steam pressure that is forced through the porous molds. The clay parts are self-supporting and can be demolded immediately after they have been ram pressed."

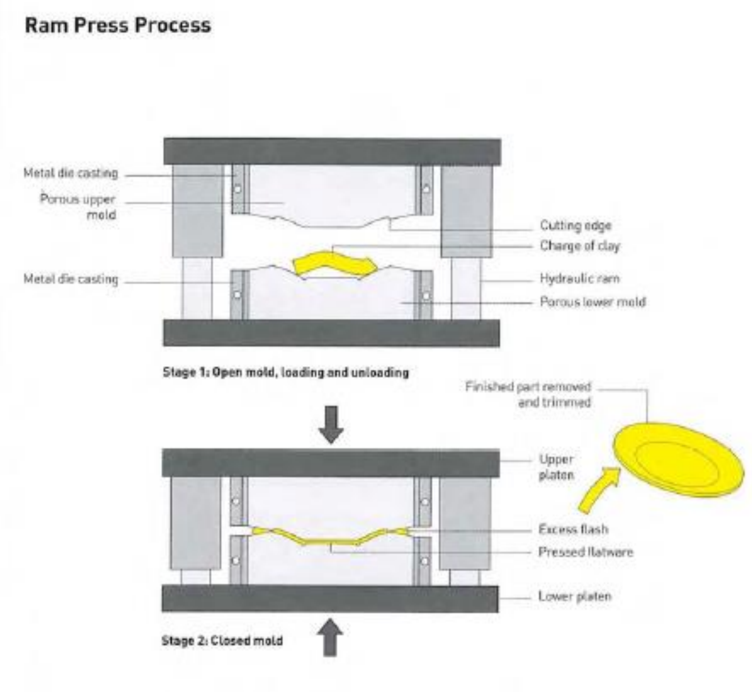


Figure 24. Ram pressing process (Thompson, 2010)

Next is an idea of what that molds could look like:

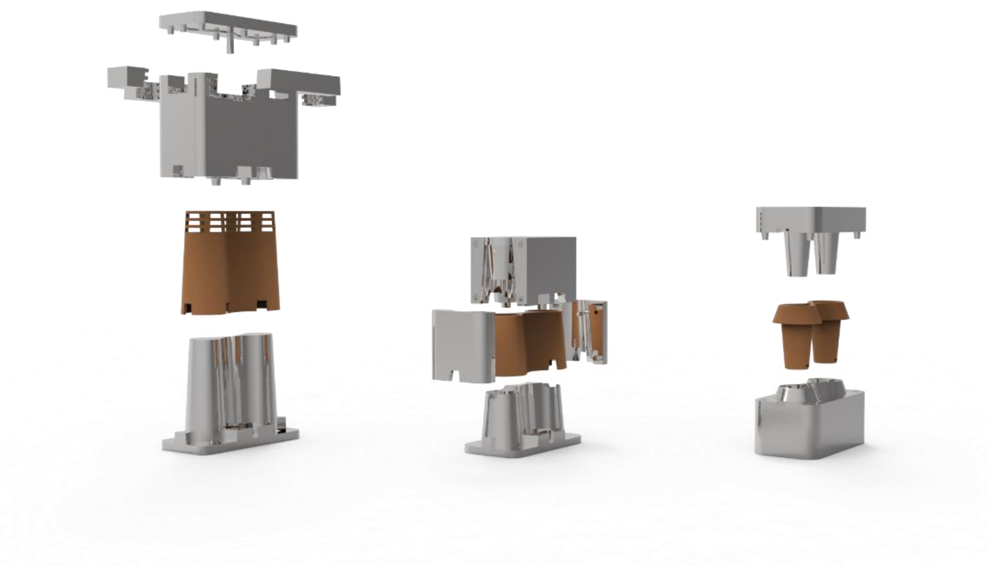


Figure 25. Possible mold ideas

Drying

After the pieces have been demolded they must be dried, so they are placed in drying equipment where heated air is circulated.

Firing

Last is firing up the pieces. They are placed in industrial ovens, where the material will be sinterized, gaining the desired properties.

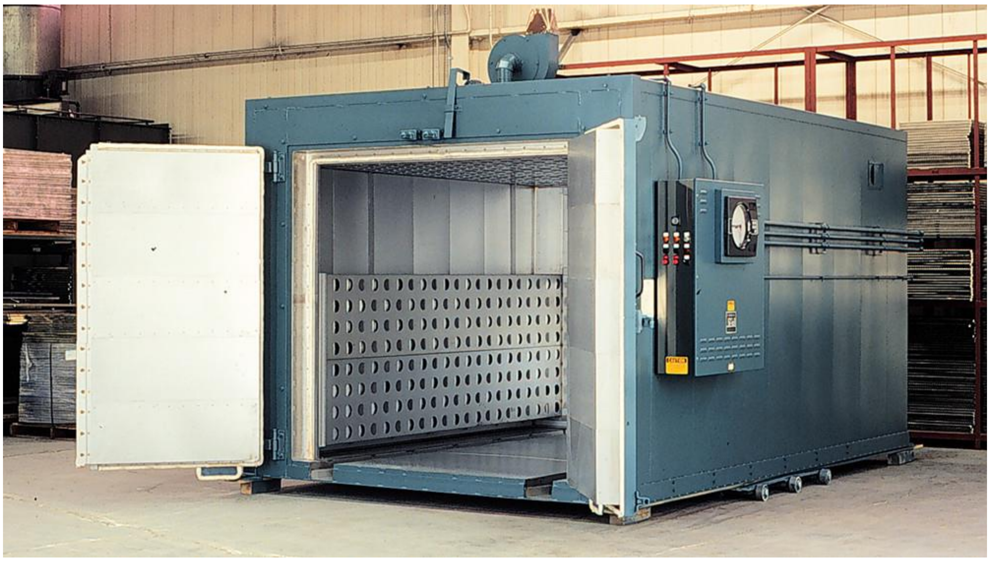


Figure 26. Industrial Oven (Industrial Quick Search Manufacturer Directory, s.f.)

3.2.3. Assembly

The assembly of the product is made in situ and simple enough for a client to make themselve. The manufacture could offer this as an extra service, but no assembly is required previously to sending to the client.

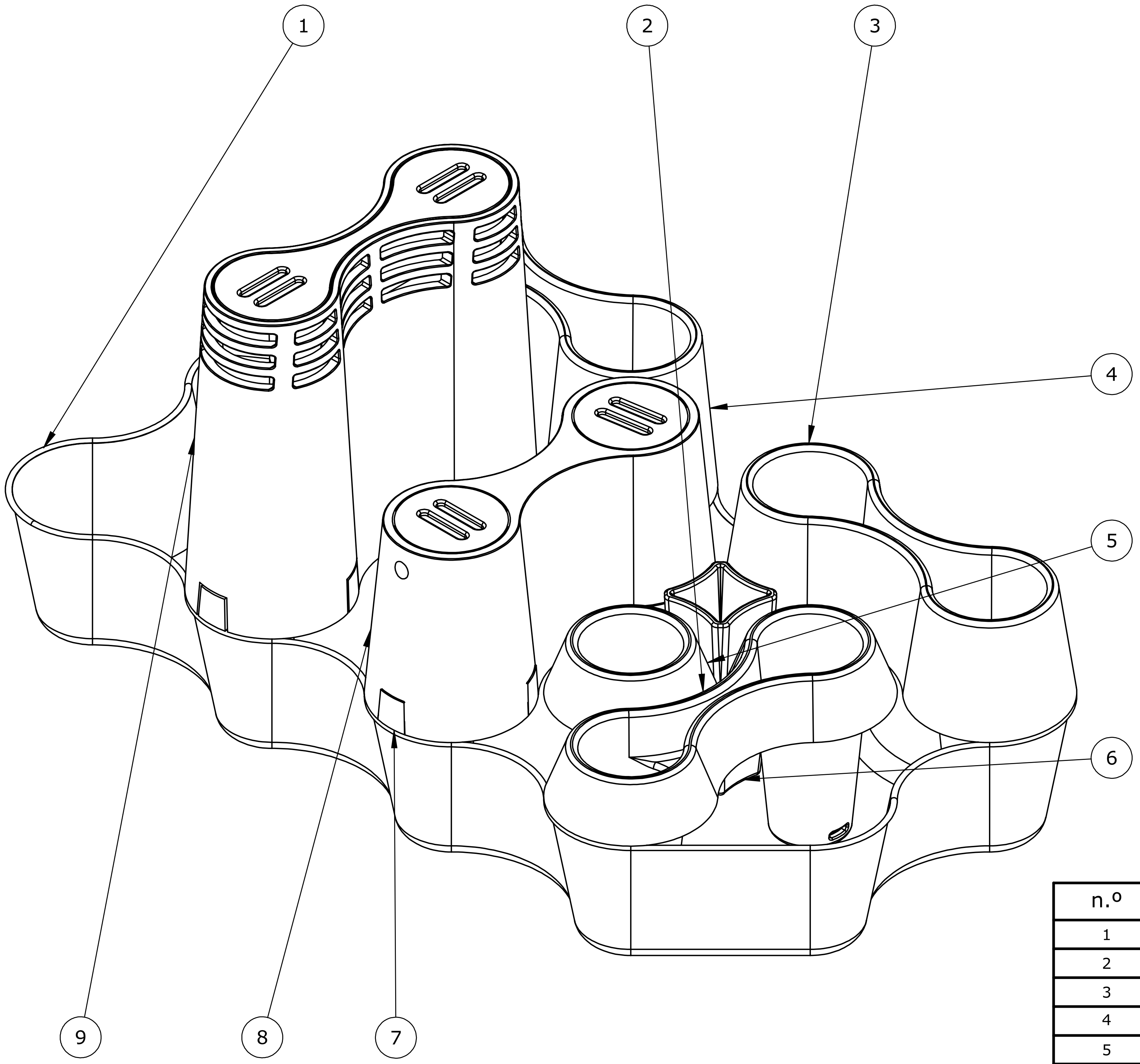
First, the surface of the building is covered in basins, whose sides fit into each other.

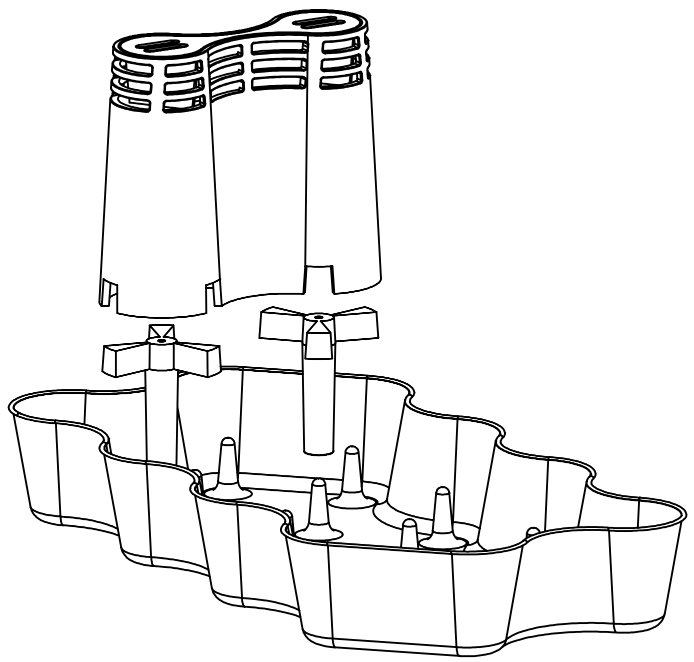
Before placing the modules, the Bird nest lids must be placed on the Bird nests and the Windcatcher inserts in the Windcatchers.

Then all the basic modules can be placed as previously designed for the specific place. To do that they just need to be fitted into the poles of the basins, fitting them in the holes the modules have below. For the Windcatcher and the Bird nest two supports must be placed first in the poles, and then they will be fitted on the supports.

Finally, the Inter planters can be placed in between the other modules. After that the product is ready for the installment of the garden.

TECHNICAL DRAWINGS





n.º	Designation	Units	Others
1	Basin	1	
2	Low Planter	1	
3	Medium Planter	1	
4	High Planter	1	
5	Individual Planter	1	
6	Inter Planter	1	
7	Support	2	
8	Bird nest	1	
9	Windcatcher	1	

	Date	Name	Signatures
Drawn	10/05/2024	Antón SR	
Verified			

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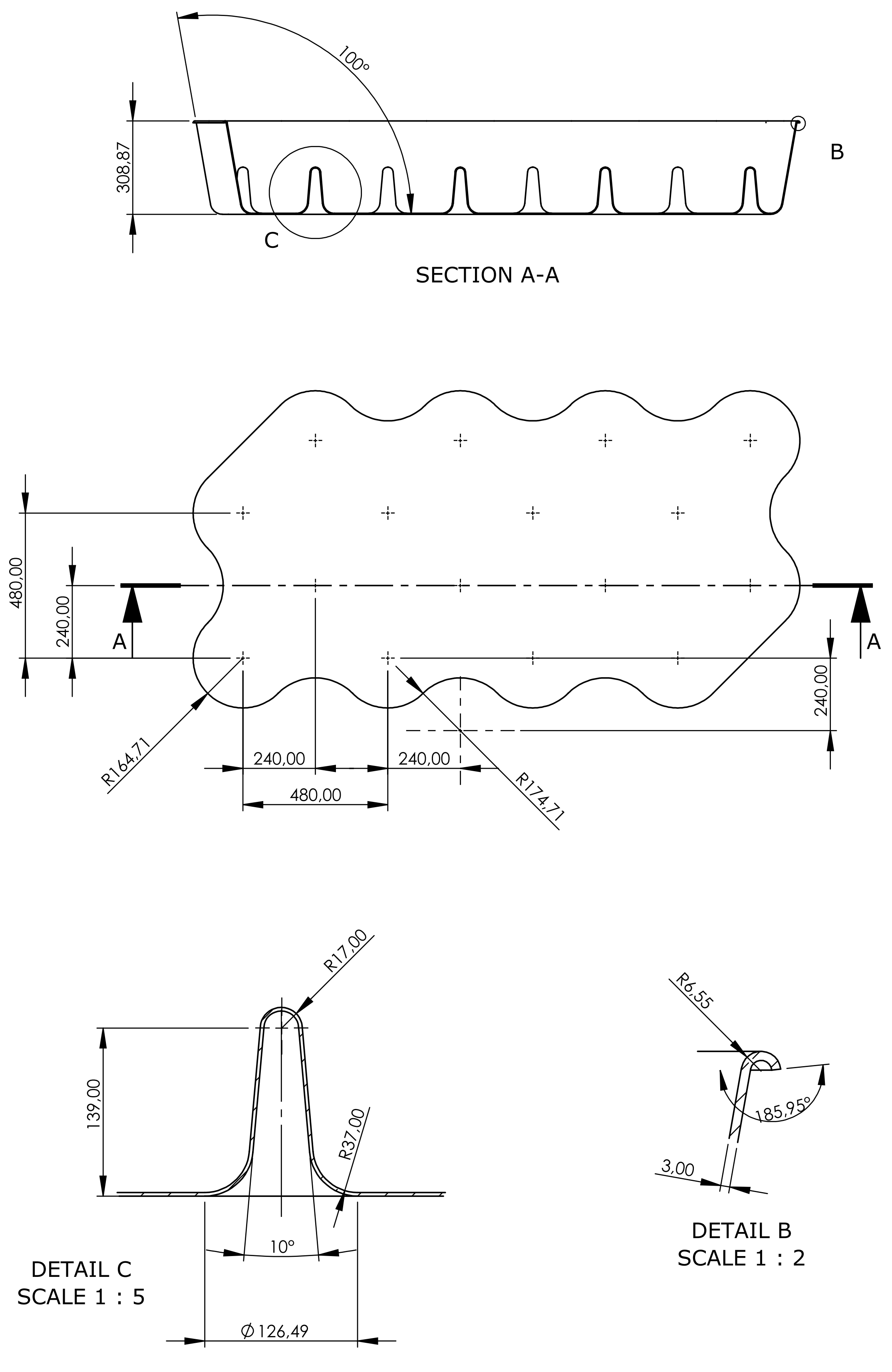
Scale 1:10	Designation: Assembly View	Number 1 of 14
	Project: Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
		Replaced by



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Scale		Number 2 of 14
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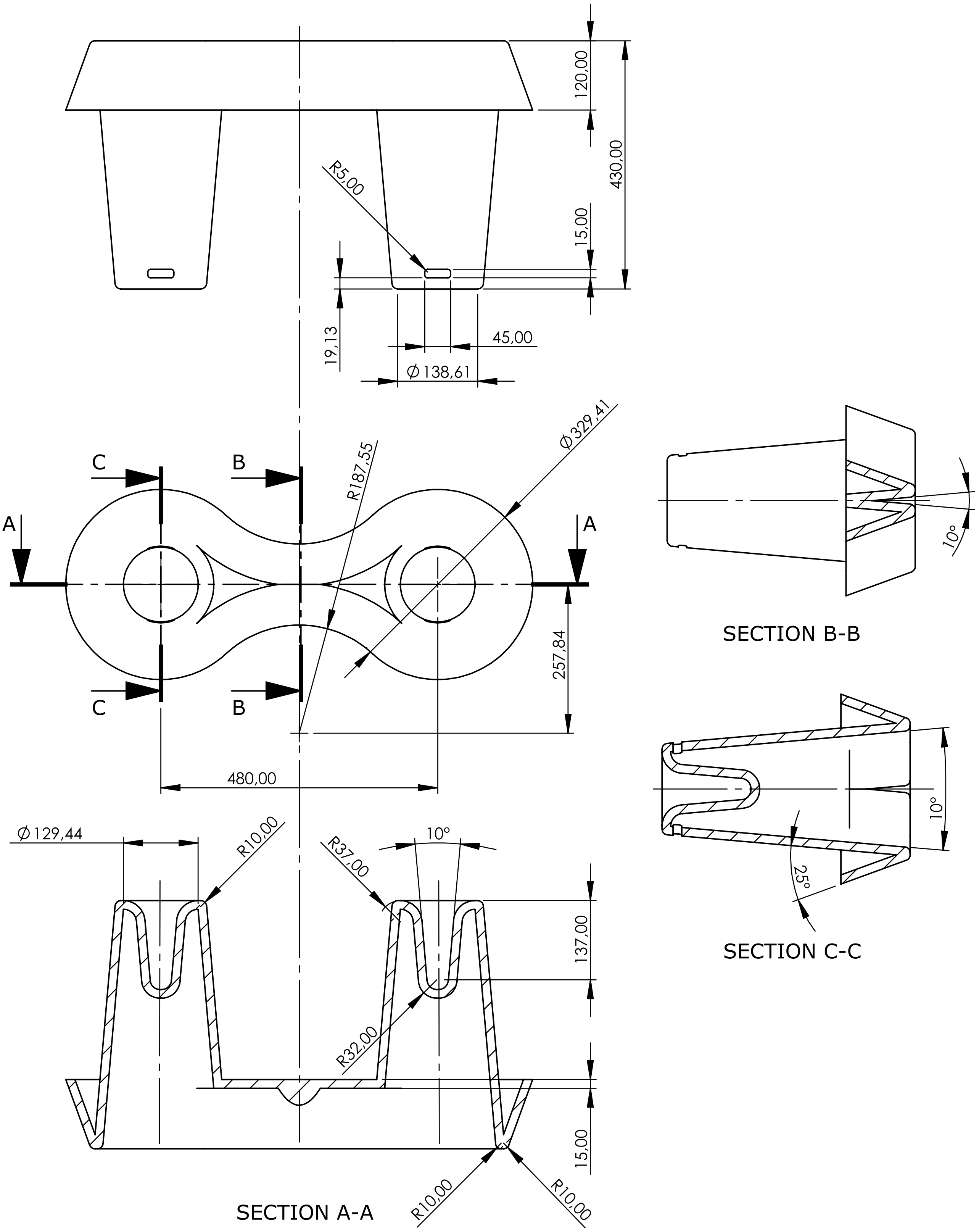

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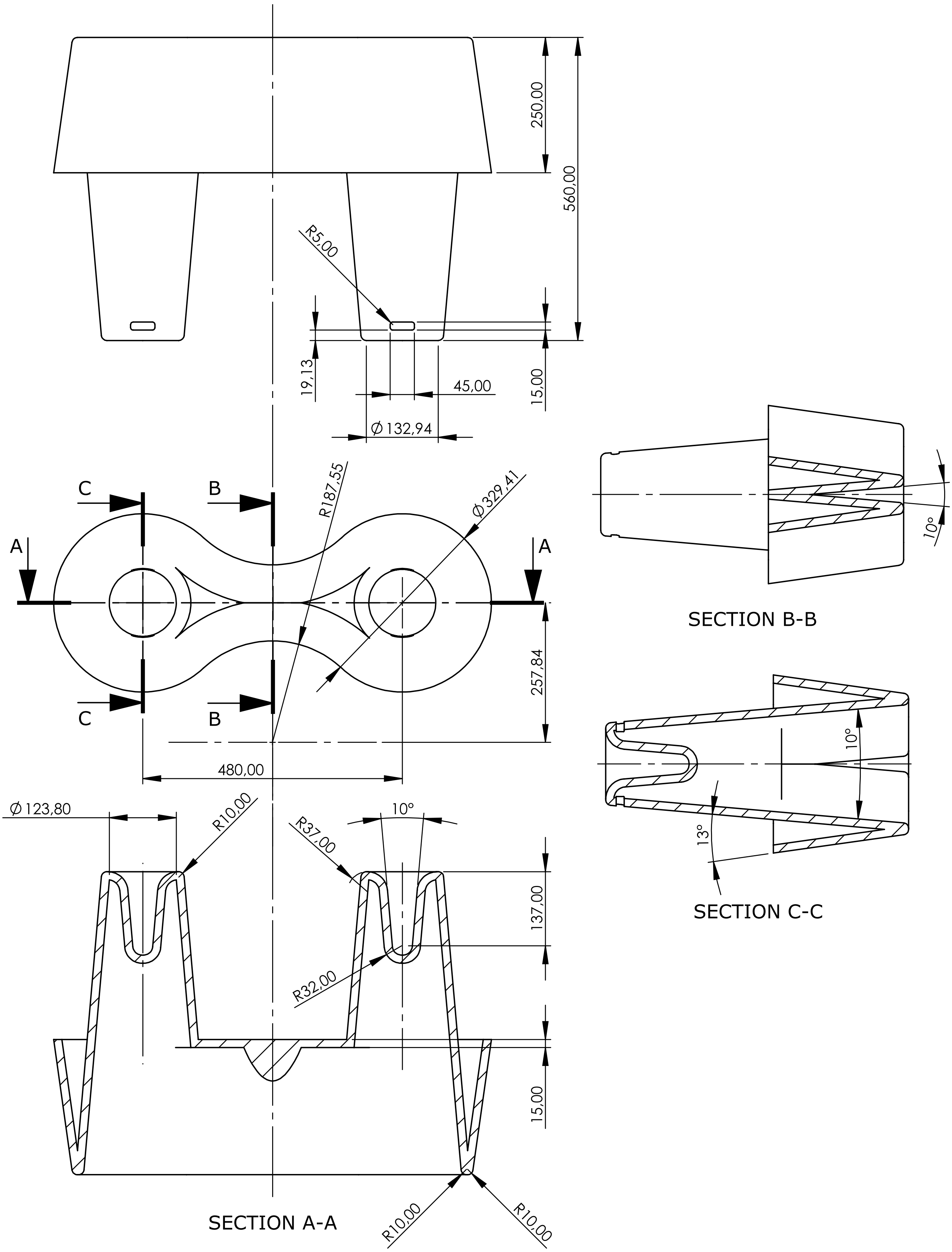
Scale 1:10	Designation: Piece 2: Low Planter	Number: 3 of 14
	Project: Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
		Replaced by



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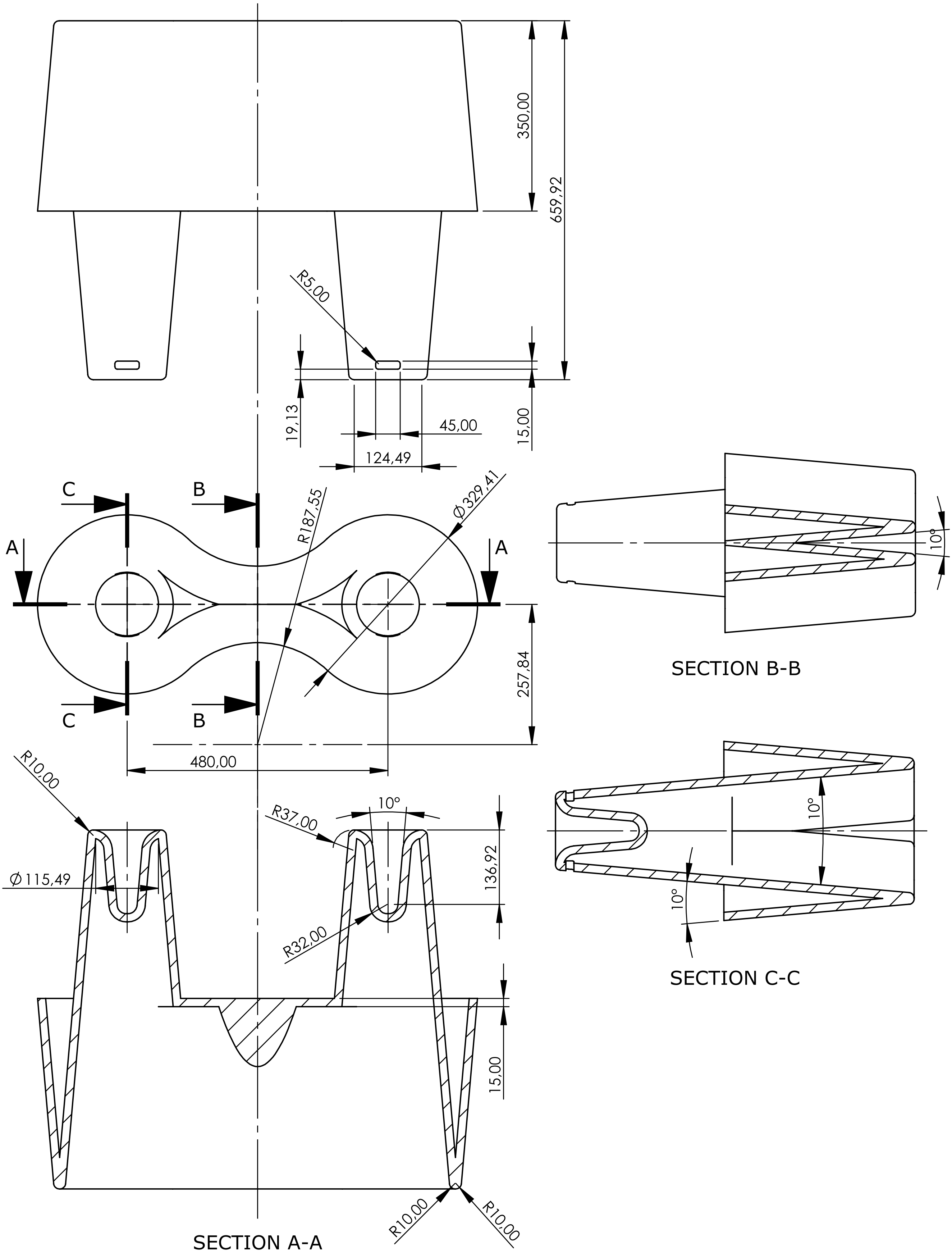
Scale	Designation	Piece 3: Medium Planter	Number 4 of 14
1:10			Replaces
	Project	Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaced by



	Date	Name	Signatures
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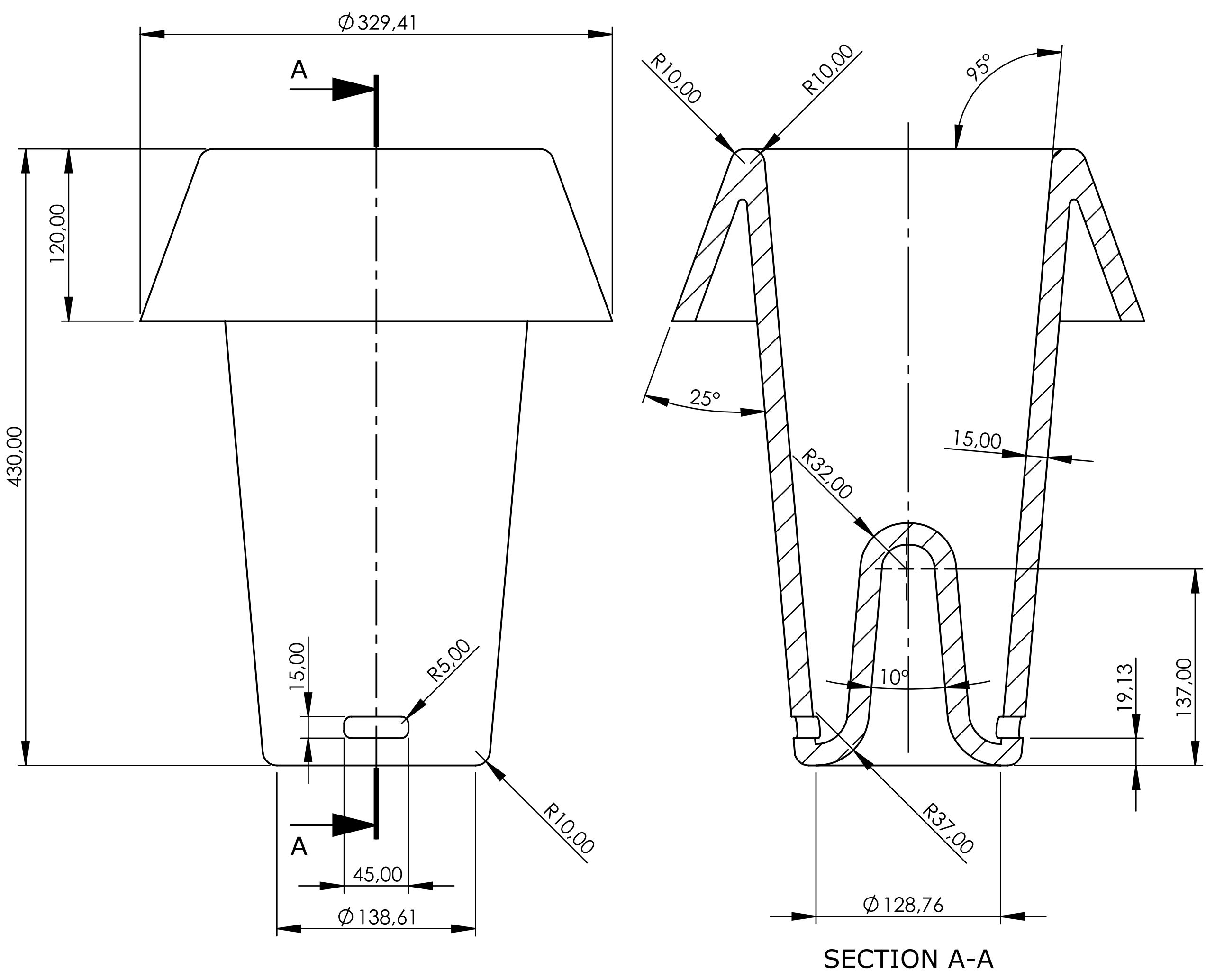
Scale	Designation	Piece 4: High Planter	Number 5 of 14
1:10	Project	Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
			Replaced by



	Date	Name	Signatures
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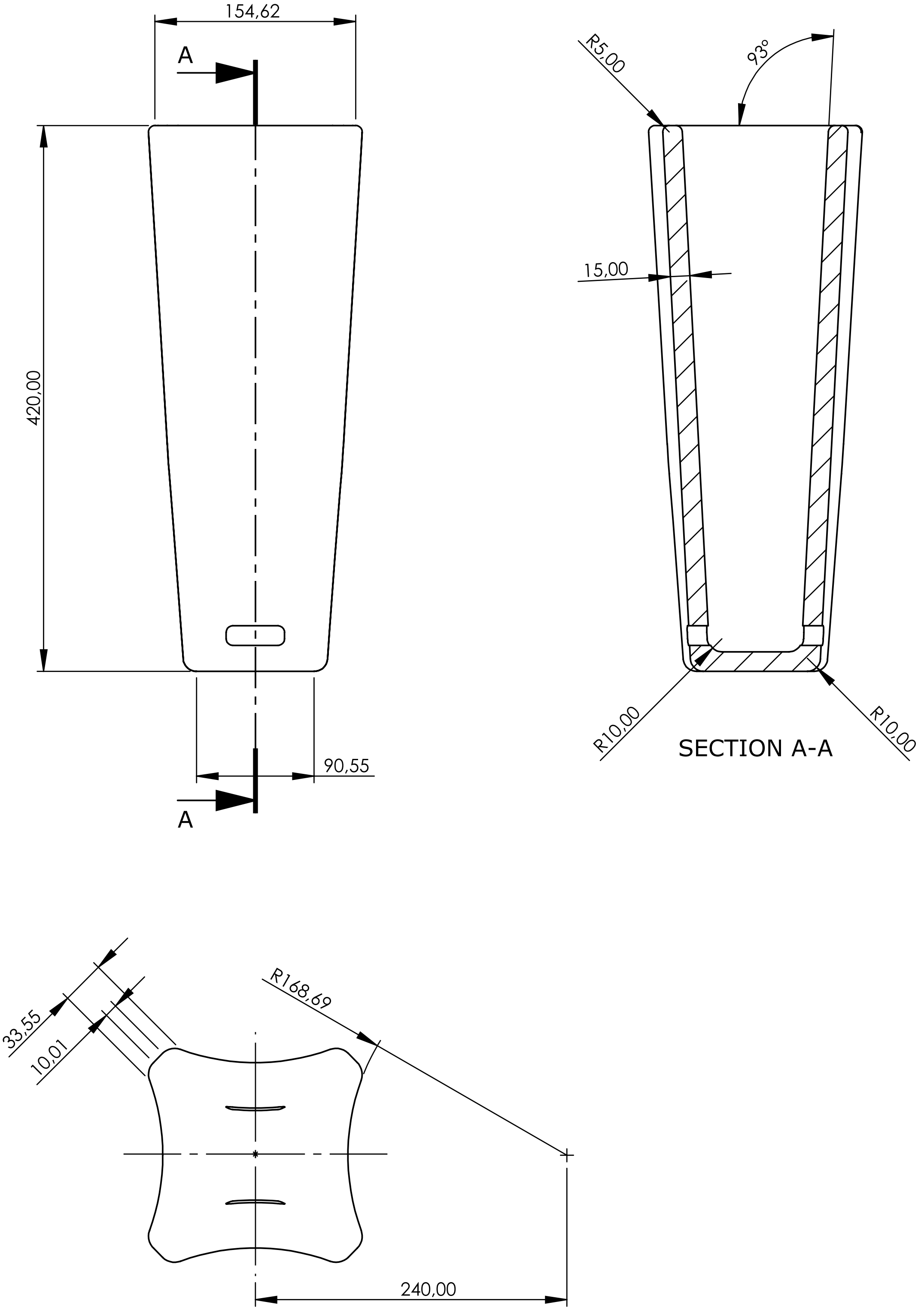
Scale 1:5	Designation: Piece 5: Individual Planter	Number: 6 of 14
	Project: Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
		Replaced by



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Drawn	10/05/2024	Antón SR			
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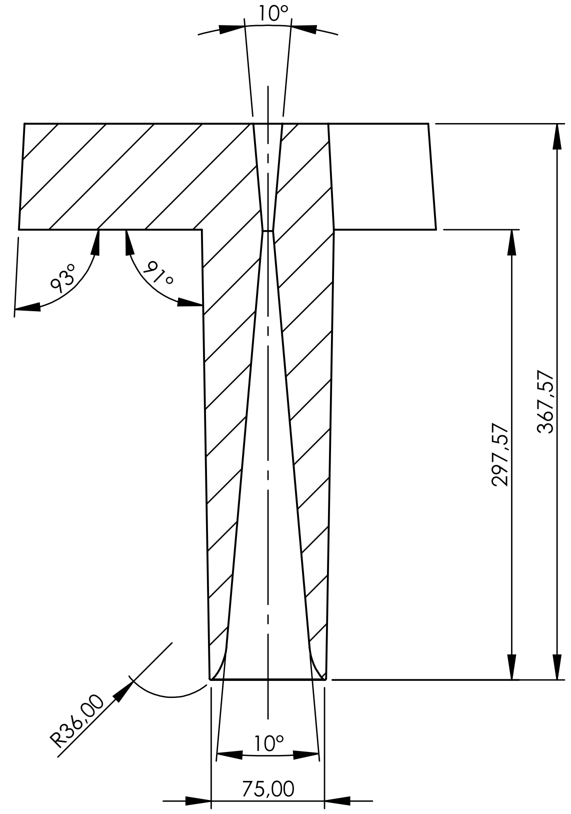
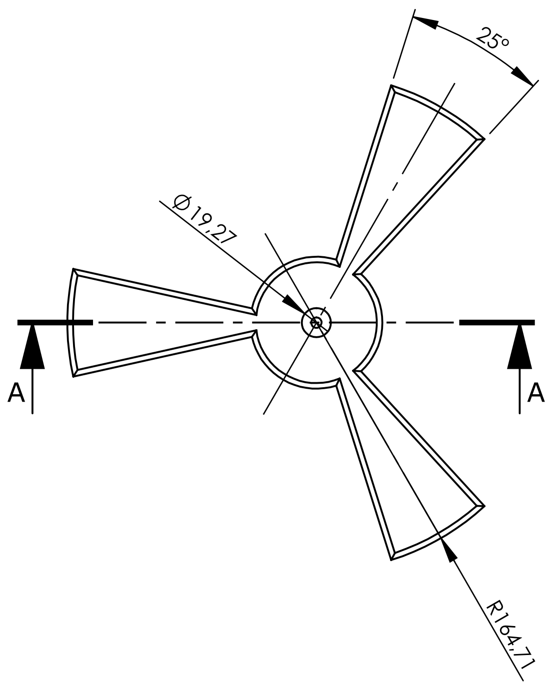
Scale	Designation	Piece 6: Inter planter	Number 7 of 14
1:5	Project	Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
			Replaced by



SECTION A-A



	Date	Name	Signatures		
Drawn	10/05/2024	Antón SR		Escuela Técnica Superior de Ingeniería del Diseño	THE HAGUE UNIVERSITY OF APPLIED SCIENCES
Verified					

Scale	Designation	Piece 7: Basin	Number	8 of 14
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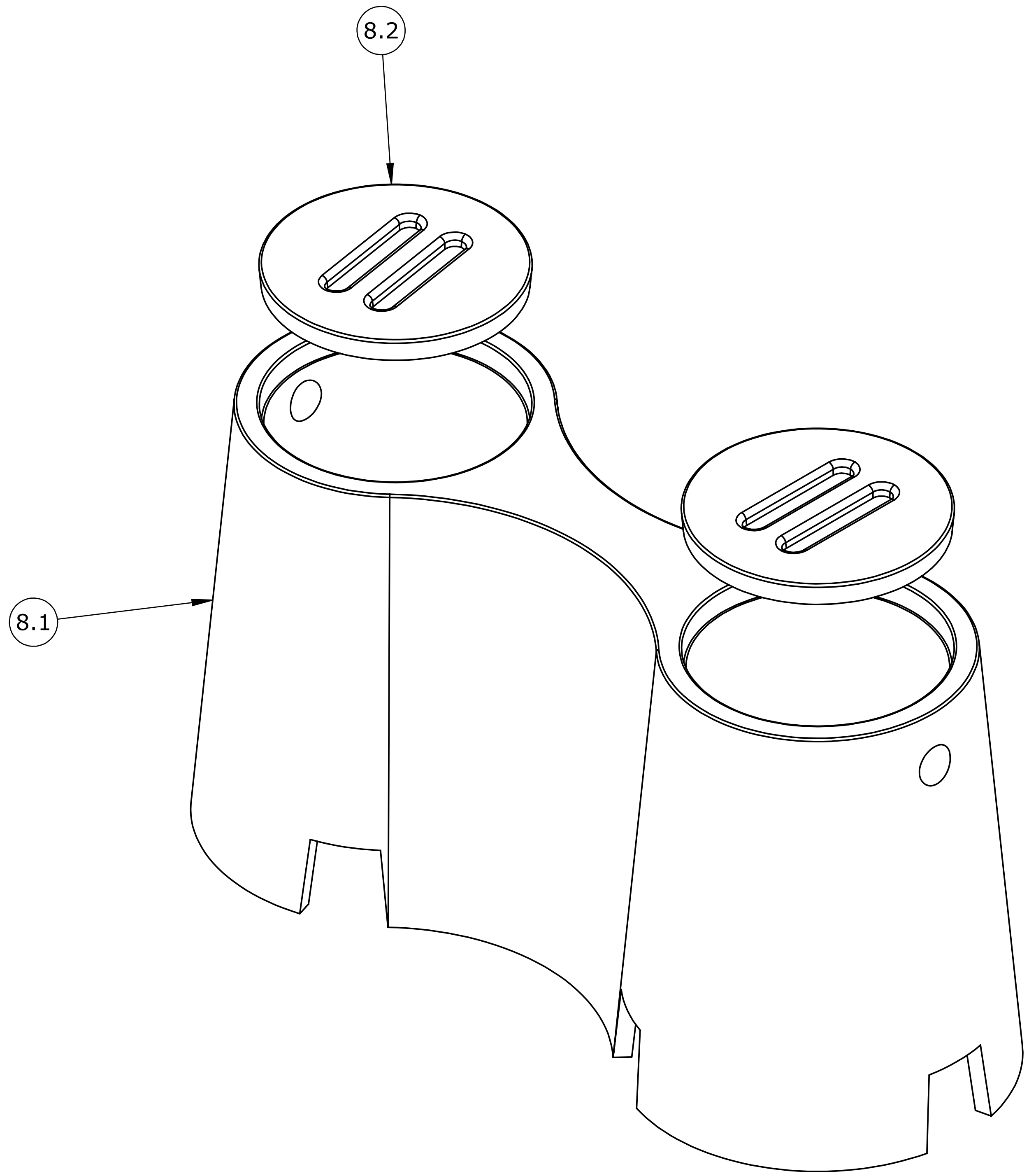

n.º	Designation	Units	Others
8.1	Bird nest Body	1	
8.2	Bird nest Lid	2	

	Date	Name	Signatures
Drawn	10/05/2024	Antón SR	
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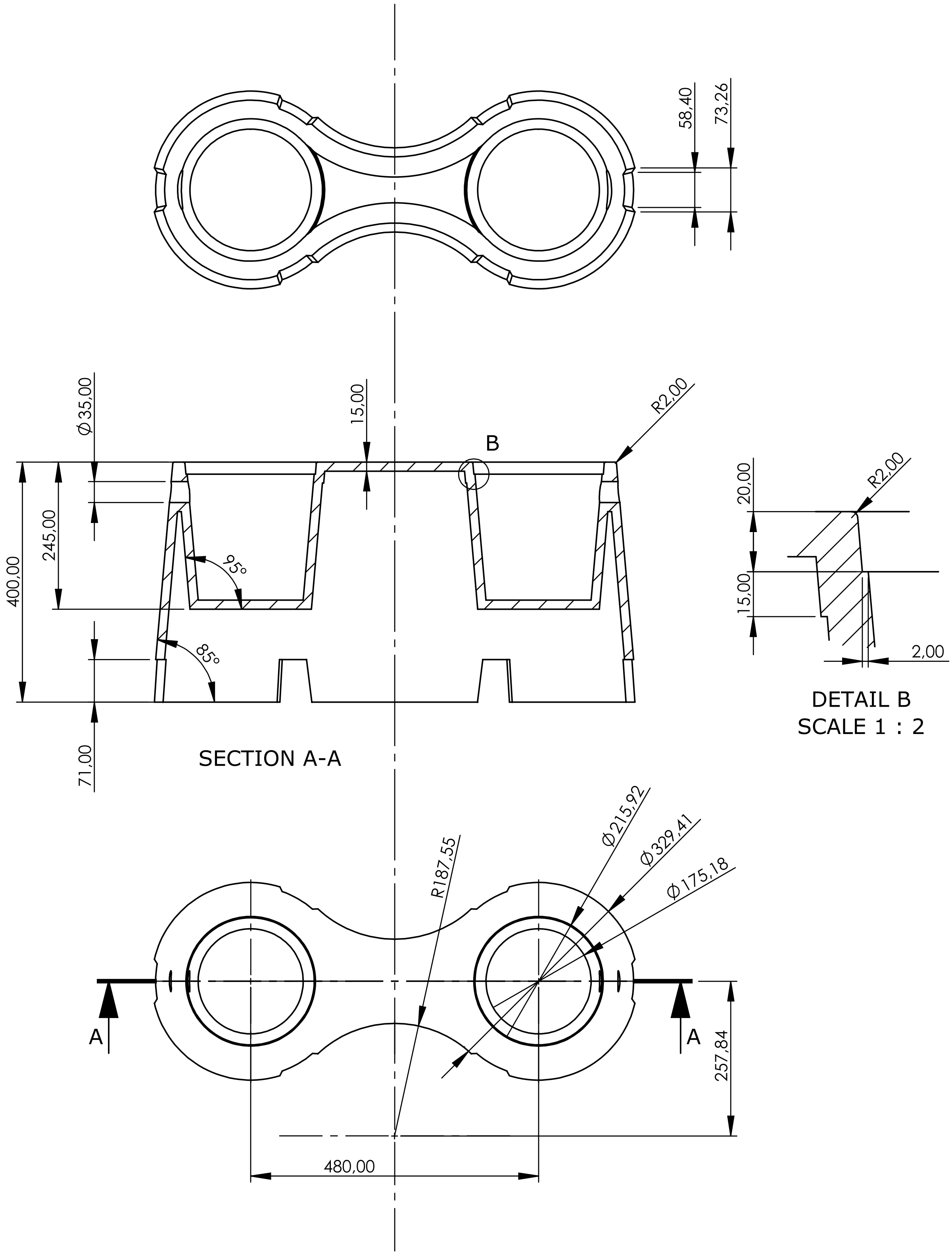
Scale 1:5	Designation: Subassembly 8: Bird nest	Number: 9 of 14
	Project: Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
		Replaced by



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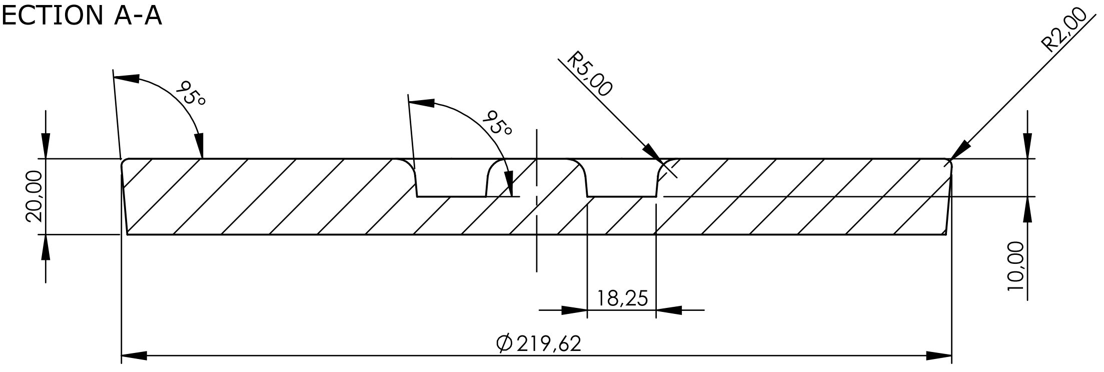
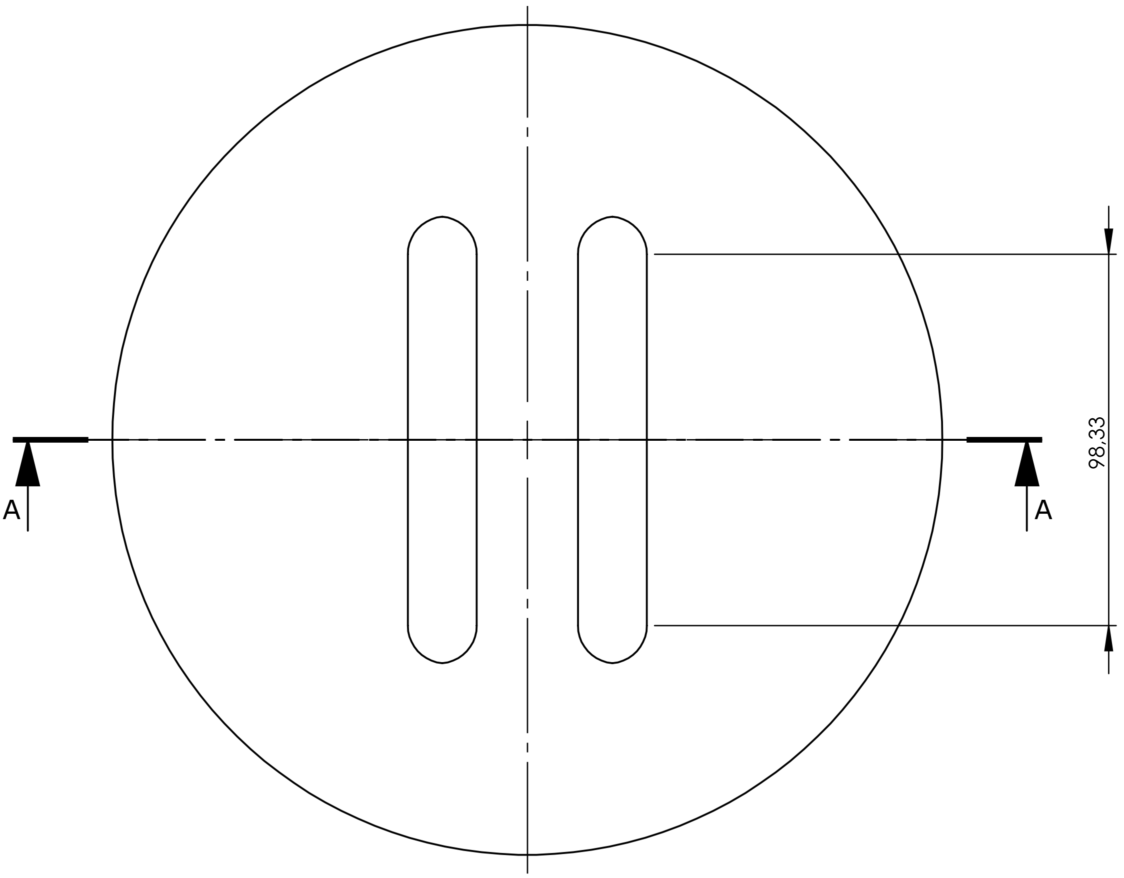
Scale	Designation	Piece 8.1: Bird nest Body	Number 10 of 14
1:10	Project	Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
			Replaced by

SECTION A-A





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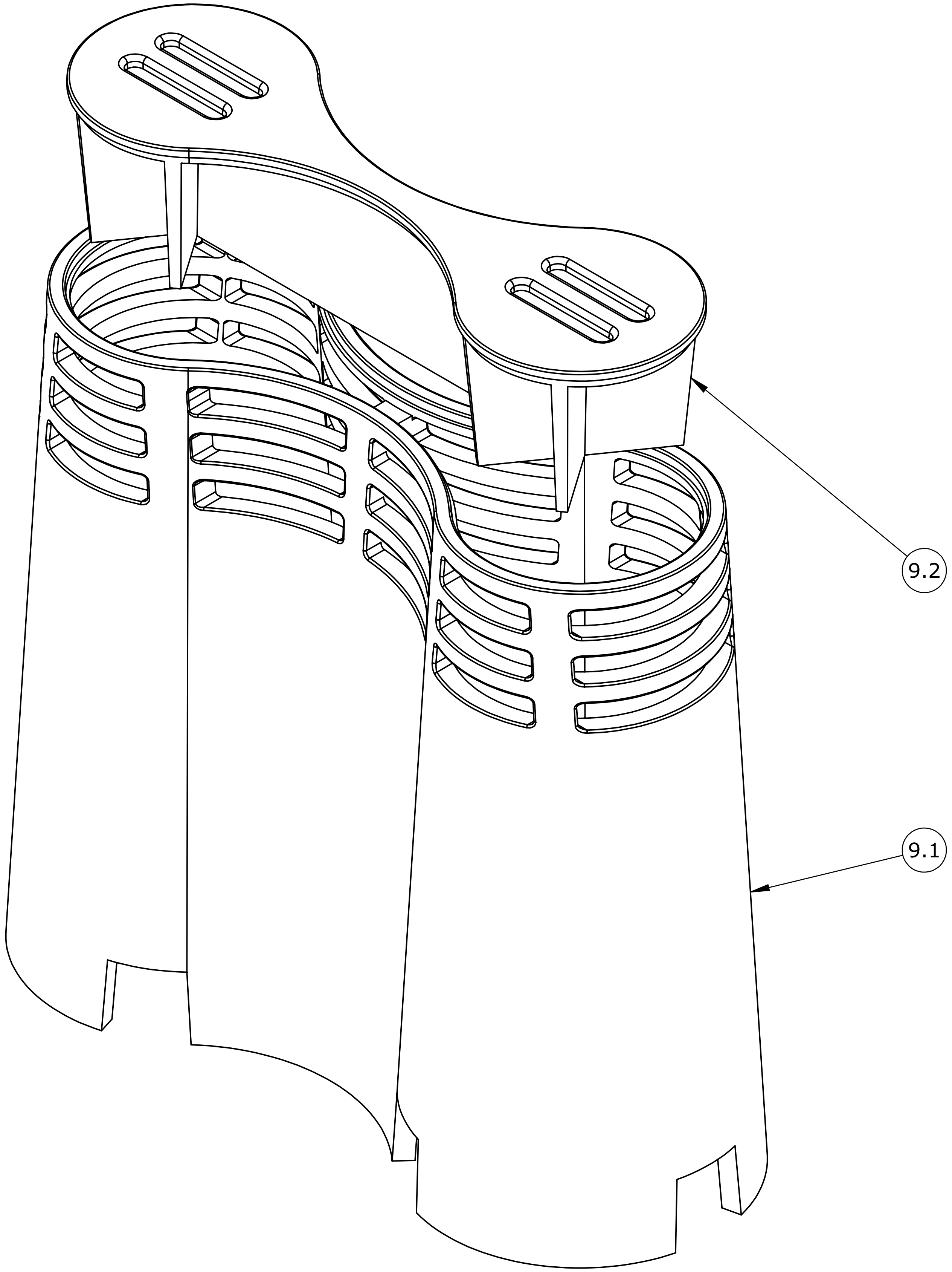
Scale 1:2	Designation: Piece 8.2: Bird nest lid	Number 11 of 14
	Project: Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
		Replaced by



n.º	Designation	Units	Others
9.1	Windcatcher Body	1	
9.2	Windcatcher Insert	1	

	Date	Name	Signatures
Drawn	10/05/2024	Antón SR	
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Scale 1:5

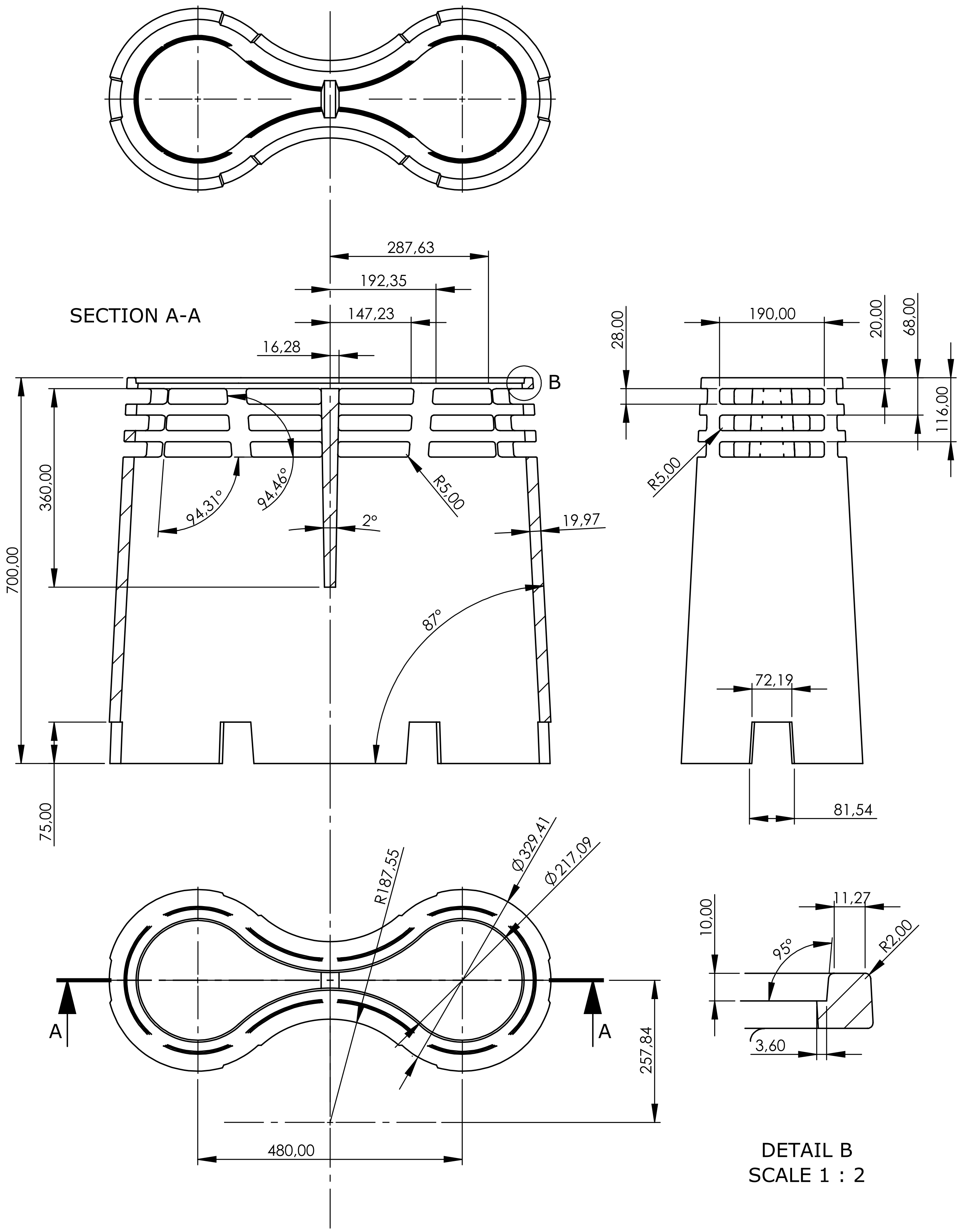
Designation: Subassembly 9: Windcatcher

Project: Design of a modular system for the implementation of green roofs and passive ventilation on a building cover

Number 12 of 14

Replaces

Replaced by



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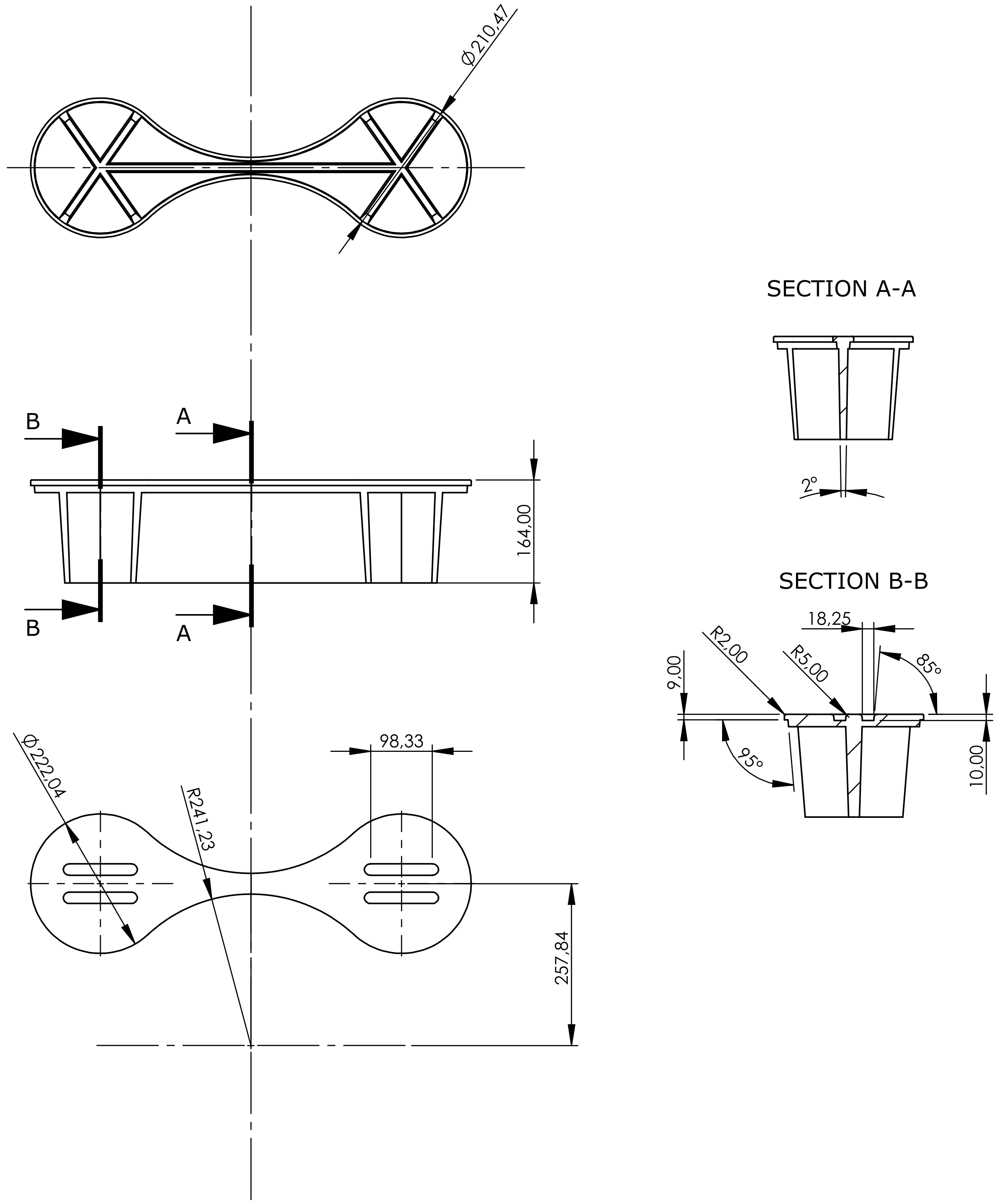
Drawn	10/05/2024	Antón SR		Escuela Técnica Superior de Ingeniería del Diseño
Verified				THE HAGUE UNIVERSITY OF APPLIED SCIENCES

Scale	Designation	Piece 9.1: Windcatcher body	Number 13 of 14
1:10	Project	Design of a modular system for the implementation of green roofs and passive ventilation on a building cover	Replaces
			Replaced by



	Date	Name	Signatures		
Drawn	10/05/2024	Antón SR		Escuela Técnica Superior de Ingeniería del Diseño	THE HAGUE
Verified					
Scale 1:10	Designation	Piece 9.2: Windcatcher insert		Number	14 of 14
	Project	Design of a modular system for the implementation of green roofs and passive ventilation on a building cover		Replaces	
				Replaced by	

BUDGET

1. Basin

BASIN

MATERIAL COST

RAW MATERIAL

Zinc is 2582,5663 €/T, so that is the price of a coil. One coil is 35m and 1,5 m are needed for each basin. That makes it that a coil can produce 23,333 (the decimals are taken into account because the spare is scrap material) basins, making the cost per basin 110,68€

Subtotal 1 110,68 €

OUTSORCED PRODUCTS

A personalized deep drawing mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 250 Tn with a cost of approximately 30000€. With a service life of 50000 pieces, its cost per piece is 0,60€.

Subtotal 2 0,60 €

PARCIAL TOTAL 1 111,28 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Punching and blanking

Duration of the operation	10	s
Second class operator rate per hour	15,27	€/h
Cost per operation	0,042	€

- Deep drawing

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

Subtotal 1 1,31 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 1,31 €

MANUFATURING COST = 111,28+1,31 = 112,59€

2. Low Planter

LOW PLANTER
MATERIAL COST RAW MATERIAL Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 12554,31 cm^3 and a density of 1,97 g/cm^3, the mass of material is 24,74 kg. **Subtotal 1** 51,04 € OUTSORCED PRODUCTS A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€. **Subtotal 2** 0,10 € ______________________________ **PARCIAL TOTAL 1** 51,14 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 51,14+10,85 = 61.89€

3. Medium Planter

MEDIUM PLANTER

MATERIAL COST

RAW MATERIAL

Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 19207,66 cm^3 and a density of 1,97 g/cm^3, the mass of material is 37,84 kg.

Subtotal 1 78,22 €

OUTSORCED PRODUCTS

A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€.

Subtotal 2 0,10 €

PARCIAL TOTAL 1 78,32 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 78,32+10,85 = 97,07€

4. High Planter

HIGH PLANTER

MATERIAL COST

RAW MATERIAL

Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 24230,50 cm^3 and a density of 1,97 g/cm^3, the mass of material is 47,73 kg.

Subtotal 1 98,67 €

OUTSORCED PRODUCTS

A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€.

Subtotal 2 0,10 €

PARCIAL TOTAL 1 98,77 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 98,77+1,31 = 109,52€

5. Individual Planter

INDIVIDUAL PLANTER

MATERIAL COST

RAW MATERIAL

Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 5700,84 cm^3 and a density of 1,97 g/cm^3, the mass of material is 11,23 kg.

Subtotal 1 23,21 €

OUTSORCED PRODUCTS

A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€.

Subtotal 2 0,10 €

PARCIAL TOTAL 1 23,31 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 23,31+10,85= 34,06€

6. Inter Planter

INTER PLANTER

MATERIAL COST

RAW MATERIAL

Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 3147,62 cm^3 and a density of 1,97 g/cm^3, the mass of material is 6,20 kg.

Subtotal 1 12,82 €

OUTSORCED PRODUCTS

A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€.

Subtotal 2 0,10 €

PARCIAL TOTAL 1 12,92 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 20,85 €

MANUFATURING COST =12,92+10,85 = 23,77€

7. Support

SUPPORT
MATERIAL COST RAW MATERIAL Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 2683,03 cm^3 and a density of 1,97 g/cm^3, the mass of material is 5,29 kg. **Subtotal 1** 10,94 € OUTSORCED PRODUCTS A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€. **Subtotal 2** 0,10 € **PARCIAL TOTAL 1** 11,04 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 10,94+10,85 = 21,79€

8. Bird nest

8.1. Body

BIRDNEST BODY
MATERIAL COST RAW MATERIAL Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 16720,35 cm^3 and a density of 1,97 g/cm^3, the mass of material is 32,94 kg. **Subtotal 1** 68,09 € OUTSORCED PRODUCTS A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€. **Subtotal 2** 0,10 € **PARCIAL TOTAL 1** 68,19 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 68,19+10,85 = 79,04€

8.2. Lid

BIRDNEST LID
MATERIAL COST
RAW MATERIAL
Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 701,33 cm^3 and a density of 1,97 g/cm^3, the mass of material is 0,70 kg.
Subtotal 1 1,45 €
OUTSORCED PRODUCTS
A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€.
Subtotal 2 0,10 €
PARCIAL TOTAL 1 1,55 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 1,55+10,85 = 12,40€

9. Windcatcher

9.1. Body

WINDCATCHER BODY
MATERIAL COST RAW MATERIAL Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 23985,28 cm^3 and a density of 1,97 g/cm^3, the mass of material is 24,06 kg. **Subtotal 1** 49,74 € OUTSORCED PRODUCTS A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€. **Subtotal 2** 0,10 € **PARCIAL TOTAL 1** 49,84 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 1,31 €

MANUFATURING COST = 49,84+10,85 = 60,69€

9.2. Insert

WINDCATCHER INSERT

MATERIAL COST

RAW MATERIAL

Scarva Pottery Suppliers supplies with the fireclay used to make this part in bags of 25kg each at 51,68€. It is dry, so the amount of weight per piece is approximately the same as the weight of the final piece. With a volume of 3854,27 cm^3 and a density of 1,97 g/cm^3, the mass of material is 7,59 kg.

Subtotal 1 15,69 €

OUTSORCED PRODUCTS

A personalized mold is needed. It is estimated that because of the complexity of the piece the mold will need to stand up to 50 Tn with a cost of approximately 5000€. With a service life of 50000 pieces, its cost per piece is 0,10€.

Subtotal 2 0,10 €

PARCIAL TOTAL 1 15,79 €

LABOR COST

DIRECT LABOR

The breakdown includes, for each step of the manufacturing process, the type of operator who will perform the task, the hourly rate associated with that operator, and the duration of the task. The data has been extracted from the bibliographic research conducted.

- Rehumectation

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Press molding

Duration of the operation	10	min
First class operator rate per hour	16,95	€/h
Cost per operation	2,83	€

- Drying

Duration of the operation	5	min
Second class operator rate per hour	15,27	€/h
Cost per operation	1,27	€

- Firing

Duration of the operation	30	min
First class operator rate per hour	16,95	€/h
Cost per operation	8,48	€

Subtotal 1 10,85 €

OUTSORCED OPERATIONS

Subtotal 2 0€

PARCIAL TOTAL 2 10,85 €

MANUFATURING COST = 15,79+10,85 = 2,64€

10. Assembly

ASSEMBLY
MATERIAL COST
RAW MATERIAL
Subtotal 1 0€
OUTSORCED PRODUCTS
Subtotal 2 0€
PARCIAL TOTAL 1 0€
LABOR COST
DIRECT LABOR
Subtotal 1 0€
OUTSORCED OPERATIONS
Subtotal 2 0€
PARCIAL TOTAL 2 2,55€

MANUFACTURING COST= 0+0 = 0 €

11. Total price per unit

This is an estimate of an average basin, selecting at least one of each module.

Name	Units	Material costs (€)	Labor costs (€)	Final costs (€)
Basin	1	111,28	1,31	112,59
Low planter	1	51,14	10,85	61,99
Medium planter	1	78,32	10,85	89,17
High planter	1	98,77	10,85	109,62
Individual planter	2	46,42	21,70	68,12
Inter planter	9	116,28	97,65	213,93
Support	4	44,16	43,40	87,56
Bird nest body	1	68,19	10,85	79,04
Bird nest lid	2	3,10	21,70	24,80
Windcatcher body	1	49,84	10,85	60,69
Windcatcher insert	1	15,79	10,85	26,64
Assembly	-	0,00	0,00	0,00
TOTAL		683,29	250,86	934,15

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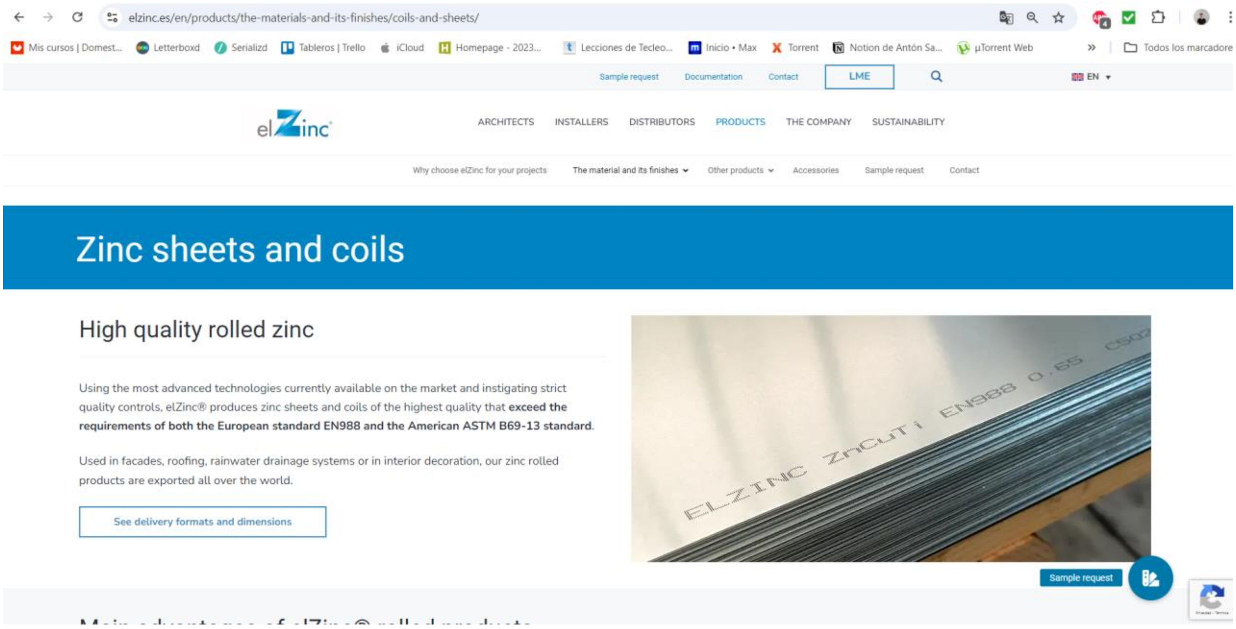
APPENDIXES

1. Documentation

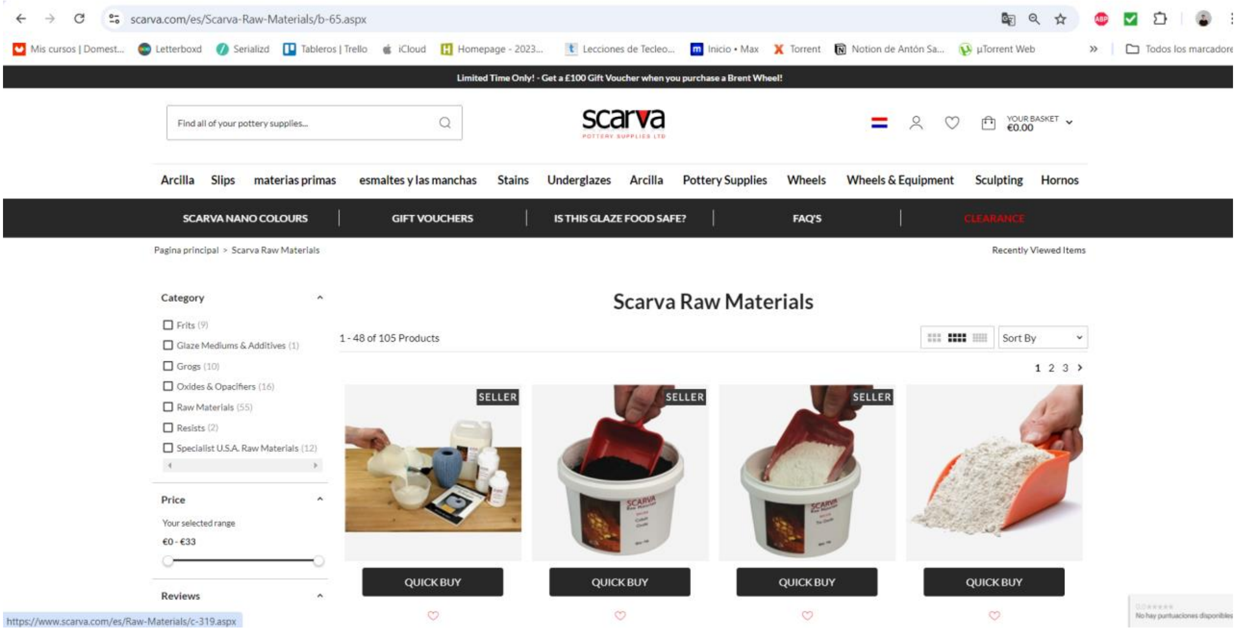
Provider of Zinc: elZinc

https://elzinc.es/en/the-company/rdi/elzinc-a-quality-brand/



Provider of terracotta: Scarva Pottery Supplies

https://www.scarva.com/es/Scarva-Raw-Materials-Fireclay-RM1078/m-9157.aspx



2. Client Interview

2.1. Introduction

The following document is about the first interview we did with our client Jacco, we used the interview/conversation to get more insight on what the goal of the project is, what boundaries we need to work around and what resources we are allowed to use. At the end you can read about an overall conclusion on the interview.

2.2. Interview questions and answers

Does it need to be a whole new system or a product or structure?

Product could add or change spatial development plan/advice that would be needed for the product.

Different ideas, lots of research, lots of inspiration for Jacco's thesis.

What are the limits of changing parts of the existing building?

just additions to the buildings, surrounding would be possible to make some changes.(possibly replace small products)

Are we supposed to come up with one detailed or less detailed solutions?

It has to be manufacturable, but not in all the way in detail, one solution, I think.

Can it be a solution that needs extended inputs from building or the public network?

Rather not, but again depends on the product. If it needs something like water, find a way to collect that.

Can it be a specific solution for this building, or does it have to be a solution that can be used on other buildings as well?

For other areas as well

In what way would you like the solution to be sustainable?

Circular economy would be ideal, not mandatory but ideal. The preference for sustainability comes from Laura.

Does it have to be a detailed solution that would be directly manufacturable or more like a concept?

Concept is alright, as long as it can be validated.

Can it be just a material solution, for example a change of materials that are being used in a façade?

A product, something that adds to the building, in the case of the environment we could replace stuff.

How much temperature decrease do you expect for the solution to be?

Not any specific amount, just decrease.

To what extent does our solution need to be innovative? In example would adding trees or other plants be a solution as well?

Investigate innovations from technical sources and apply them, not existing solutions.

What will our project solution be used for?

Jacco's thesis, our product will help him give ideas for his thesis.

What is exactly the case of study, the Oval or the whole campus?

The whole campus

Is there a way to contact you outside class through WhatsApp or something else?

In real life you can't reach clients all the time so also not this time.

Is there a budget for the solution?

Not really, look at current solutions ratio of how much it helps to the costs.

Does the solution necessarily need to be based on organisms?

Si

What did you tell the other groups?

Adaptive - Building - Skin

Keep it on the biological side before you think about the technical possibilities.

2.3. Conclusion

The project solution would preferably be a product that's going to be an addition to the building. It can also be a product for the surrounding area or a small change in spatial development. We are allowed to make small changes but no rigorous changes to the building. The solution should be applicable to the campus at first, but it should also be applicable to other buildings with minor changes. The level of elaboration should be a manufacturable concept. There is no budget for the solution, but it has to be reasonably priced for the amount of heat reduction it creates.

3. Desk Research: Current Urban Heat Situation

3.1. Related Research Questions

What does the current heat situation look like?

Which elements of the city/buildings are contributing to urban heat?

What are the ones that have more impact?

3.2. General context

Definition

Urban Heat Island (UHI) refers to the phenomenon of cities having higher temperatures than the surrounding rural areas. This is because:

> Structures such as buildings, roads, and other infrastructure absorb and re-emit the sun's heat more than natural landscapes such as forests and water bodies. Urban areas, where these structures are highly concentrated and greenery is limited, become "islands" of higher temperatures relative to outlying areas. These pockets of heat are referred to as "heat islands." (U.S. Environmental Protection Agency, n.d.)

Basically, urban environments tend to absorb a higher amount of radiation than rural ones, and have a harder time dissipating the accumulated heat.

> Trees, vegetation, and water bodies tend to cool the air by providing shade, transpiring water from plant leaves, and evaporating surface water, respectively. Hard, dry surfaces in urban areas – such as roofs, sidewalks, roads, buildings, and parking lots – provide less shade and moisture than natural landscapes and therefore contribute to higher temperatures. (U.S. Environmental Protection Agency, n.d.)

It is also important to note that this effect is more drastic at night, when the city materials start to release all the heat accumulated during the day, making it more difficult to cool the air.

Causes

The main determinants of UHI intensity are, according to van Hove, et al. (2011) are:

- **City size**

Being the bigger cities the ones with major intensities of UHI.

- **Urban design and structure**
  - **Urban green**
    Vegetation gives shade and converts solar energy into latent heat energy by evapotranspiration (which means that it needs a water source to sustain this effect). Parks in cities also have a night cooling effect to the proximal areas.
  - **Urban surface water**
    Having bodies of water, a cooling effect on surrounding areas, caused by evaporation, heat absorption and possibly the fact that it provides a free wind path.
  - **Urban geometry**
    Referring to the dimensions and spacing of buildings in the city, with those affecting wind flow, energy absorption and a given surface's ability to emit long-wave radiation back to space (With the sky view factor (SVF) measuring this. It refers to the proportion of the sky that is seen from a certain element of the city). Cities with many narrow streets and tall buildings become urban canyons, which can block natural wind flow that would bring cooling effects and also impede the release of heat to the atmosphere.

  - **Properties of urban materials** (radiative and thermal)
    This refers to how in general urban materials have a lower albedo than materials in rural areas, higher heat capacities and most of them are impermeable for moisture.
- **Anthropogenic heat**
  Referring to all the heat generated by human activities.

Characteristics

The Heat Island Effect is not the same in all parts of a city. Because of the reasons explained before, there will be variations among the city itself.

The U.S. Environmental Protection Agency (n.d.) also defines two types of Heat Islands, based on the ways they are formed, their impacts and the methods available to cool them:

- **Surface Heat Islands**
  Referring to the Urban Surface absorbing and emitting heat.
- **Atmospheric Heat Islands**
  Referring to the temperature of the air above urban areas.

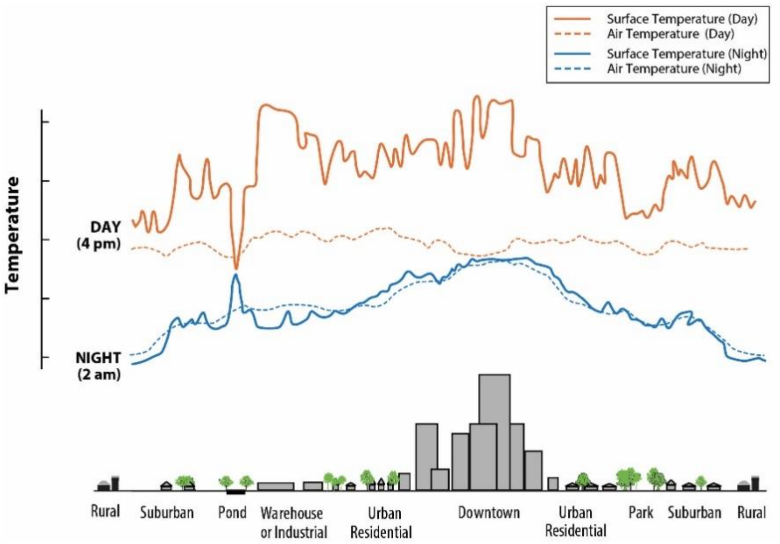


Figure 27. Heat Island Effect Diagram (U.S. Environmental Protection Agency, n.d.)

Consequences

Among the consequences of Urban Heat Haider Taha (2004) mentions:

- Creation of a wind pattern or circulation, which is typically a convective cell located in the UHI vicinity.
- Increased cloudiness and rainfall.
- Increased ambient temperatures.
- Increased mixing of pollutants in the boundary layer.
- Increased temperature-dependent emissions of air pollutants.
- Photochemical production of smog generally positively correlated with temperature.
- Affecting energy usage.

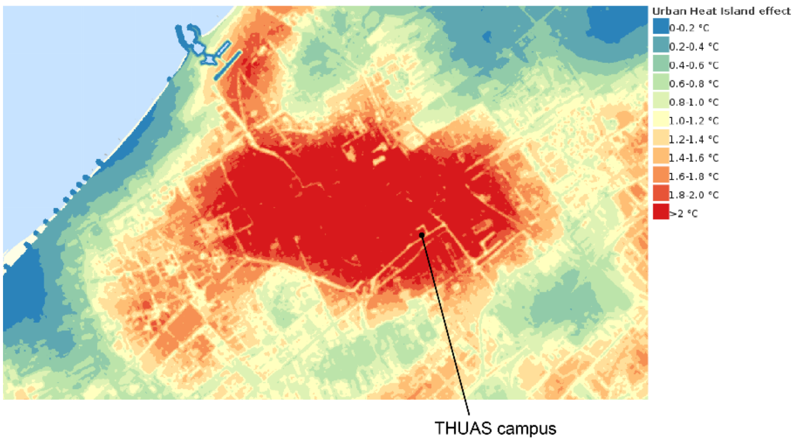
While all of them are worrying, one of the most noticeable ones is the increased ambient temperature, having the heat waves in 2003 and 2006 in the Netherlands caused an excess mortality between 1400 and 2200 (van Hove, et al., 2011). This affects especially the elders.

3.3. Specific context

For the context of this project, we are working on the THUAS campus as the subject of our study, so this section is dedicated to analyzing the specific situation of urban heat in relation to the THUAS campus and the Hague.

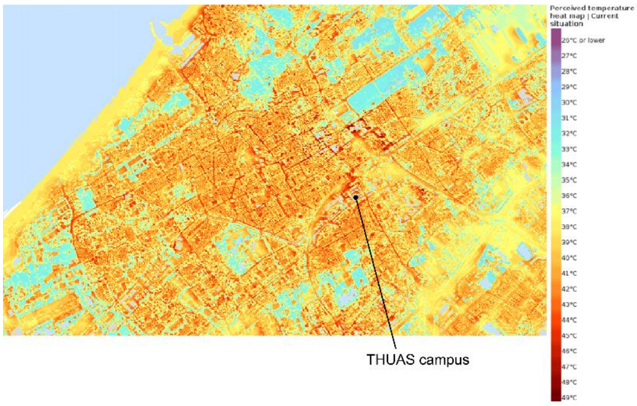
Figure 28. Case of study (Neerland in 3D, n.d.)

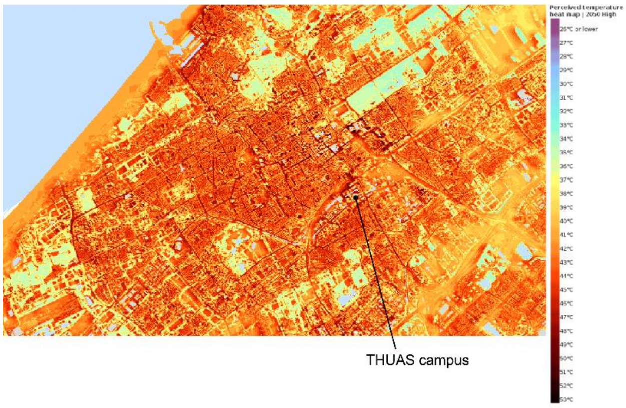
The following map has been generated thanks to Klimaateffectmap, showing the medium temperature in The Hague urban area, in comparison with the surrounding rural areas. This is a typical measure to show the effect of UHI. It shows that because of UHI the temperature in our area of study is at least 2ºC higher.



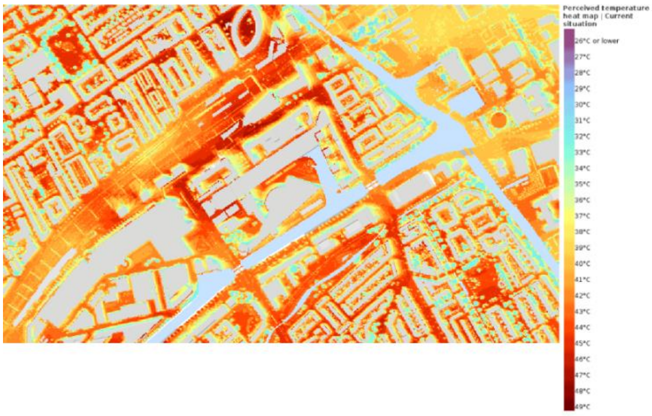
Next, we have the perceived temperature in the city, presenting the average perceived temperature in ºC for the period of 12:00-18:00 local time on a hot summer day. This temperature is also referred to as the Physiological Equivalent Temperature or PET. The results are based on weather measurements dating from 1 July 2015, i.e., a hot day occurring approximately once every 5.5 years in the current climate.

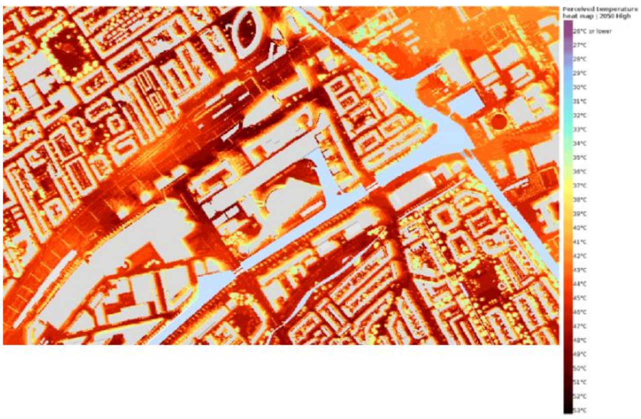
The next map shows the estimated situation for the year 2050 is nothing is done to try and slow climate change.





Next is a close-up of the THUAS campus, with the same two images.



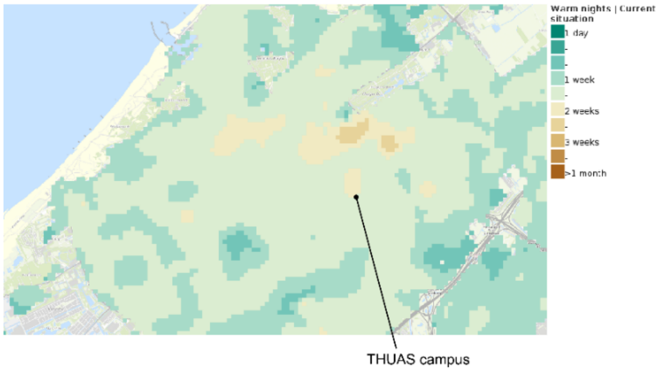


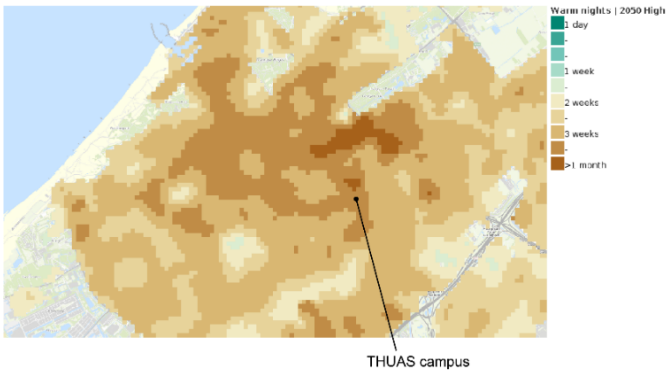
According to (Klinaateffectatlas, n.d.) comfortable PET should be below 23ºC. As we see in the images, the campus would be subjected between moderate and great heat stress in the current situation, and a very worrying situation in 2050, being the most worrying location the square in front of the main building.

Perceived temperature (in °C)	Perception	Physiological stress level
18-23	Comfortable	No stress
23 – 29	A little warm	Slight heat stress
29 – 35	Warm	Moderate heat stress
35-41	Hot	Great heat stress
>41	Very hot	Extreme heat stress

Figure 29. Comfort and Perceived Temperature (Klinaateffectatlas, n.d.)

Next is a representation of the current and 2050 situation of the number of nights where the temperature doesn't go below 20ºC in any moment of the night (warm nights), with the consequent risks for the health of the affected areas.





Finally, a graph of the internal temperature of the building during a year is shown, specifically the Strip, where the temperature sensors are located.

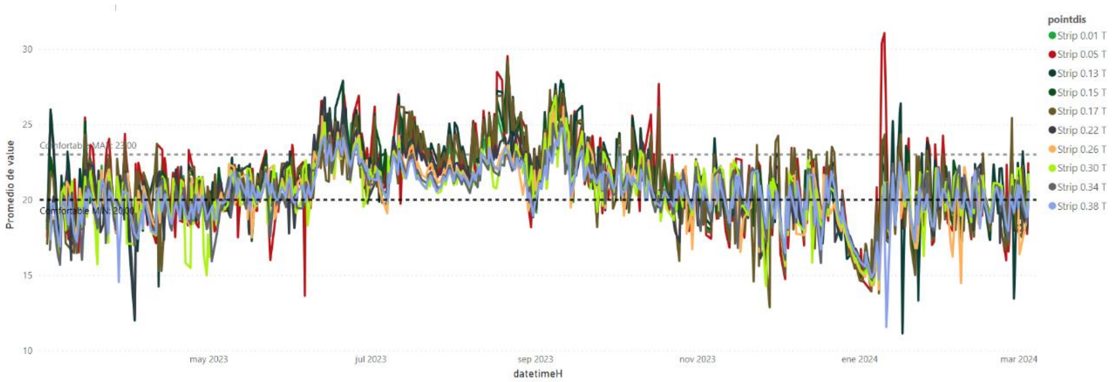


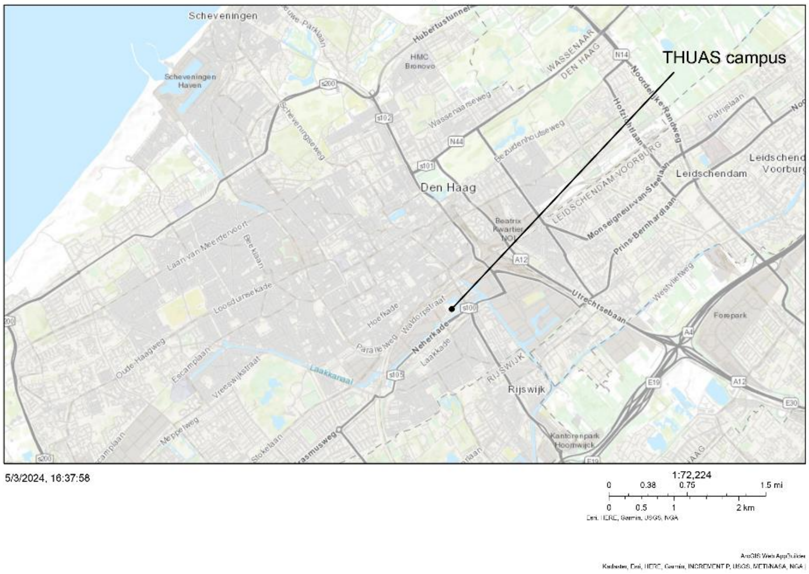
Figure 30. Building temperature during a year (Facility Management Living lab, n.d.)

Causes of Urban Heat in The Hague

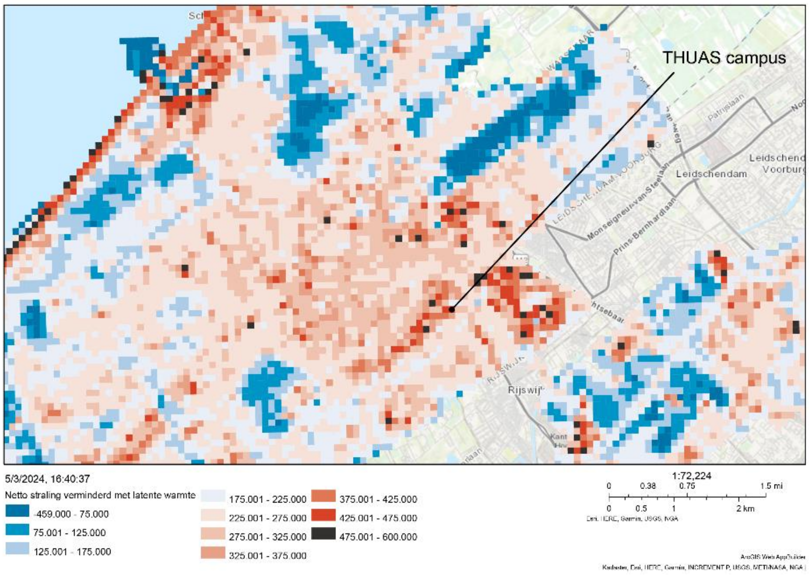
In the next section, thanks to the tool *Hittekaart Den Haag 2017*, maps analyzing the different factors that influence UHI effect in The Hague are shown. They have no units, that's why it was chosen to show the whole city, as a means to have a comparative analysis between areas.

Extracted maps

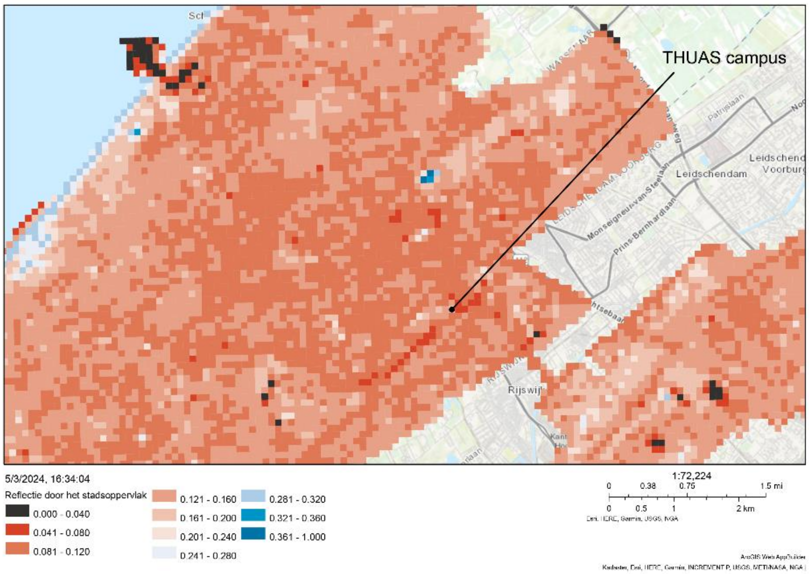
Base map



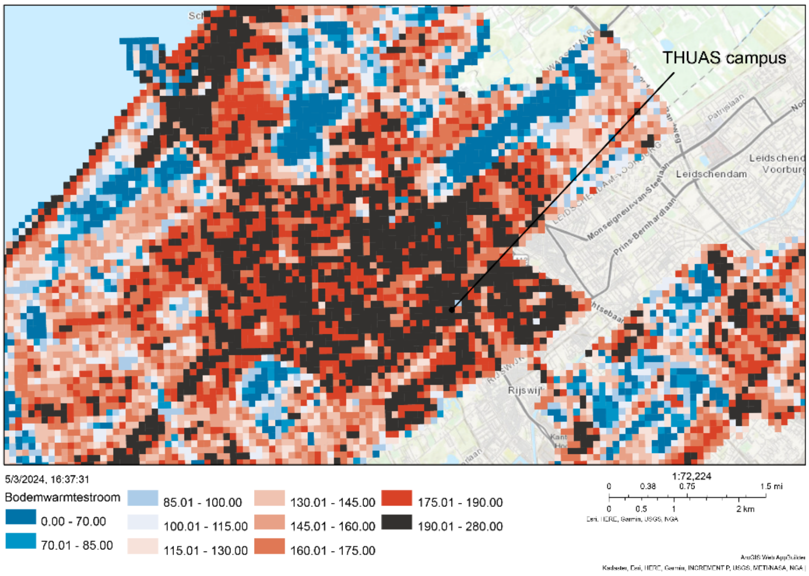
Net radiation less latent heat



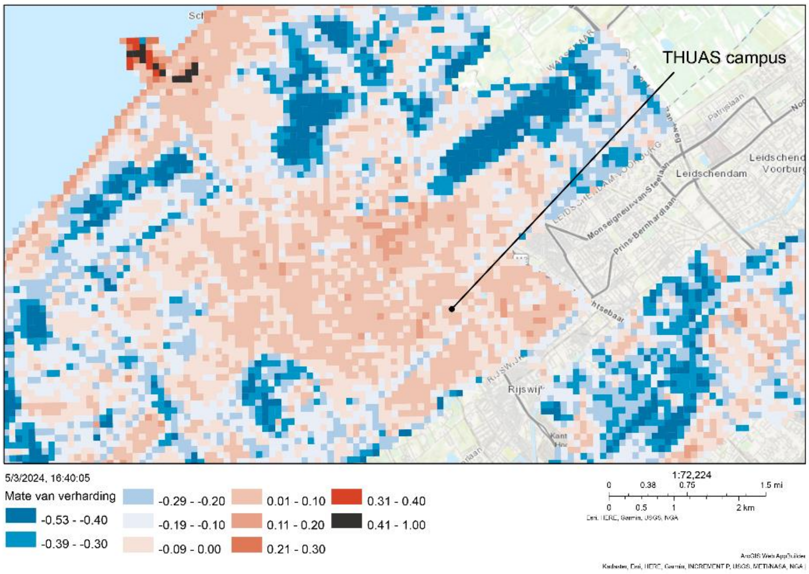
Reflection



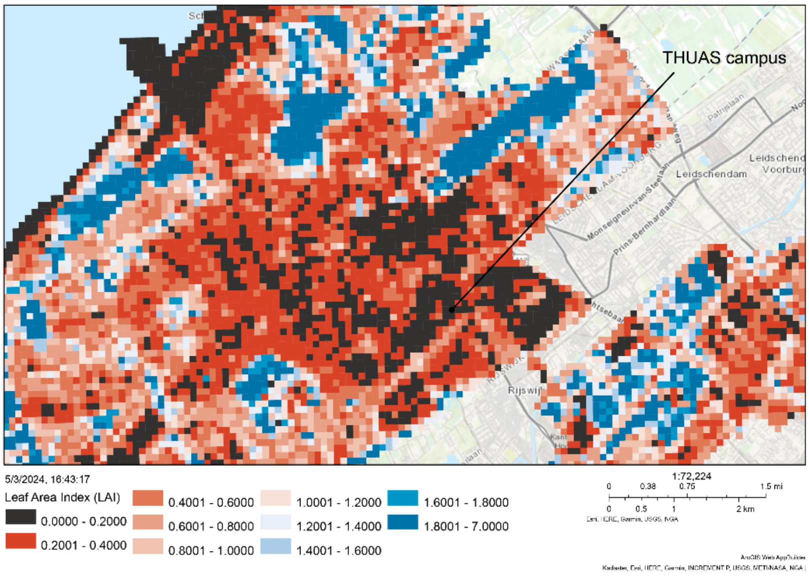
Ground heat flow



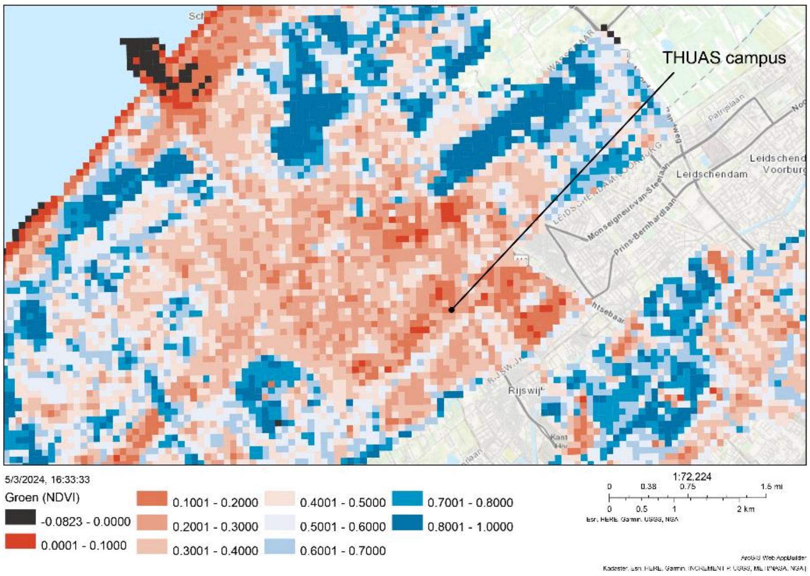
Hardening



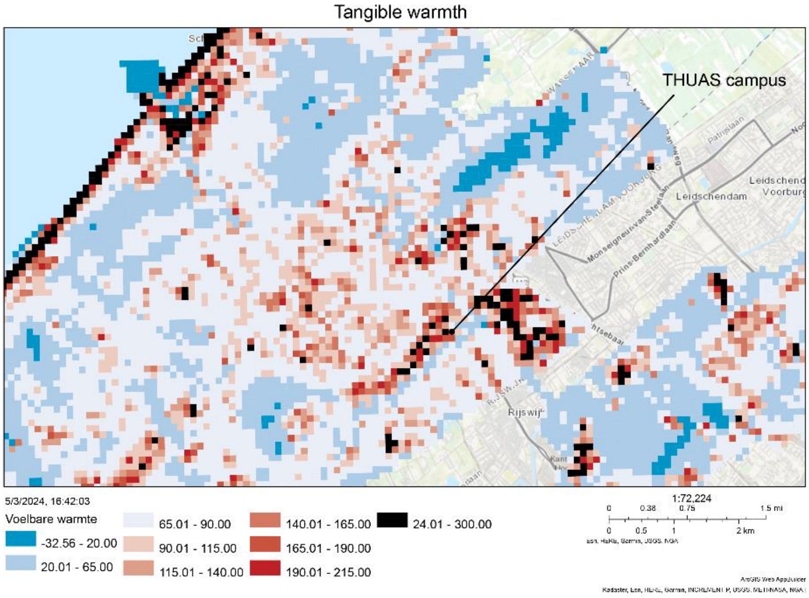
Leaf area



Greenery



Tangible warmth



Used Concepts

The explanation of the different concepts used (Opendata Portaal geoinformatie Den Haag, n.d.) is the following:

Net radiation

The net radiation that the Earth's surface receives from the sun. The radiation that the earth's surface reflects is not part of this, nor is the heat that the earth's surface radiates.

Latent heat

Latent heat is the energy used in the evaporation of water. Green and surface water are the important 'users' of latent heat. Latent energy means cooling the environment.

Tangible warmth

Sensible heat is the convection heat used to heat air. This heating mainly takes place above surfaces with a high temperature. (Small) turbulences play an important role in the conversion of surface temperature to air temperature: so-called eddies.

Ground heat flow

Ground heat flow is the heat absorbed by the soil, by buildings, and by surface water. The stored heat is released again at night and influences the nocturnal heat island.

Net radiation less latent heat

Latent heat does not contribute to warming of the urban environment. Reducing the net radiation with latent heat therefore provides a better picture of the energy that causes heat problems.

Degree of hardening

Normalized Difference Built Index (NDBI) reflects paving (or perhaps more accurately: the lack of greenery). Paving contributes significantly to urban heat. Paving seals the soil, prevents water from evaporating and prevents the growth of vegetation. Paving thus prevents solar radiation from being converted into latent energy. Paving also has the ability to store heat during the day. This stored heat is released again at night. Dune sand and reclaimed construction sites also appear as 'hardened' in such analyses.

Reflection by the city surface

Albedo is an indicator that expresses the extent to which buildings, streets and the ground reflect solar radiation. In general, a high albedo value causes buildings and cities to heat up less.

Green (NDVI)

Normalized Difference Vegetation Index (NDVI). Vegetation evaporates water through transpiration, using latent energy (Q_e). Vegetation thus reduces the urban heat island.

Leaf Area Index (LAI)

Leaf Area Index (LAI) indicates the extent to which an area is covered by foliage. Vegetation evaporates water through transpiration, using latent energy (Q_e). Vegetation thus reduces the urban heat island.

Shade (mid-July)

Shade is an effective remedy against heat development. Shade prevents the city or earth's surface from being exposed to solar radiation (Q^*), the main source of urban heat. Shown is the shading in mid-July. Shading caused by vegetation is included in the analysis.

Sky view factor

The sky view factor is an indicator that shows the extent to which the city or earth surface is exposed to the sky. While shade affects heat during the day, the sky view factor mainly does so at night.

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4. Sun Desk Research

4.1. Introduction

To find a solution for urban heat, there are many categories to look into. As a team, we split them up in three: shade (protection from sun and heat), ventilation and evaporation and the category water. In the next part of the research, you will find the part of the research made by the author of this report.

4.2. Organisms

Of the 68 organisms selected in the *bio brainstorm*, 15 have developed strategies that protect them from light, either from the heat that it causes or from the harmful effects of radiation.

- Cactus family
- Desert Snail
- Hippopotamus
- Mescal cactus
- Tree bark
- Saharan Silver Ants
- Staghorn fern
- Armored Stink Beetle
- *Vibrio harveyi*
- Alpine Edelweiss
- Quiver tree
- Giant sequoia
- Radio trophic funghi
- Desert marigold
- Land snail

4.3. Strategies and mechanisms

In these organisms we find different strategies to protect themselves from light. Having analyzed every organism individually, the different strategies that they use could be grouped as it follows:

- Shading by parts of the day, creating currents by the different temperatures (Cacti family, Tree bark)

This is a strategy that some plants have, where they project irregular shadows over themselves along the day, creating a temperature difference on their surface that promotes the creation of air currents.

- Shrinking underground in the heat (Mescal cactus)

This is the specific strategy of the mescal cactus, that dries up when its hot so that it hides underground, avoiding the light that hits the surface.

- Transforming UV energy in other kinds of energy (*Vibrio harveyi*, Radio trophic funghi)

These organisms have developed metabolic routes capable of transforming UV radiation into another form of energy: bioluminescence or growth.

- Reflecting UV light by color coating (Desert Snail, Quiver tree, Land Snail, Alpine Edelweiss)

This strategy refers to those organisms that have developed some kind of external layer, generally white, that reflects the light based on its chromatic characteristics.

- Reflecting UV light by structural coating (Hippopotamus, Armored Stink Beetle, Tree bark – cellulose and tannins)

This strategy refers more to those organisms that also have developed some kind of external layer, but that instead on their color, trust on the structural properties of this coating to reflect the light.

- Reflecting the UV light by hairs (Saharan Silver Ants, Desert marigold)

This strategy is similar to the previous one, but instead of being a coating that covers the entire surface below, it's hair that thanks to its structural properties reflects the light.

- Trapping UV light in hairs until it dissipates (Alpine Edelweiss)

This is a strategy specific to the Alpine Edelweiss, that also reflects the light by color, but has these hairs made of fibers with a diameter close to the UV length, allowing it to trap the UV rays inside the fiber until the energy dissipates.

- Structure that shades the surface below, creating a layer of cooler air (Desert snail, staghorn fern, Giant Sequoia)

This strategy refers to those organisms that by any kind of structure create a shade on a surface, thus creating a cooler layer (or multiple layers) of air between that surface and the cause of the shadow.

4.4. Biological and abstracted design principles

The design principles that could be used in this category are the following:

BDP's:

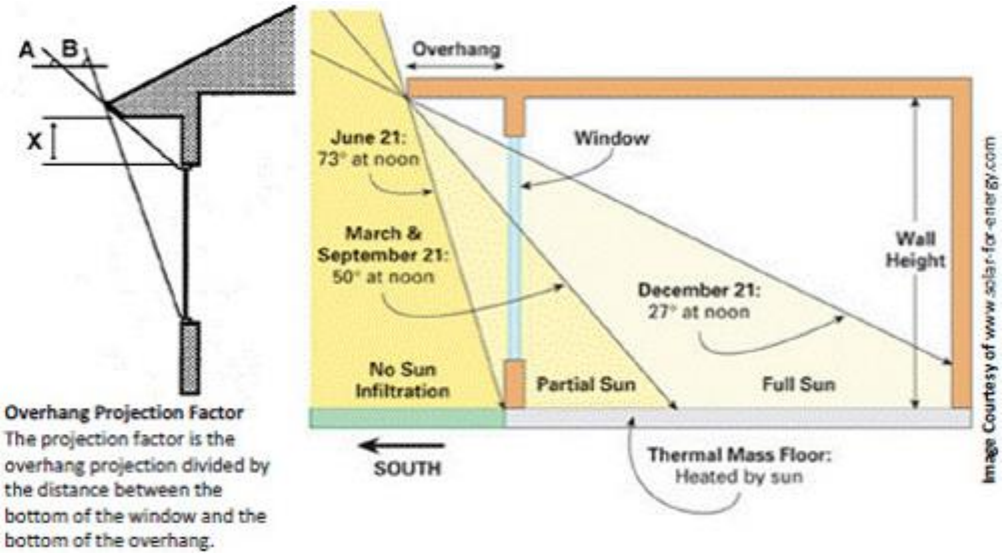
1. Saharan Silver ants employ specialized hairs to combat extreme heat. These prism-shaped hairs reflect a significant portion of incident light and aid in heat dissipation, crucial for survival in temperatures exceeding 70°C. Positioned atop stones or dry vegetation during foraging, the ants experience substantially cooler rest spots. Their hair structure facilitates light reflection through stacking, enhancing reflectivity, especially beyond 30° angles. However, beyond 90°, reflectivity decreases, impacting total internal reflection. Additionally, in the mid-infrared range, the hairs' reduced reflectivity enhances emissivity, enabling efficient heat dissipation through radiative heat transfer. This adaptation allows the ants to manage body temperatures that peak at around 50°C during foraging, ensuring survival in the scorching desert environment.
2. To create striking colors and catch the attention of females, the male Indian peacock have developed feathers with a special structure that reflects the light of specific wavelengths.
   The feathers are composed by barbs that are at the same time composed by tiny structures called barbules. This barbules have a structure of a 2D quasi-square and several layers lattice of melanin in a matrix of keratin, and airholes in the middle of each square lattice.
   This structure acts as photonic crystals. That means that light scattered from each particle interferes in some directions with each other and radiates secondary emission in others, being that directions a function of the wavelength and the distance between layers. That means that some wavelengths are "trapped", and others are reflected.
3. To protect its living cells from the harmful effects of the UV radiation, the Alpine Edelweiss have developed a protective layer of filaments over its sun-facing surface.
   These filaments are transparent, but have a special structure composed of a series of fibers close in size to the wavelength range of UV radiation. Thanks to this size-closedness it is able to reflect incising, specific frequencies of UV rays and channel them along the spaces in between the fibers, also charging them with the energy of the rays close in frequency, and dissipating all of it by circulating it in between the fibers.
   This way the UV rays don't reach the living cells of the plant, whereas the rest of the visible range of frequencies does.

ADP's:

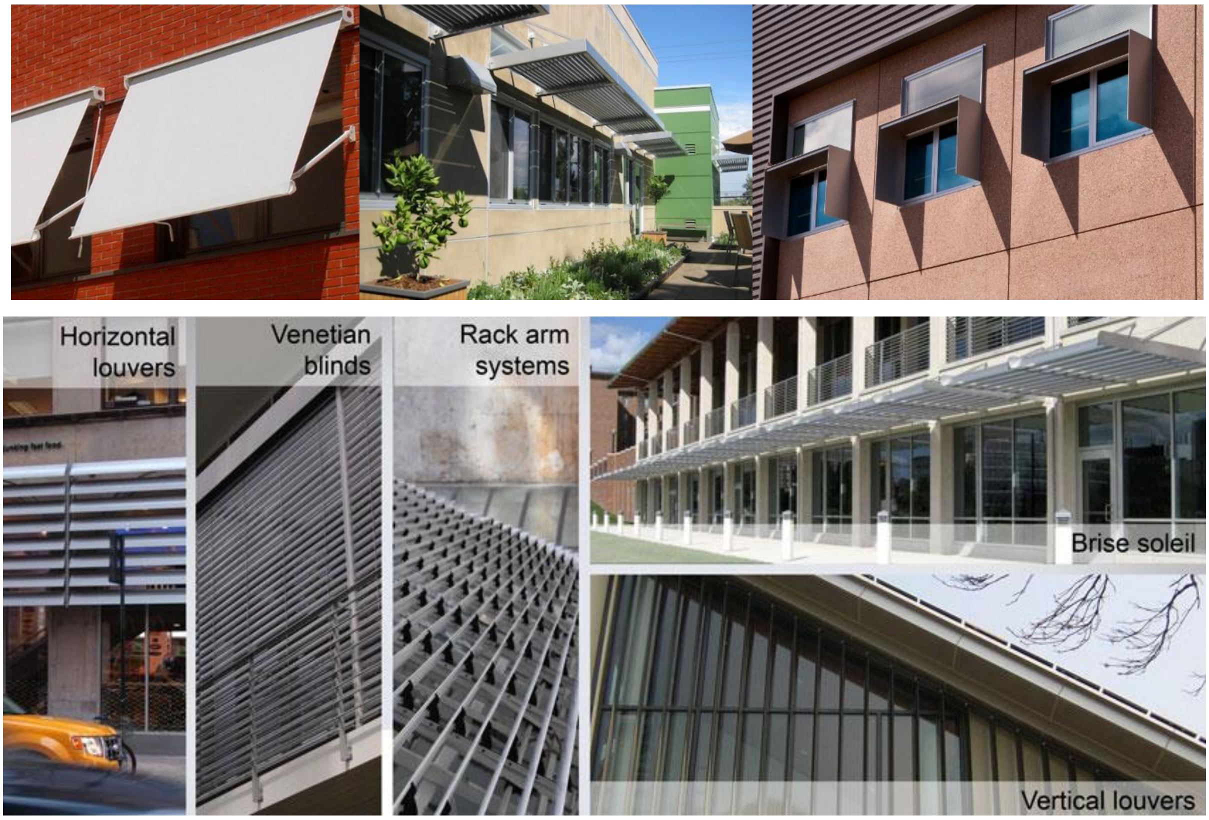
1. Visible and near infrared light gets reflected inside prism shaped strands, this way the surface underneath the strands gets hit less by the wavelengths of visible and near infrared light. For these prisms to work optimally it is important that the light hits these prisms in a certain angle. The angle in which the light starts reflecting significantly starts at 30° and ends at 90°. In order to make sure the least amount of light hits the surface underneath the prism shaped strands are stacked on top of each other with an offset of half a strand width. This way the light that is able to pass through one strand, goes into the next strand and gets reflected.
   The prism shaped strands reflect less light in the mid-infrared range, around 8 μm. The surface underneath the prism shaped strands radiates light in the 6 to 16 μm range. This way the surface underneath the prism shaped strands is able to radiate heat back to the surrounding surface.
2. To obstruct specifically the UV part of the spectrum to pass through, use a transparent structure of a planar slab bearing a grating-like surface corrugation (with a protrusion width close to the UV range of frequencies) to reflect specific frequencies on light in between the protrusions, charge them with the energy of those rays close in frequency, and dissipate all of their energy by conducting then along the channel, while allowing other frequencies of light to pass through.
3. To reflect specific wavelengths of light, use a 2D square lattice with a distance between vertices on the order of the light wavelength, to "trap" certain wavelengths in the lattice and reflect others (change the distance between vertices to change reflected wavelength).

4.5. Building solutions

In this section we collect the different already existing solutions in relation to sun protection.

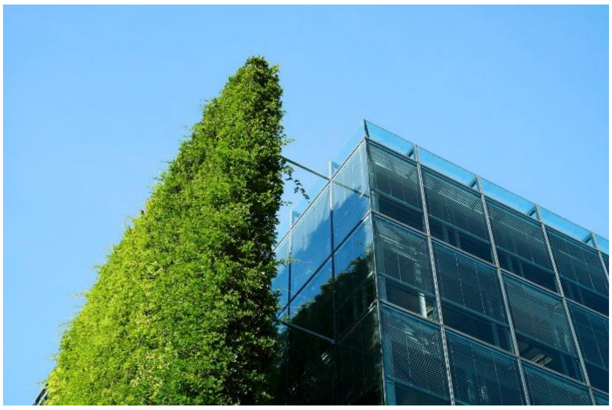


This image represents constructing towards the use of sun energy. In summer, when the sun is high, the overhang shades the window, impeding light to enter the building and heat the interior. In winter, when heating is desired and the sun is lower, the interior is warmed by enetring light.

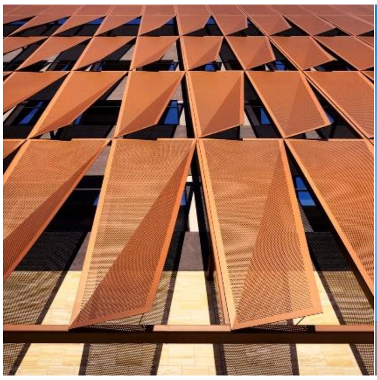


Different shading solutions for windows exist, being exterior solutions more suitable for cooling. Blinds (several types), awnings and overhangs are the most usual ones. Brise



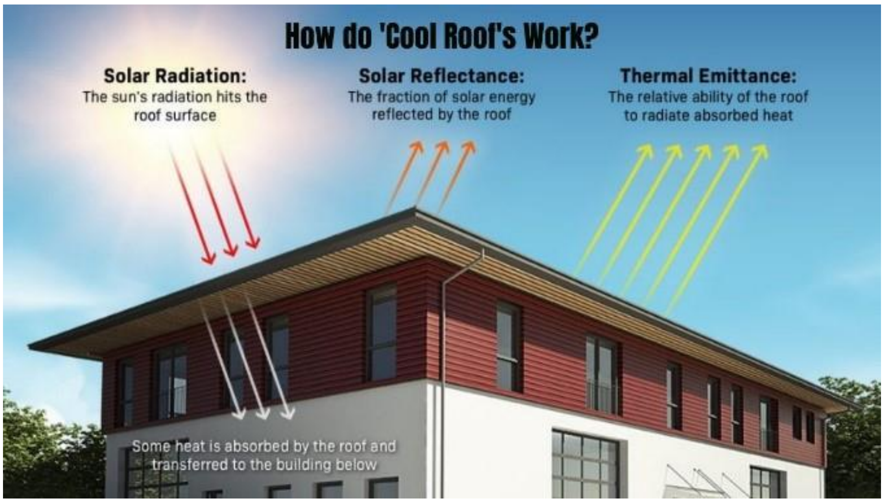


Jalousies crate and additional layer of temperature protection and insulation. Additionaly, those with wholes in them can add a cooling effect thanks to the Venturi effect. Redirection of energy or cooling with vegetation evapotranspiration are also options.




Other facade solutions that focus more on shading and less on the secondary layer.

The case of Al Bahar Towers, where they have an automatized facade element that closes only when light is hitting that part of the building.



This image represent the use of roofs with high albedo to avoid heating up, by reflecting the radiation back into the sky.

4.6. Urban solutions

Between urban solutions, trees and vegetation are the most effective solution to cool down streets, but due to their high maintenance costs, and water needs their use needs some complementary elements.

Green corridors in Medellin

The use of withe paint on streets or urbanism prevent cooling by reflecting ratiation back into the sky.


Concept – Sculptural rope canopy Arizona

Urban canopies and street coverings help protect the surface of the city: streets and squares from the sun. Some models with vegetation for a cooling effect already exist

Self made shading solutions in LA

Solutions made by the inhabitants of cities forced by the innaction of the city administration to make decent conditions of the streets.

Metropol Parasol

Queen's square Valencia

Pergolas and parasols of differents shapes, sizes and materials installed in public and exterior spaces help protect th inhabitants of cities from the sun.

Conclusion on current solutions in sun protection

Most of the current solutions have something to do with shade or reflection of light. Currently most solutions that are based on reflection use just mainly color. To reflect light they use lighter colors on buildings and pavement for example to make sure these don't absorb as much heat as darker colored objects, this is called albedo effect. For shade the solutions can be categorized in mainly three groups, natural provided shade, static product provided shade and dynamic product provided shade. For now the example that uses natural provided shade are mostly static excepted from plants blowing a bit in the wind. It would be interesting to look at product solutions that include natural shading but are also dynamic and can adapt to the current situation.

5. Bio brainstorm

Researcher	Function	Organism common name	Organism Scientific name	Strategy (how the organism meets the function)	Mechanism	Abstracted Design Principle	Quoted excerpt from literature
Example	Maintain homeostasis, protect from temperature	African Bush Elephant	*Loxodonta africana*	Random patches all over the elephant's skin act as a thermal window; higher concentration of blood vessels = more heat can escape	"By directing their blood supply near the surface of small patches of skin scattered around their bodies, elephants can lose heat rapidly, allowing them to fine-tune their internal temperature." (Gray 2010)	Direct fluids through channels in concentrated surface areas to regulate internal temperature to decrease towards the lower (external temperature) of that area	"First, we noticed independent thermal windows, highly vascularised skin areas, on the whole elephants' body and second we observed distinct and sharply delimited hot sections on the elephants' pinnae. The frequency of thermal windows increased with increasing ambient temperature and body weight." "By directing their blood supply near the surface of small patches of skin scattered around their bodies, elephants can lose heat rapidly, allowing them to fine-tune their internal temperature." (Gray 2010)
Example		Black-tailed prairie dog	*Cynomys ludovicianus*	Prairie dogs create one burrow opening at a higher point than another. Downwind, there is lower air velocity, so higher pressure. This creates a vacuum like effect, and air gets sucked in and through the mound, cooling the interior. This is basically the Bernoulli's Principle in action.	Prairie dog tunnels are built with alternating opening levels so that when air flows over the tops of these openings, it creates a suction airflow (Bernoulli)	Tunnels with alternating heights create a vacuum effect whch cools the interior.	"As air flows across a surface, a gradient in flow speed forms, where air moves slower the closer it is to the surface." "When a breeze crosses the mounds, air enters the burrow through the lower mound and leaves through the higher."
Example	Protect from temperature	Cactus Family	*Cactaceae*	The ribs of the cacti create a neighboring area of shade, which means slightly cooler air temperatures in that zone. Not only does the shade help the plant void evapotranspiration, but the shaded and non-shaded areas create little pockets of warmer and cooler air. This generates a convection current, like a mini breeze, which can further cool the cactus.	Ribs of a Cactus receive the heat from the sun on one side and the cool of the shade on the other side, reducing the internal temperature as a whole. The spines of a cactus create pockets of circulating air that rise with the heat and thus create a convectional airflow.	Radial alternating horizontal perpendicular fins allow cooler and warmer surface sections and generate a mini ventilation able to cool the main structure.	"The alternating planes of light and shade of the vertical cooling ribs of the torch thistle produce rising and falling air currents, which improve heat radiation." "Presumably as a result of the turbulence and airflow patterns created by the ribbing, hc [the heat convection coefficient], expressed on a unit surface area basis was 67% greater than for a smooth cylinder of the same outside diameter under the turbulence intensity appropriate to field conditions (12). Since the ribbed surface area for this barrel cactus was 54% greater than that of the circumscribing polygonal surface, the total convective loss per level would be just over 2.5-fold higher than for a smooth cylinder."
Example	Protect from light, loss of liquids, temperature	Desert Snail	*Sphincterochila boissieri*	The reflective, white shell reflects most light/heat away from the snail. In addition, the ground below it is slightly shaded from the snail itself. This in combination with the ground's ability to release heat more slowly keeps the snail cooler.			"The answer lies in its high reflectivity in combination with the slow conduction of heat from the substrate. .... In the total range of the solar spectrum, therefore, we can say that the snails reflect well over 90% of the incident radiant energy."
Example	Maintain homeostasis, protect from temperature	Gila monst	*Heloderma suspectum*	Cloacal evaporative cooling: a previously undescribed means of increasing evaporative water loss at higher temperatures in a desert ectotherm. Also use urinary bladder as a "water resevoir"			[The] steep rise in cloacal EWL coincided with an increasing suppression of body temperature relative to ambient temperature. Dehydration to 80% of initial body mass led to a delay in the onset and an attenuation of the dramatic increase in cloacal EWL. These results emphasize the potential value of EWL for thermoregulation in ectotherms and demonstrate for the first time the role of the cloaca in this process. Gila monsters reduce cloacal EWL rates when dehydrated by increasing the minimum temperature at which significant cloacal EWL occurs and by reducing evaporative flux at higher temperatures.
Example	Protect from light, protect from microbes	Hippopota	*Hippopotamus amphibius*	Secrete two acids from secretory ducts under the skin, as well as mucus. Both are liquid crystals, one banded with dark concentric rings scatters light to block the sun and acts as a sunscreen and absorbs UV light. The other reduces the viscosity so the mixture can spread more easily over the hippos surface. They start clear, turn red and orange, and settle into a brownish hue. The red and orange acids combine with mucus and spread over the hippo when it grazes at night, so it hardens and settles before the hippo goes back into the water during			"What they found were two unstable and highly acidic compounds -- one red, which they named hipposudoric acid, and one orange, which they named norhipposudoric acid. Although the two chemical pigments are unstable on their own, when they dry on the animal's skin in the presence of mucus, they harden and stick around for hours. Thus, the thick, sticky mixture is tough enough to survive the hippos' daylong soaks, all the while absorbing sunlight in both the ultraviolet and visible range [source: Saikawa]."

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Example	Protect from temperature	Jungle can	*N/A*	Multi layered canopy cools layers below. Tropical rainforests prosper with higher temperatures.			In other words, tropical forests cool local climate and help generate rainfall.
Example	Manage moisture, and modify position relative to sun/heat source	Mescal Ca	*Ariocarpus fissuratus*	Cactus swells up when it rains (and is thus cooler, and shrinks into the ground - almost entirely under the surface) in the heat.			"...converts the dehydration-induced shrinking during the beginning of the dry season to reduce the shoot length and submerge below the desert floor. After just one seasonal rainfall the hydrating shoot reemerges by pushing the photosynthesizing apex out of its soil cover into the light and open air."
Example	Maintain homeostasis, protect from temperature	Ochre Sea	*Piaster ochraceus*	Intakes colder-than-air sea water in body cavities during high tide and stores the water until low tide when exposed to high temperatures. (short term only)			"Here, we show that the intertidal sea star Pisaster ochraceus modulates its thermal inertia in response to prior thermal exposure. After exposure to high body temperature at low tide, sea stars increase the amount of colder-than-air fluid in their coelomic cavity when submerged during high tide, resulting in a lower body temperature during the subsequent low tide. Moreover, this buffering capacity is more effective when seawater is cold during the previous high tide. This ability to modify the volume of coelomic fluid provides sea stars with a novel thermoregulatory 'backup' when faced with prolonged exposure to elevated aerial temperatures."
Example	Distribute gases - manage airflow	Red Mang	*Rhizophora mangle*	Aerenchyma and corkwarts in leaves of mangrove provide Knudsen internal airflow through heated air pressurization to aerate anoxic roots.			"Leaves of Rhizophora species (Evans et al. 2005, 2008, 2009) absorb air from the atmosphere and transport this air to their roots. Specifically, external air moves into cork warts of leaves (Fig. 1). Once inside leaves, air becomes heated and moves from leaves to petioles and beyond, a process termed Knudsen flow (Dacey, 1981). This process has been described extensively by Hook et al. (1972), Dacey (1981, 1987), Armstrong et al. (1988, 1996), Mevi-Shutz and Grosse (1988), Grosse (1996), Grosse et al. (1996). This internal air moves within aerenchyma tissues of petioles, stems, and roots.
Example	Sense temperature cues from the environment; Physically assemble structure; Protect from temperature	South Ame	*Acromyrmex heyeri*	Colonies of South American grass-cutting ants maintain temperature and humidity via a thatched nest and systematic arrangement of nest material.			"The fact that workers closed nest openings during the desiccation phase, despite this high temperature, indicates they trade off a thermoregulatory response, i.e., the opening of apertures on the thatch at high temperatures, for maintenance of internal nest humidity… In the leaf cutting-ants genus Acromyrmex, the building of a thatched nest seems to have allowed some Acromyrmex species to extend their distribution range more in the southern temperate regions, compared with those inhabiting subterranean nests…Besides their occurrence in temperate regions, thatch-builder Acromyrmex species have also colonized some South American semi-arid and hot regions." (Bollazzi and Roces 2010b:10-11)
Example	Distribute energy, maintain homeostasis	Toco Touc	*Ramphastos toco*	Non-insulated bill acts as a thermal window. When hot, blood vessels dilate and heat can escape from blood. When cold, blood vessels constrict, conserving heat.			"The toco toucan has the remarkable capacity to regulate heat distribution by modifying blood flow, using the bill as a transient thermal radiator. "
Example	Protect from light, temperature	Tree bark	*Plantae Kingdom*	On a microscopic level, bark both absorbs and reflects radiation to maintain homeostasis thanks to a combination of cellulose and tannins. On a larger scale, trees with paper-like bark, air bubbles are trapped much like in feathers, providing insulation for the tree. Others have rough surfaces that can create shade, similar to how a cactus functions.			"Optimal reflection of incoming radiation is not the only condition for keeping surfaces cool. The second condition, optimal emission at a temperature that the object reaches (approximately 40 °C) has also been demonstrated here." Many tree barks show a paper-like structure with sheets peeling off, generating highly heat-insulating, trapped air spaces between them (e.g. birch, paper-bark tree). Other tree barks have developed a very rough surface that produces a lot of shadowed areas amongst the illuminated ones"

Example	Protect from temperature	Wasps	*Polistinae*	The wasps build an extra layer of outer empty combs to protect from both cold and heat			such a high ambient temperature can be prevented by outer layers of combs where no or few broods are present. In the previous study (Hozumi et al. 2005) that was conducted in the summer, the nest temperature at the brood combs were below 33°C even when ambient temperature was 42°C in spite of the lack of thermoregulation by adult wasps.
Example	Protect from temperature	Western Honeybee	*Apis mellifera*	Water forages collect water, store the droplets in cells throughout hive, use fanning to accelerate evaporative cooling.			"Water is collected by water foragers, then distributed around the hive and in cells containing eggs and larvae; fanning accelerates its evaporation, as does regurgitation and evaporation on the tongue (Lindauer, 1955). "
Rens Claassen	Protect from temprature/ light	Saharan silver ants	*Cataglyphis bombycina*	The ants are covered with prism shaped hairs, those hairs are able to reflect total light internally, also the structure of the hairs help to radiate heat to cooler surroundings. The total internal reflection drops the temperature by 2 degrees Celsius. The way the hairs radiate heat back to a cooler environment reduces the ants temperature by 5-10 degrees Celsius.	The prism shaped hairs bend the light rays 90 degrees, so the light reflects back into the air instead of the light rays hitting the ants skin underneath.		
Rens Claassen	Protect from light/ temperature	Leafcutter ants	*Atta vollenweideri*	The leafcutter ants build a massive maze consisting of tunnels and chambers nearly 6 meters below ground. On top of that structure they build mounds up to 1 meter high consisting of the clay the dug out from below combined with leaves and twigs. These cones shaped mound have one or more holes in them, so when a breeze passes they create a low pressure area over het mounds which will cause air to flow out of the tunnelsystem.	The way this works is due to Bernoulli's law, which describes the relationship between speed of flow and pressure of air and gas. the rounded shape of the mound causes air to move faster at the top than across the base, this will result in airflow from the bottom to the top. Depending on the carbondioxide levels in the tunnels the ants make the openings of the mounds bigger or smaller. also when the temprature drops in the nest they cover op the holes and make them smaller.		
Rens Claassen		rock squirrel	*Otospermophilus variegatus*	Rock Squirrels change their coats during the seasons for seasonal heat regulation. during the process the structure of their coats changes but the color remains consitent.			
Rens Claassen	transpire to cool and protect from light and heat to preserve water	staghorn fern	*Platycerium bifurcatum*	The staghorn fern consists of two leaf types, a non-productive leaf that is a rounded heart-shape and starts as a green-leaf and turns brown paper-like over time, these leafs cover and protect the roots of the plant and form a shield-like structure. the other leaves are the fertile leaves. they are lighter green and shaped like a the horns of a stag, the leaves can grow up to 45cm long. These leaves are covered in little hairs that help to cool doen the plant through evaporation. Being a epiphytic plant means that they grow on other larger without being parasitic that's	The protective shield of the non-productive leaves protect the roots and base they grow on from evaporating water, while the little hairs covering the fertile leaves provide a large surface area for the plant to cool down through evaporation. This plnnt can withstand the highest temperatures in a high humidity area.		
Rens Claassen	preserve water for cooling	kangaroo rat	*Dipodomys*	Kanngaroo rats have a specialized kidney that allows them to make super concentrated urine, this way they reduce water too stay cool better. They are also nocturnal which helps to withstand the heat.	dipodomys can produce hyperosmotic urine with a average of 5500 mOsmol l−1, they are able to do this due to their extreme long loops of henle. This results in better water preservation in their bodies.		

Rens Claassen	Protect from light/ temperature	armored stink beetle	*Eleodes armata*	This beetle has several ways to stay cool, they do this by being nocturnal, burying itself but they also have a reflective cuticle. This last one has several smart ways to protect them from the heat	The cuticle is covered in a wax like substance, this provides them with a waterproof barrier which helps to preserve water and reduce evaporation. The cuticle also reflects light which helps the beetle to cool down.		
Antón Salvador	Protect from light	Bacteria	*Vibrio harveyi*	This bacteria transforms harmful ionizing radiation into light by channeling some of the reactive species produced by the ionizing UV radiation into their bioluminescent pathways in order to eliminate the harmful substances.	Transform luminic energy of the sun (heat and light) back into light through metabolicing the reactive species produced by the ionizing UV radiation into their bioluminescent pathways.		"This suggests that the bioluminescence is somehow related to preventing damage from the ionizing radiation. Research has demonstrated that bioluminescence requires radical initiators or reactive oxygen species in order to provide the energy required to release a photon. It is conceivable that bacteria are capable of channeling some of the reactive species produced by the ionizing UV radiation into their bioluminescent pathways in order to eliminate the harmful substances."
Antón Salvador	Protect from light	Alpine Edelweiss	*Leontopodium nivale subsp. Alpinum*	"The hollow hairs composing the fuzz are each about 10 micrometers in diameter—though that varies quite a bit—and are criss-crossed across the surface of the plant in a disheveled manner. Each one is made up of parallel fibers, each around 0.18 micrometers in diameter, which is close to the wavelength of UV light. When sunlight strikes its surface, the plant reflects most of the wavelengths that it doesn't need for photosynthesis or other biological functions—except for UV. The fibers comprising the hairs			"This plant has developed a layer of filamentary hair which covers the bracts surrounding the flowerheads and, with less density, the entire aerial part of the plant. This fleece protects from dehydration and cold, but also turns out to shield the covered living cells from harmful ultraviolet radiations. This protection is not obtained, as sometimes mentioned, by reflection but rather by absorption within the protective hair layer." (Vigneron et al. 2005:8) "They found that the hairs are made up of parallel fibres 0.18 micrometres across, which is close to the wavelength of UV light. This means they can interact with UV light, steering it along the length of the leaves, says Vigneron. In this way, the UV light is absorbed over a large number of hairs instead of penetrating to the plant's body." (Anonymous, 2007:20)
Antón Salvador	Protect from temperature	Australian Fan Palm	*Licuala ramsayi*	The plant develops really thin leaves to keep the heat capacity low, and also is composed by segments tilted in a way that guides the air blowing through the surface of the leaf to transport off the heat.	Keeping heat capacity low and creating channels for the air to flow, as a mean of transporting off heat.		"One (adaptation) is, of course, water evaporation, which, however, is restricted to areas with sufficient water supply. Another strategy is to keep the heat capacity low by means of building very light leaf structures so that the accumulated heat can easily be transferred to the atmospheric environment. It is also known that the leaf size decreases geographically with increasing solar energy input." (Zähr et al. 2010: 285) "A suitable model plant was found in the fan palm Licuala ramsayi from northeastern Australia (Fig. 7). Its leaf fan provides a large solar absorber area. However, the leaf is cut into segments, which are tilted in such a way that the air can pass freely through the fan transporting off heat. In addition, during a heavy storm, the fan follows the wind and the segments reorganize to a streamlined pattern from which they recover unharmed." (Zähr et al. 2010: 289)
Antón Salvador	Protect from temperature	Grass tree	*Xanthorrhoea (Genus)*	It grows its leaves stuck together in a way that it creates a layer of air that acts as a heat insulator.	Creating an insulating layer of airs by difficulting it flowing away from the organism.		"This country [southwestern Australia] is also one of the headquarters of the grass tree…It is neither a grass nor is it a tree. It is a distant relative of the lilies. But it does have very long narrow leaves that resemble grass, and they are born in a great shock on the top of a stem that looks like the trunk of a tree and may be up to ten feet high. However the core of this trunk is not timber but fibre and what seems to be bark is, in fact, the tightly compacted bases of the leaves which are shed annually from beneath the crown as the plant grows higher. These bases are glued together by a copious flow of gum and they form a very efficient heat insulation. Since the plant sheds one ring of leaves annually, counting the rings of bases in this fire-proof jacket gives an indication of age and reveals that the grass trees not only grow only a foot or so in a decade but that a mature one may be about five hundred years old and therefore be the survivor of dozens of fires." (Attenborough 1995:190-191)
Antón Salvador	Protect from temperature / Preserve water	African Bullfrog	*Pyxicephalus adspersus*	When conditions are dry, american bullfrog uses its hind legs to burrow deep into the ground, then sheds several layers of its moist skin to create a hard cocoon, locking in the moisture, and estivates until conditions are humid again.			"Several species of amphibians form cocoon-like structures, continuous around the body but separated from the stratum corneum. This usually happens after the animals burrow into the soil and are subjected to drying conditions. (...) The functional significance of cocoon formation seems to be in the protection that the keratinised layers provide against desiccation" Pyxicephalus adspersus forms a cocoon when it is subjected to slow desiccation over a period of several weeks if it is unable to burrow beneath the surface of the substratum. In the laboratory, cocoon formation is best induced if the frog is placed on clean, wet gravel about 4 cm deep. If the gravel is allowed to dry out slowly, the frog will settle down in one place and shut its eyes. Over the next 2-5 weeks the appearance of the dorsal skin will change from moist and shiny to rather dry, dull and sometimes wrinkled. A thin cocoon, removed 4 weeks after formation, covered the whole body dorsally and ventrally, the legs, and head including the eyes"

Antón Salvador	Protect from temperature	Kangaroo	*Macropus (Genus)*	There's a network of blood vessels in their forearms that's capable of cooling down their whole body. When they lick them until they're soaking wet, their whole body temperature is lowered as the saliva evaporates.	Promoting cooling when necessary by water evaporation on an area that concentrates a lot of heat.		"Birds of several orders supplement panting by holding the mouth open and rapidly fluttering the gular area. The energy required for this gular flutter is small in relation to the amount of water evaporated, and some birds that use gular flutter are able to main- tain body temperature near 42 °C for hours in environmental temperatures exceeding 47 °C"
Luc van Poppel	Maintain homeostasis, regulate temperature	Jackrabbit and elephants	*Lepus townsendii*	Increased surface area in large ears to expose the blood vessels to cool surrounding air.	The large ears of this rabbit contain lots of blood vessels to expose as much body heat to the surrounding air to radiate all the body heat (obtained by running quickly) out of it's body.	Radiating body heat by increased surface area.	This cooling mechanism based on blood circulation helps to prevent overheating and maintain the jackrabbit's body temperature within set boundaries. It's also an important water conservation technique given the jackrabbit's arid habitat, as it reduces the need for evaporative cooling mechanisms, such as panting or sweating, which involve the loss of water. At air temperatures around 86° Fahrenheit (30° Celsius), convection from the jackrabbit's ears can shed all of the animal's excess heat.
Luc van Poppel	Maintain homeostasis, regulate temperature	Cuvier's beaked whale	*Ziphius cavirostris*	Body temperature is regulated by cooling down and heating up blood in different parts of a deep diving whale.	The whales body has many fragile parts. Each needs slightly different temperature to function correctly. By counter current heat exchanging through veins and arteries, the whale can manage it's temperature. It's body has larger epidural veins to get cool blood to it's warmer core to cool it down. It also works the other way around in other surrounding water temperatures.	Natural HRV cooling system inside an animals body.	countercurrent heat exchange (CCHE) occurs if the temperature of the arteries is higher than that of the veins; warmed blood is returned and body heat is trapped in the core…Three examples of CCHEs found in cetaceans are…a flat array of juxtaposed arteries and veins found in the reproductive coolers of cetaceans…a vascular bundle, an array of relatively straight, parallel channels, an optimum configuration for CCHE (Scholander, 1940), such as is found in the chevron canals of cetacea…[and] a periarterial venous rete (PAVR), which is a rosette of veins surrounding an artery.
Luc van Poppel	Maintain homeostasis, regulate temperature	Thomson's gazelle	*Eudorcas thomsonii*	Cooling brain to run longer and keep lower temperature then predator.	The rete is like a setup of blood vessels in a space near the brain's base. When warm blood goes to the brain from the carotid artery, it passes through tiny arteries in this space. Here, it gives off some heat to cooler blood coming back from the nose. The now cooled blood keeps going to the brain.	Cooling blood traveling to the brain.	In a running Thomson's gazelle, body temperature rises more than brain temperature such that a difference between brain and body temperature has been measured at 2.7° C. A predator like the cheetah must stop running when its body (and brain) temperature reaches 40.5° C, but the gazelle can keep running as its body temperature rises above 43° because its brain temperature still hasn't exceeded 40.5°. The ability to keep a cool head can thus give the gazelle a survival edge in these predatory pursuits as he can outlast the cheetah who cannot maintain a cooler brain.
Luc van Poppel	Maintain homeostasis, regulate temperature	Thorny dragon	*Moloch horridus*	Drinking water through grooves in skin.	This desert lizzard lives in dry Australian planes of sand. It uses that sand to extract moisture. It's skin acts as a sponge, or a capillary system. This directs the water through it's skin to it's mouth. The water cools down the elextrons in the lizards system.	Natural water-cooling system.	Another inhabitant of the Australian desert is the incredible thorny devil, which makes the most of the tiniest of drops of moisture. Even without rare rain, the thorny devil can brush past a droplet of morning dew and end up with it in its mouth. The animals's amazing skin is full of tiny grooves which are capable of soaking up any precious moisture and through a capillary system, directing it to their mouth, no matter where on their body it lands. It's like a complicated, internal straw.
Luc van Poppel	Maintain homeostasis, regulate temperature	Pelicans	*Genus Pelecanus*	Exposing moist membranes to air to increase rate of evaporation.	Gural fluttering, by fluttering the gular area or vibrating the muscles and bones in their throats they expose moist membranes to air. This enables effective evaporation wich helps the animals cool down. The energy required for this is small in relation to the amount of water evaporated. This helps them to maintain lower body temperatures in extreme enviromental heat.	Vibrating method to increase cooling by evaporation.	gular fluttering. Rapidly vibrating the muscles and bones in their throats exposes the moist membranes in their throats to air, enabling more effective evaporation. The action uses up very little energy and birds are able to do it whilst sitting still.
Luc van Poppel	Maintain homeostasis, regulate temperature	African crocodile	*Crocodylus porosus*	Gaping, mouth open to regulate body temperature.	A crocodile opens it's mouth, more frequently on windy days, to expose the moist surface of it's tongue and palate to convective heat loss. This results in reduced surface temperature in the mouth and head. This doesn't contribute to lowering the crocodiles entire body temperature, but it allows the crocodile to stay on it's preferred spot, on land. Of course, the crocodile could cool off in the water, but this strategy could be used in the problem for urban heat.	Increasing natural convection by opening it's mouth to expose moist surfaces.	Recently, Spotila, et al.,(1977) have suggested that gaping functions to reduce heat gain on an alligator's(or crocodile's) head while it is on land in full sun and, thereby, allows the alligator to remain on land as its body temperature continues to rise to preferred(=stable) levels. This suggestsion is consistant with my interpretation of the function of gaping based on observations in the field.

Joe Meliëzer	Protect from temprature/ light	Camel	*Camelus dromedarus*	Insulate with a thick fur layer to protect the skin and keep sweat fluids from evaporating.	By insulating the skin and sweat glands from hot air and evaporation with a thick layer of hair (about 4 inches/10 cm). The hairs keep the hot air out and the sweat in. This way the animal stays cool and loses heat through sweating.	Insulating thick fur layer makes it possible to keep hot air out and let the animal transfer heat through sweat out of the body but not outside the insulating fur. No water or fluids are lost due to evaporation.	Camels have sweat glands distributed throughout their skin, from which water removes body heat through evaporation, much as in humans. Camel skin is also covered by thick fur—4 inches (10 cm) deep in places. This fur doesn't impede the evaporation of water . What it does do is insulate the camel from incoming heat.
Joe Meliëzer	Protect from temprature/ light	Blacktailed jackrabbit	*Lepus californicus*	Losing temprature of the blood by spreading it out thinly through the airs where the hot blood can cool the air.	The Jackrabbit has large airs where the blood flows through the veins and is spreak out thinly. The veins are very small and close to the surface so the heat is transfered easily to the air surrounding the ears. By using the bloodveins in the ears of the animal to cool off, it limits waterloss.	tempreture regulation by transfering heat from small superfical veins.	The jackrabbit's large ears provide an expansive surface area of exposed skin loaded with blood vessels. When the surrounding air temperature is slightly below body temperature, as when it retreats from hot desert sun into shade, the blood vessels in the outer part of its ears widen in a process called vasodilation. This results in greater circulation of warm blood from the body's core to the jackrabbit's ears, where heat is lost to the cooler surrounding air.
Joe Meliëzer	Protect from temprature/ light	Quiver tree, Namibia	*Aloe Dichotoma*	The white coating reflects sunlight so the heat of the branches rises limited.	Because of the reflection of the white coating more heat en light is reflected. This helps to keep the general heat of the branches lower and save water on evaporation en transpiration.	The branches of the tree are protected from the heat of the sun by a reflective coating of white powder	The quiver tree that grows in the Namib is a kind of aloe. Like the rest of its family, it has thick succulent leaves growing in a rosette, but these are hoisted twenty feet in the air, each at the end of a stumpy branch. That in itself is a way of escaping the worst of the devastating heat and reducing the amount of moisture inevitably lost by evaporation from the surface of their leaves. The branches themselves are thickly covered in a fine white powder. That too helps in keeping cool for it reflects the sun's heat instead of absorbing it…The branches and trunk are filled with a soft fibre that can hold a great quantity of water." (Attenborough 1995:269)
Jens van 't Riet	Protect from temperature / light	Saharan silver ant	*Cataglyphis bombycina*	Deflecting the sunlight with the little hairs the ant grows all over its body	The Saharan silver ant has tiny prism formed hairs which are prism shaped. This prism shape combined with the rufflled surface of the two-sides pointing up and the flat side pointing in the direction of the ant combined make it that the light reflects of the ant. This phenomon we call total intern reflection (ITR)	A prism shaped hair which is ruffled on the two sides pointing to the sun and the side pointing at the organism which needs to be flat	The hair of Saharan silver ants reduces heat absorption by efficiently reflecting sunlight and dissipating heat. This enables the ant to stay cool in the midday Sahara, where temperatures can reach up to 47°C (117°F). The hairs, with their unique shape, achieve this through three distinct mechanisms:
Jens van 't Riet	Protect from temperature / light	Desert snail	*Sphincterochila boisserieri*	Deflecting the sunlight with the surface of its shell and also providing shade with it	The surface of the snail is highly reflective, this results in 95% reflection while also providing shade this gives the snail up to 5 degrees temperature difference with the surface temperature. This is nog the only thing the snail can do, it can also go up one whorl which will result in up to 15 degrees temperature difference with the surface temperatures.	A highly reflective shell material, while also providing shade and being able to not be on the surface	How desert snails survive high temperatures: The surface of the shell is highly reflective, resulting in 95% reflectance within the near infrared, 90% in the visible spectrum (a). While the maximum air temperature might reach 43 °C (109 °F) , surface temperatures can reach 65 °C (149 °F). However, shading and the rough surface of the soil results in a temperature of 60 °C (140 °F) (d). During the heat of the day, the snail retreats into an upper whorl where the temperature is an even cooler 50 °C (122 °F) (b). Heat flows in the direction of lower temperature, result in heat flow through the shell, with resultant decrease higher in the shell.
Jens van 't Riet	Protect from temperature / light	Wasp	*Paravespula germanica*	The cuticle of wasps provides a cooling mechanism by use of hairs, thin layers, and tracheal branches.	The wings are connected to a cuticle on the dorsal medial side of the wasp there is a thin layer on it and the wings can work as a abdomin. this can ventilate air through the wasp and all the wasted energy that is made into heat can be ventilated out this way	A airpump transporting the wasted energy out of the body which prevents it from heating up	The temperature in this region of the prothorax is higher by 6-9°C than that at the tip of the abdomen, and this in actively flying hornets outside the nest (workers, males or queens) as well as in hornets inside the nest that attend to the brood in the combs. On viewing the region from the outside, one discerns a canal or rather a fissure in the cuticle, which commences at the center of the dorsal surface of the prothorax and extends till the mesothorax. Thus the length of this canal or fissure is ~5-7 mm and it is seen to contain numerous thin hairs whose shape varies from that of the hairs alongside the structure. Beneath the cuticle in this region there are dorsoventral as well as longitudinal muscles in abundance, much the same as the musculature in the remaining thoracic segments (i.e. the meso- and metathorax), which activate the two pairs of wings. The canal-bearing segment is of course devoid of wings, and its dorsoventral muscles are attached to the cuticle, which in this region resembles a bowl harboring several layers of epithelium that boasts numerous butterfly-shaped tracheal branches. Additionally there are layers that display lymph-filled spaces and also perforated layers and depressions, and beneath all these is a lace-like layer that also coats the cuticle's hollows. Underneath the cuticle proper, there are numerous large

Jens van 't Riet	Protect from temperature / light	Thorny devil	*Moloch horridus*	Very great at transfering heat to air and water which are easily obtainable for a thorny devil	Because of its nano texture its able to transfer heat at a quick rate. The thorny devil is able to absorb water with all of it's body this water and also the air get's heated and the thorny devil electrons get cooled when the water is hotter than the water slowly get's replaced by new water so the electrons can cool again.	A material build up with this nano-texture with a material that is better at transfer heat to air or water	The above-mentioned references reveal that nano-texturing is useful for enhancing heat transfer rate. Herein, we employ various nanomaterials (thorny-devil nanofibers, reduced graphene-oxide (rGO), and silver nanowires) which yield different nano-textured surfaces and thus different heat transfer patterns in forced convection of water over such surfaces. All these nanomaterials possess high surface-to-volume ratios, and being deposited on a surface create a “fluffy” layer which facilitates enhanced heat transfer.
Jens van 't Riet	Protect from temperature / light	Eucalyptus tree	*E. tetragona*	It uses evaporation to cool itself	Because of its ability to evaporate water from its leaves the water gets out of the cells of the plant this water than gets cooled down by the wind which makes it possible for the plant to cool itself down.	Water supply that gets evaporated somewhere where the wind can travel through	In present research, temperature reduction between inlet and outlet air through eucalyptus fibres is investigated as a factor for evaporative cooling performance. Besides cooling capacity and COP for eucalyptus fibres were analysed for better understanding of the material's performance. Thermodynamic analysis and process optimization were also conducted to improve the efficiency of eucalyptus fibre based evaporative cooling system by the use of different inlet temperatures and air velocities during the testing.
Daria Zakahrenko	Influences microclimates to reduce urban heat	Giant Sequoia	*Sequoiadendron giganteum*	Giant sequoias influence microclimates by their sheer size and the amount of water they transpire.	Through transpiration and shading, sequoias help cool the surrounding air, thus contributing to lessening the urban heat island effect. Their large biomass and extensive canopies interact with solar radiation and atmospheric conditions to influence local climates.	Large trees like sequoias can be considered as natural air conditioners, which through their biological processes and physical presence, help to cool down their immediate environment.	"Our study is likely the most thorough to ever measure and model microclimate effects of sequoias, or potentially any other large trees." (Eckmann et al., 2017).
Daria Zakharenko	Seasonal thermoregulation	Burrowing Parrot	*Cyanoliseus patagonus*	Burrowing parrots exhibit a seasonal response to thermoregulation, adopting different strategies in summer and winter to maintain thermal homeostasis.	The mechanism involves altering metabolic rates and body mass to adapt to seasonal temperature changes.	demonstrate an energetic conservation strategy that adjusts metabolic function and body mass in response to environmental temperature, important in their unpredictable habitat.	"The burrowing parrots' seasonal thermoregulatory responses represent that of energy conservation which is important in an unpredictable environment." (Zungu, M. M., Brown, M., & Downs, C. T. (2013). Seasonal thermoregulation in the burrowing parrot (Cyanoliseus patagonus). Journal of Thermal Biology, 38(1), 47–54).
Daria Zakharenko	Water collection from fog and thermal regulation	Namib Beetle	*Stenocara gracilipes*	The Namib Desert beetle has evolved to collect water from morning fogs through its unique body surface, which aids in its thermal regulation by preventing overheating.	Its back is covered with hydrophilic bumps that attract and condense water from the fog, which then flows down into hydrophobic channels towards the beetle’s mouth for ingestion.	The combination of hydrophilic and hydrophobic surfaces allows for the efficient collection of water droplets from the air, which is a form of resource acquisition that also aids in thermoregulation by cooling the body.	"Some beetles in the Namib Desert collect drinking water from fog-laden wind on their backs. We show here that these large droplets form by virtue of the insect's bumpy surface, which consists of alternating hydrophobic, wax-coated and hydrophilic, non-waxy regions" [(Parker & Lawrence, 2001)]
Daria Zakharenko	Thermal Regulation and Tolerance	Pompeii worm	*Alvinella pompejana*	Adaptation to extreme hydrothermal vent environments	Unique amino-acid composition in proteins, especially collagen, high levels of charged residues and smaller aliphatic residues like alanine	**: Proteins in body are adapted to maintain functionality at high temperatures by utilizing an amino acid composition that provides stability and robustness in extreme environments	"Analyses reveal that both species display the same high GC-biased codon usage and amino-acid patterns favoring both positively-charged residues and protein hydrophobicity" which are indicative of thermal adaptation (Jollivet et al., 2012)
Daria Zakharenko	thrive in radiation-rich environments	Radiotrophic Fungi (diffrent species)	*Varies, includes species like Cryptococcus neoformans among others*	Radiotrophic fungi use melanin to harness radiation and convert it into chemical energy, which is a unique adaptation not found in most fungi.	Melanin pigments in the cell walls of these fungi capture radiation and utilize it for growth, a phenomenon termed 'radiotropism	The ability to utilize ionizing radiation as an energy source through melanization can be seen as a form of 'biological solar panel' which converts radiation into usable energy.	Dadachova, E., & Casadevall, A. (2008). Ionizing radiation: how fungi cope, adapt, and exploit with the help of melanin. Current opinion in microbiology, 11(6), 525-531. "The discovery of melanized organisms in high radiation environments...raises the tantalizing possibility that melanins have functions analogous to other energy harvesting pigments such as chlorophylls."
Daria Zakharenko	Thermal regulation and buffering in extreme temperatures	Sociable weaver	*Philetairus socius*	Sociable weavers construct large communal nests that provide an insulated environment, which is crucial for managing thermoregulation in the arid savannahs of Southern Africa.	The nests are built with an outer layer that buffers against high external temperatures and an inner layer that retains heat during colder conditions. The complex structure of the nest chambers, with their long entrance tunnels, contributes significantly to this insulation.	The architecture allows for a stable microclimate inside, protecting from extreme external temperatures and reducing the energetic cost of thermoregulation.	The thermoregulatory benefits of the communal nest of sociable weavers Philetairus socius are spatially structured within nests, with the extent of buffering effect depending on the position of nest chambers within the communal structure. This indicates that access to the benefits generated by the structure may vary among individuals, likely influencing social organization within colonies" (Dijk et al., 2013).

Fran Albuquerque	Protect from temperature / Maintain homeostasis	Yellow bumblebee	*Bombus fervidus*	The body of bumblebees maintains a regular temperature via counter-current heat exchange and a heat-shunting mechanism.	As the bumblebee flies, its chest muscles produce a lot of heat. Instead of letting all this heat stay in the chest, the heat starts moving towards the abdomen. This is because the bumblebee has blood vessels that carry warm blood from the hot chest to the cooler abdomen. The key to this system is that the blood in these vessels flows in opposite directions (counter-current). Warm blood from the chest flows close to cooler blood that's moving back towards the chest.	Transfer of heat between fluids flowing in opposite directions.	"1. The narrow passage within the petiole between thorax and abdomen is anatomically constructed so that counter-current exchange should retain heat in the thorax despite blood flow to and from the cool abdomen. "2. However, the counter-current heat exchanger can be physiologically circumvented. Exogenously heated bumblebees prevented overheating of the thorax by shunting heat into the abdomen. They also regurgitated fluid, which helped to reduce head temperature but had little effect on thoracic temperature. "3. Temperature increases in the ventrum of the abdomen occurred in steps exactly coinciding with the beats of the ventral diaphragm, and with the abdominal 'ventilatory' pumping movements when these were present. The ability to prevent overheating of the thorax by transport of heat to the abdomen was abolished when the heart was made inoperative. "4. At low thoracic temperatures the ventral diaphragm beat at a wide range of rates and with varying interbeat intervals, while the heart beat at a high frequency relative to the ventral diaphragm, but at a very low amplitude. However, when thoracic temperature exceeded 43 °C the amplitudes of both were high, and the interbeat intervals as well as the heating frequencies of the two
Fran Albuquerque	Regulate temperature	Arabian oryx	*Oryx leucoryx*	The Arabian oryx has been observed to use selective brain cooling as a mechanism to cope with aridity.	The selective brain cooling in the Arabian oryx involves the cooling of the brain relative to the rest of the body. This is achieved through physiological adaptations that allow cooler blood from the nasal passages, cooled by evaporation, to lower the temperature of the blood going to the brain.	Systems and structures that utilize evaporative cooling techniques to selectively regulate temperature.	"Selective brain cooling is a thermoregulatory effector proposed to conserve body water and, as such, may help artiodactyls cope with aridity. We measured brain and carotid blood temperature, using implanted data loggers, in five Arabian oryx (Oryx leucoryx) in the desert of Saudi Arabia. On average, brain temperature was 0.24±0.05°C lower than carotid blood temperature for four oryx in April. Selective brain cooling was enhanced in our Arabian oryx compared with another species from the same genus (gemsbok Oryx gazella gazella) exposed to similar ambient temperatures but less aridity. Arabian oryx displayed a lower threshold (37.8±0.1°C vs 39.8±0.4°C), a higher frequency (87±6% vs 15±15%) and a higher maximum magnitude (1.2±0.2°C vs 0.5±0.3°C) of selective brain cooling than did gemsbok. The dominant male oryx displayed less selective brain cooling than did any of the other oryx, but selective brain cooling was enhanced in this oryx as conditions became hotter and drier. Enhanced selective brain cooling in Arabian oryx supports the hypothesis that selective brain cooling would bestow survival advantages for artiodactyl species inhabiting hot hyper-arid environments."
Fran Albuquerque	Protect from temperature / Maintain homeostasis / Protect from loss of liquids	Water bear	*Tardigrada*	The waterbear survives extreme environmental conditions by entering a reversibly suspended metabolic state known as cryptobiosis.	The waterbear curls up into a tiny ball called a "tun" and gets rid of almost all its water, basically drying itself out. While in this dried-out ball shape, waterbears make special proteins and sugars that protect their cells from damage.In this state, they put their metabolism on pause. This means they stop all their body's normal	Ability of organisms to reversibly suspend their metabolic processes in response to extreme environmental conditions, thereby entering a state of suspended animation.	"Most incredible of all, however, is the virtually indestructible nature of tardigrades while they remain in cryptobiosis. In laboratory experiments, cryptobiotic specimens have been chilled in liquid helium to -457°F (-272°C), which is only marginally above absolute zero. They have also been heated to temperatures exceeding 300°F (149°C), exposed to radiation doses far in excess of the lethal dose for humans, immersed in vats of liquid nitrogen, concentrated carbolic acid, hydrogen sulphide, brine, and pure alcohol, and even bombarded by deadly streams of electrons inside an electron microscope. Yet when removed from all of these incredibly hostile
Fran Albuquerque	Protect from temperature / Protect from loss of liquids	Agave plants	*Agave*	Agave plants utilize Crassulacean Acid Metabolism (CAM), which is an adaptation for increased water use efficiency.	Agaves store water in their thick, fleshy leaves, allowing them to draw on this reserve during dry periods. These capture surface moisture from light rains or dew that wouldn't penetrate deeply into the soil. This minimizes water loss through transpiration by reducing the leaf surface area exposed to the sun and by having a waxy coating that reduces water evaporation.Many agaves have leaves that funnel water toward the plant base, aiding in water collection and root absorption. CAM plants, like agave, are special because they open their tiny leaf pores (stomata) at night instead of during the day. This nighttime opening helps them	Resourceful Conservation and Optimization./ Separate resource accumulation from processing phases, taking advantage of more favorable conditions at different times or in different environments	**Check scanned paper in the link**
Fran Albuquerque	Protect from temperature / Capture, absorb, or filter energy	Australian fan palms	*Licuala ramsayi*	The leaf of the Australian fan palm gathers light, stays cool, and avoids wind damage by subdivision into tilted segments.	The segments of the leaf are tilted in such a manner that allows air to pass freely through the fan. This airflow facilitates heat dissipation, preventing the leaf from retaining excessive heat that could potentially damage the plant's cellular structures and biochemical processes. The structure of the Licuala ramsayi's leaves also offers an advantage during heavy storms. The segments can reorganize into a streamlined pattern, reducing resistance against strong winds. After the storm	Adaptive segmentation and tilt mechanisms to manage thermal regulation and enhance structural durability in response to environmental stresses.	"A suitable model plant was found in the fan palm Licuala ramsayi from northeastern Australia (Fig. 7). Its leaf fan provides a large solar absorber area. However, the leaf is cut into segments, which are tilted in such a way that the air can pass freely through the fan transporting off heat. In addition, during a heavy storm, the fan follows the wind and the segments reorganize to a streamlined pattern from which they recover unharmed." (Zähr et al. 2010: 289)

Fran Albuquerque	Regulate temperature	Chameleons	*Chamaeleonidae*	Chameleons are well-known for their ability to change color, a characteristic that serves multiple purposes, including camouflage, communication, and physiological regulation, particularly in relation to body temperature control.	The color change in chameleons is facilitated by specialized cells in their skin called chromatophores, which contain different pigments. When a chameleon needs to warm up, it can change its skin color to a darker shade. Dark colors absorb more sunlight compared to light colors, thereby increasing the chameleon's body temperature. This is particularly useful in the morning when they need to raise their body temperature to become active after a cool night. Conversely, when the environmental temperature is high, and the chameleon needs to avoid overheating, it can change its color to lighter shades. Light	Ability to shift coloration from dark to light shades allows for the modulation of solar radiation absorption.	"Many chameleons, and panther chameleons in particular, have the remarkable ability to exhibit complex and rapid colour changes during social interactions such as male contests or courtship. It is generally interpreted that these changes are due to dispersion/aggregation of pigment-containing organelles within dermal chromatophores. Here, combining microscopy, photometric videography and photonic band-gap modelling, we show that chameleons shift colour through active tuning of a lattice of guanine nanocrystals within a superficial thick layer of dermal iridophores. In addition, we show that a deeper population of iridophores with larger crystals reflects a substantial proportion of sunlight especially in the near-infrared range. The organization of iridophores into two superposed layers constitutes an evolutionary novelty for chameleons, which allows some species to combine efficient camouflage with spectacular display, while potentially providing passive thermal protection."
Anastasia Donea	Minimize water loss	Aloe	*Aloe Vera*	Aloe vera's strategy for heat protection revolves around its capacity to store significant amounts of water within its leaves, which helps it survive in hot, arid environments. This water storage capability is coupled with the ability to minimize water loss through transpiration, a critical adaptation for enduring prolonged periods of heat and drought.	The gel inside Aloe vera leaves is rich in water, nutrients, and polysaccharides, acting as a reservoir to support the plant during extreme heat and dry conditions. The leaves are coated with a thick cuticle that reduces water evaporation. Moreover, Aloe vera leaves are shaped in such a way that they can reflect sunlight, and their orientation allows for minimal direct exposure to the sun's rays, further reducing heat absorption and water loss.	Integration of water storage and reflective surfaces for efficient thermal management.	"Influence of biofertilizers on some physiological traits and leaf fresh weight of Aloe vera under different irrigation regimes showed biofertilizers (especially the combination of MF and PSB) utilization on factors such as total chlorophyll and carotenoid contents, leaf proline, and soluble sugar amount under heat stress" (Khajeeyan et al., 2019).
Anastasia Donea	Collect moisture	Lichens	*Thallus*	Lichens employ a dual strategy involving high albedo (reflectivity) to deflect solar radiation and a symbiotic relationship between fungi and algae to retain moisture efficiently. This symbiosis enables lichens to perform photosynthesis while minimizing water loss in extreme temperatures.	The structure of lichens, with their crusty, leafy, or branching forms, increases surface area while also enhancing their ability to capture and retain moisture from the air, dew, or rain. Their ability to reflect sunlight reduces the amount of heat absorbed, helping to maintain a cooler microenvironment. Additionally, some lichens can enter a desiccated, dormant state to survive dry periods, reactivating with moisture availability.	Enhancing reflectivity and moisture retention for thermal protection.	Antarctic mosses, however, can have canopy temperatures well above air temperature... Antarctic mosses, therefore, optimize for brief periods during summer to maximize photosynthesis and minimize respiratory carbon losses in cold conditions" (Perera-Castro et al., 2020). While this excerpt discusses mosses, similar principles apply to lichens in Antarctic environments, demonstrating adaptations to optimize thermal conditions.
Anastasia Donea	Tolerate the heat	Thorny devil	*Moloch Horridus*	Thorny devils utilize color change and specialized skin structures as strategies to navigate their hot, arid habitat. These adaptation serves to regulate body temperature. As well they posses mirco-channels along their skin to direct water into their mouth allowing him to get water passively	Their ability to change color from pale colors (reflecting heat) during hot conditions to darker colors (absorbing heat) in cooler conditions helps in thermoregulation. The skin's texture, including ridges, captures moisture from the air, fog, or rain, which is then directed towards the mouth through capillary action, aiding in hydration.	Adaptive coloration for thermal regulation and surface design for water harvesting.	Adsorption and movement of water by skin of the Australian thorny devil (Agamidae: Moloch horridus): This research highlights the thorny devil's unique adaptation for inhabiting arid regions. The lizard's skin, with channels between overlapping scales, collects water by capillarity and passively transports it to the mouth. This study showcases the lizard's capability to optimize water absorption and reduce water loss, a critical adaptation in hot, dry habitats (P. Comanns et al., 2017).
Anastasia Donea	Maintain homeostasis, regulate temperature	Great roadrunner	*Geococcyx californianus*	Great roadrunners exhibit behavioral strategies such as gular fluttering and body orientation to minimize heat stress. These behaviors are complemented by physiological mechanisms that efficiently regulate body temperature.	Gular fluttering involves rapid movement of the thin skin in the throat area, facilitating evaporative cooling. By orienting their bodies to minimize direct sunlight exposure and maximizing wind exposure, roadrunners can further reduce heat absorption. Their feathers also provide insulation and shade, reducing skin temperature.	Behavioral and physiological adaptations for thermal regulation.	Roadrunners: Energy Conservation by Hypothermia and Absorption of Sunlight: This study reveals that roadrunners utilize sunning to maintain basal metabolic levels at lower ambient temperatures, conserving energy through behavioral adaptations. In darker conditions, roadrunners may undergo hypothermia, further demonstrating their ability to adjust physiologically to varying thermal environments for energy conservation (R. D. Ohmart & R. C. Lasiewski, 1971).

Anastasia Donea	Protect from light/heat	Desert Marigold	*Baileya*	The desert marigold employs a strategy of high reflectivity to combat heat stress. Its leaves and flowers are covered with fine hairs that reflect sunlight, helping to keep the plant cool.	The reflective hairs on the desert marigold's leaves and flowers act as a protective barrier against the sun's rays, effectively reducing leaf temperature and preventing overheating. This adaptation not only minimizes water loss through transpiration but also protects the plant's tissues from potential damage caused by excessive heat.	Using reflective surfaces to mitigate heat absorption.	A replicated experiment with fourteen flowering plant species hymenopteran parasitoids on corn marigold (Chrysanthemum segetum) and corn chamomile" (Fitzgerald & Solomon, 2004). This excerpt doesn't directly address heat protection but highlights the adaptability of marigold species in diverse environments, including hot, arid conditions.
Anastasia Donea	Dissipate heat	Fennec fox	*Vulpes zerda*	Fennec Fox employs several strategies to survive in the Sahara Desert, one of the harshest environments on Earth. Its large ears serve dual purposes of dissipating heat and locating prey underground. Its thick fur reflects sunlight during the day and conserves heat at night, and its burrowing habit helps avoid the extreme daytime heat.	The Fennec Fox's large ears, which are unusually big in relation to its body size, enhance its ability to release excess heat into the environment, thereby cooling its body. The thick fur on the fox's body, including its feet, protects it from the hot sand, while its light color reflects the sun's rays. Burrowing into the cooler underground provides a refuge from the daytime heat. Furthermore, its nocturnal behavior minimizes water loss through evaporation, crucial for survival where water is scarce.	Leveraging anatomical features for thermoregulation and adopting behavioral strategies to minimize water loss and heat exposure.	The small body sizeincreases dissipation of metabolic heat by passive conduc tance, but limits heat storage potential as utilized by larg er animals. Above ambient temperatures of 32–34°C,body temperature rises quickly to a critical level. Smallcanids rely on non-evaporative heat loss for dissipatingheat, and can increase conductance through assuming asprawling position of the legs, by having large ears, andthrough use of "thermal windows" where fur is thin andshort.
Evy winkelman		saharan silver ant		the saharan silver ant has a strategy to prevet over/heating in hot environments. It does this by reflecting the sunlight and exert as much heat as possible.	the ant is able to reflect the sunlight with prisma schaped hairs on its exoskeleton. this decreases its body temperature by 2 percent. its surface area is maximal because of these hairs so that he is able to exert more heat.	reducing heat by reflecting the sun radiation and by increasing surface area, more heat can be lost	the hairs reduce heat absorption by maximizing the amount of light that is reflected off their surface, a process known as total internal reflection. Second, the hairs also reduce heat absorption by reflecting sunlight (solar radiation) from both visible and non-visible parts of the electromagnetic spectrum, including the near-infrared. And third, the silver ant has a particularly effective method of offloading excess heat. The shape of the hairs increases the ant's ability to radiate heat—known as emissivity
evy winkelman		snow algae	*Chlamydomonas nivalis*	the algae can survive in extreme cold because it reflects UV/radiation without taking away its ability to photosythesize	its chloroplatst are surrounded with a lipid dropled with the pigment carotenoid pigment known as astaxanthin. it absorbs the uv/rays to prevent the rays to harm celstructures. Microalgae are ideal model organisms due to their fast growth, strong adaptability to extreme environments, and high oil contents.	a cooling mechanism that works on reflecting light with pigments	
Xander van den Brink	Protect from temperature	Otter	*Lutra lutra*	Long scales on the underhair of otters and fur seals trap air to retain heat and prevent water penetration.	The Otter has a layer in its fur that is called under hair. With this layer of hair it is able to trap air and create air pockets what makes it able to trap heat and prevent cold water from coming into it's fur. This way staying warm.	Insulation system to regulate heat and prevent water penetration.	
Xander van den Brink	Protect from temperature	Australian fan Palm	*Licuala ramsayi*	Slightly tilted leafs that make the air easily pass trough.	The Australian fan palm uses a special leaf structure that allows wind to easily pass trough the leafs. the leaf are all slightly tilted to make a perfect structure for the wind to pass trough this way cooling the entire plant.	A cooling mechanism trough leaf structure.	
Xander van den Brink	Protect from temperature	Lichens	*Cryptothele*	takes up and holds moisture extremely well to protects from heat.	Lichens takes up water extremely well, it can take up half of it's dried bodyweight in just ten minutes. It makes full use of moisture and only needs a little bit of time for it. This way in cases of draught or extreme heat it is able to survive.	Structure to absorb and hold water very well.	
Xander van den Brink	Protect from temperature	Land snail	*Cepaea nemoralis*	Uses a specific pigment on it's shell to prevent it from heating up quick.	The land snail has a specific color on it's shell to prevent it from heating up quickly. It's shell has yellow pigment that reflects the sunlight, this way from heating up more then other snails.	Sructure that reflects heat	

6. NTS - Alpine Edelweiss

Contact

Antón Salvador Ríos

Champion

Alpine Edelweiss, *Leontopodium nivale* subsp. *Alpinum*

Image of Champion

Natural History

The Alpine edelweiss is a perennial herbaceous plant that can be found in European mountains, where it lives in heights up until 3400 m of altitude. The whole plant, and specially the bract (the leaves that surround the flower), is abundantly felted with white hairs. This hairs are thought to limit water evaporation because the plant distributes over very dry and windy regions, being particular resistant to growth. Apart from that the cells which make the living tissue of the plant are known to be an absorber of ultraviolet (UV) radiation, which raises the question: how does the plant resist the high flux of the energetic and harmful irradiation to which it is exposed in the high-altitude rarefied atmosphere? (Vigneron, et al., 2005)

As established before, these plans can live in very high altitudes. Due to that, they are exposed to higher levels of UV radiation, seeing that there's less atmosphere above them to absorb that radiation. It is estimated that every 1000 meters the levels of radiation increase approximately 10 per cent. (World Health Organization Radiation and Health Unit, 2016).

Because of this, the Alpine Edelweiss needs to protect itself from this harmful radiation.

Function

Protect from light

Strategy

The Alpine Edelweiss has hairs that absorb UV radiation to protect against its harmful effects.

Mechanism Description Text

To protect itself from the UV radiation, the Alpine Edelweiss has developed a layer of special filaments that cover its leaves, specially the bract. This layer allows radiation from the visible spectrum to pass through it, and hit the surface of the plant, as this radiation is needed for its life functions. However, it absorbs the UV radiation in the structure of the filaments, and dissipates it.

The structure of these filaments consists of hollow tubes of around 10 μm of diameter, whose external wall is covered with longitudinal fibers of a diameter in the order of magnitude of the UV radiation (0.176 nm).

Because of this closedness, a process called Bragg scattering of modes can happen. This process is based on Bragg's law, which links a wavelength comparable to the space in between elements of the surface it incises with the occurrence of a diffraction phenomena for which light will be reflected at certain angles and not in others. (Bragg & Bragg, 1913)

Through that mechanism, light from certain frequencies is reflected and channeled in between the fibers that cover the filament, creating what is called a guided mode: determined paths in which light of certain frequencies will be trapped and forced to transit. Due to the characteristics of the medium, that is, being a flat surface, these "modes" are short lived. Another way of saying that the energy they conduct dissipates. This happens for a lot of different frequencies in the UV range.

What happens with the frequencies in between the guided modes is that, thanks to the roughness of the surface, the guided modes are "leaky", and thus allow a process called Fano resonance to happen, for which energy of the radiation from a close frequency is introduced into the guided mode.

This is what happens in one of the filaments, so, thanks to the structure of crisscross hairs placed in a random array, the dependances that this absorption might have on the angle of incidence are mostly covered.

As established before, this only happens for waves in the UV range, so waves in the visible range will be either reflected (in all directions) or transmitted through the filament, allowing it to pass through the filaments layer.

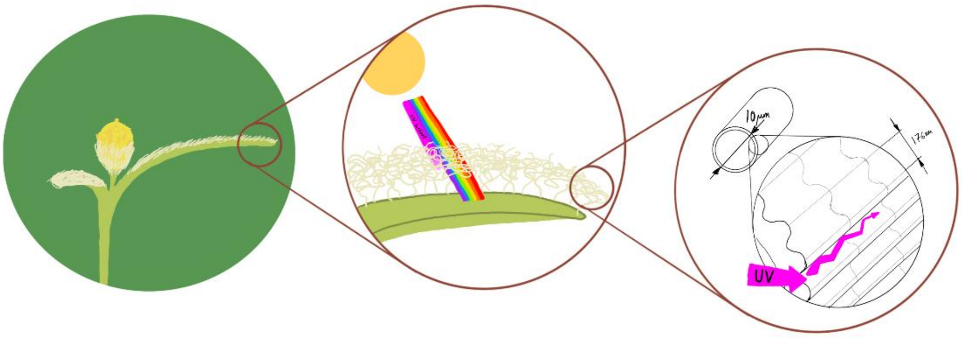
BDP = Biological Design Principle

To protect its living cells from the harmful effects of the UV radiation, the Alpine Edelweiss have developed a protective layer of filaments over its sun-facing surface.

These filaments are transparent, but have a special structure composed of a series of fibers close in size to the wavelength range of UV radiation. Thanks to this size-closedness it is able to reflect incising, specific frequencies of UV rays and channel them along the spaces in between the fibers, also charging them with the energy of the rays close in frequency, and dissipating all of it by circulating it in between the fibers.

This way the UV rays don't reach the living cells of the plant, whereas the rest of the visible range of frequencies does.

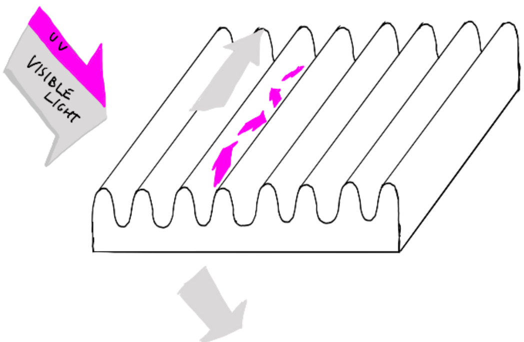
Biological Mechanism Drawing



Abstracted Design Principle

To obstruct specifically the UV part of the spectrum to pass through, use a transparent structure of a planar slab bearing a grating-like surface corrugation (with a protrusion width close to the UV range of frequencies) to reflect specific frequencies on light in between the protrusions, charge them with the energy of those rays close in frequency, and dissipate all of their energy by conducting then along the channel, while allowing other frequencies of light to pass through.

Abstracted Design Principle Drawing(s)



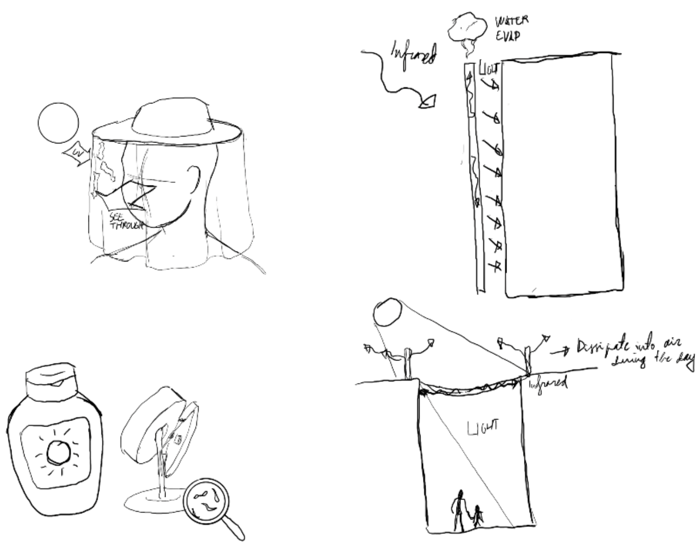
Design Ideas Description

- Transparent Veil – Protects from light
- Lotion with fibers in suspension – Protects from light

Transforming the UV trapping into infrared trapping (could be channeled into water evaporation)

- Facade complete covering. – Protects from light/Manages Heat
- Facade partial covering for ventilation - Protects from light/Manages Heat
- Street covering - Protects from light/Manages Heat

Design Ideas Drawings



Life's Principles related to the organisms 'superpowers' and the function mentioned in this NTS.

- **Be locally attuned and responsive –** Use readily available materials and energy.
  As a non-moving organism, the Alpine Edelweiss has no options to build the structures that compose the filaments
- **Integrate development with Growth –** Combine modular and nested components
  Only one of this filament can do very little for the Alpine Edelweiss. But a whole coating made by this only one structure (module) is perfect to achieve the desired function, without need for more complex solutions (And in this case, more DNA coding).
- **Be resource efficient –** Use low energy processes
  Apart from the process of growing the filaments, the process of reflecting light is completely passive, without any extra need for expending energy on the part of the plant.
- **Be resource efficient –** Use multifunctional design
  The filaments object of study in this NTS not only protect from light, but also help to reduce water evaporation.
- **Be resource efficient –** Fit form to function
  The Alpine Edelweiss has evolved to find this exact form of the filaments, that help to diffract light this way, no other shape would have worked.

- **Use life-friendly chemistry** – Build selectively with a small subset of elements.
  The whole structure of the filament is made with organic elements, as there is no other source for the plant. That is, while not specified, the filaments will be almost for sure made from a very small subset of chemical elements.

Research References

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Research Excerpts

“This has been confirmed by carefully shaving the bract surface and examining the remaining stump. This observation indicates a wall thickness below the micrometer significantly smaller than the filament diameter.” (Vigneron, et al., 2005)

“The diameter of these fibers is of the order of 0.18μm, the order of magnitude of the wavelengths of near ultraviolet radiation.” (Vigneron, et al., 2005)

“But the most spectacular reflection variation occurs when entering the near-ultraviolet region, where it is found that no light is actually back-scattered” (Vigneron, et al., 2005)

“The deficiency of reflectance and transmittance in this range of ultraviolet radiation means that a strong absorption occurs there. Note that by “absorbed” we mean radiation which looses energy while transiting through the filament wall, but also, eventually, radiation which first turns into guided waves in a Fano resonance process (see below) and then disappears with the lifetime of the guided mode.” (Vigneron, et al., 2005)

“The wooly layer tends to protect the plant from near ultraviolet (UVA, from 320 nm to 400 nm) but does not hinder the exposition to visible radiation needed to sustain biological processes. The-attenuation of the visible spectrum is essentially controlled by the reflection and not by the absorption.” (Vigneron, et al., 2005)

“Filament cross section model, as deduced from field-emission scanning electron microscopy. The structure is a hollow tube, about 10μm in diameter. An array of well-separated parallel fibers with a lateral diameter of 176 nm is attached to the external surface of the tube. In the calculations, the curvature of the wall is neglected.” (Vigneron, et al., 2005)

“The curvature can then be neglected, and we end up representing the wall as a planar slab bearing a grating-like surface corrugation.” (Vigneron, et al., 2005)

“The sharp, asymmetric lines which appear there are related to the Bragg scattering of modes which conduct light through the network of peripheral fibers. Long-lived guided modes are normally not seen in the reflectance spectrum of a flat film, as they are associated with evanescent waves in the incidence and emergence regions surrounding the film.” (Vigneron, et al., 2005)

“As a consequence, the sharp guided modes become leaky and, conversely, can be loaded with energy by an external radiation. It was shown that the superposition of the guided photonic modes with the non-resonant transiting radiation give rise, in the transmission and in the reflection spectra, to asymmetric lines whose shape has been referred to as Fano profiles. The presence of these easily recognizable structure denote the possible energy transfer from incident waves into guided modes.” (Vigneron, et al., 2005)

“It can then be expected that the process of energy transfer into UVA guided modes is very effective with this filamentary crisscross geometry.” (Vigneron, et al., 2005)

“It is unclear whether the ultraviolet absorption can take place in the filament wall itself (which should then be characterized by a complex value of its refractive index) or whether the filament hollow core actually contains an absorbing agent. However, the absorption of these high-energy radiation (3-4 eV) is likely to cause chemical damage and this mechanism should be confined to wavelengths beyond the high-energy end of the visible spectrum.” (Vigneron, et al., 2005)

"Pure water is known to absorb all electromagnetic radiations in the wavelengths range from kilometers to femtometers, except for those falling in the narrow window of the visible spectrum." (Vigneron, et al., 2005)

"(…) the fibrous structure of the external surface of the filaments not only provides a guiding support of ultraviolet radiation but also brings the roughness required for energy exchange between the incident waves and these guided modes." (Vigneron, et al., 2005)

"Alternatively, the absorption can take place in the filament wall itself. In this case, the mechanism of energy injection into the guided modes would make the absorption by these tiny structures much more effective, by lengthening the absorption path of the light. However, on the basis of the model described by Fig. 12, the coupling to guided modes can occur in both the UV and in the visible parts of the spectrum, contradicting measurements: the infrared and visible recordings have failed to show any significant absorption, while the UVA absorption approaches 100%. As a consequence, a constant value of ε'' is not realistic and a dissipative response which rapidly shifts from high to low values at the UV onset would better represent the observed absorption. Without such a shift, the edelweiss bracts would absorb nearly as much in the visible range as it absorbs the near UV and, most likely, would appear dark (…). The molecular origin of this abrupt change is more than likely. As we can see, the physical origin of the whitening of the plant leaves involves the sharp disappearance of a dissipative response between the near-UV and visible ranges. This means that, besides the purely structural effects the "pigmentary" (i.e. material-based rather than structural) mechanisms play a significant role in determining the bracts coloration." (Vigneron, et al., 2005)

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7. NTS - Indian Peacock

Contact

Antón Salvador Ríos

Champion

Indian Peacock, *Pavo cristatus*

Image of Champion

Natural History

The Indian Peafowl is a species of bird native from the forests and shrublands of Sri Lanka and India, but can also be found in Pakistan, Kashmir, Nepal, Assam, Nagaland, Burma, Java, Ceylon, Malaya, and the Congo.

The male of the Indian Peafowl exhibit one of the greatest plumages known, being considered one of the largest flying birds if the length of the tail and wing span are included. The train is discarded in January, but is grown again at a rapid pace when breeding season approaches. (Fowler, s.f.)

When displayed, the male's train spreads out in a wide fan, showing off gold, brown, green, and black feathers. There is a significant positive correlation between a peafowl's train and its mating success. Female tend to prefer more elaborate trains on their mates, as they are related to the health of the specimen. More ocelli (or informally called, eyes) and more time of display indicate a male in good health. However it's not only the genetic factors that are taken into account, but male peacocks also develop the ability to use the sun at different angles when performing visual displays such as "train-rattling" or "wing-shaking" (Dakin, 2008), creating a very impressive effect with the glows of their feathers .

Function

Reflect specific frequencies of light.

Strategy

The Indian Peacock has feathers that reflect only specific frequencies of light by a crystalline-alike structure.

Other champions

Orb weaver spider

Mechanism Description Text

To create very eye catching patterns and colors to attract the females, peacocks have developed structural pigmentation in their feathers.

A feather of a peacock is consists of many barbs sticking out from a main shaft and each barb has a lot of barbules. The barbules are curved along their long axis and slightly twisted from the roots. (Kinoshita, Yoshioka, & Miyazaki, 2008)

The surface of this barbules is composed of a series of layers of melanin rods into a matrix of keratin. If we were to make a transversal cross section, this rods would be disposed as a quasi-square lattice. At the center of each an air hole is located.

This rods act as photonic crystals, trapping the light of certain wavelength in their net, and reflecting others. The diameters of the melanin rods are between 100-130nm and the layer intervals and the light reflected is dependent on the distance of the interval between layers (the separation in the distance parallel to the surface doesn't seem relevant), with 140–150, 150 and 165–190 nm for blue, green and yellow feathers, respectively.

However, this only doesn't explain the reflection in a wide angular angle. For this the macroscopical structure of the curved barbule, and the barbules acting together cause this effect. (Yoshioka & Kinoshita, 2002)

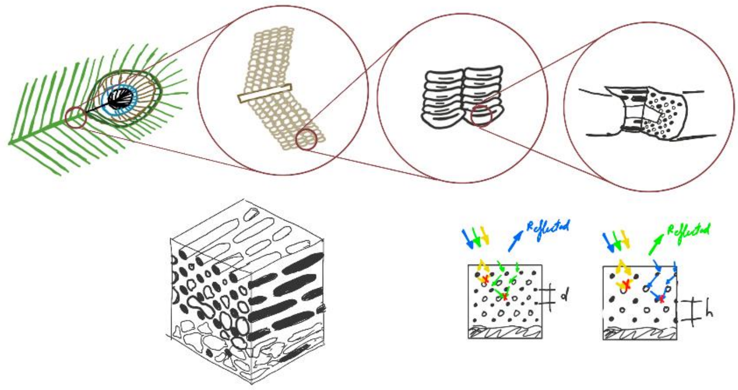
BDP = Biological Design Principle

To create striking colors and catch the attention of females, the male Indian peacock have developed feathers with a special structure that reflects the light of specific wavelengths.

The feathers are composed by barbs that are at the same time composed by tiny structures called barbules. This barbules have a structure of a 2D quasi-square and several layers lattice of melanin in a matrix of keratin, and airholes in the middle of each square lattice.

This structure acts as photonic crystals. That means that light scattered from each particle interferes in some directions with each other and radiates secondary emission in others, being that directions a function of the wavelength and the distance between layers. That means that some wavelengths are "trapped", and others are reflected.

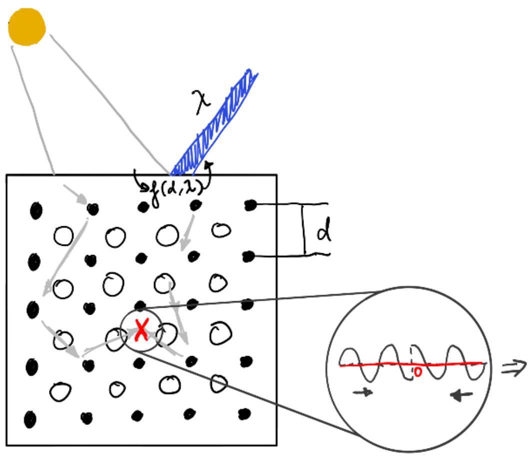
Biological Mechanism Drawing



Abstracted Design Principle

To reflect specific wavelengths of light, use a 2D square lattice with a distance between vertices on the order of the light wavelength, to "trap" certain wavelengths in the lattice and reflect others (change the distance between vertices to change reflected wavelength).

Abstracted Design Principle Drawing(s)



Design Ideas Description

- Fabrics thar reflect thermal radiation for hot and dry areas - Protects from light/Manages Heat

Design Ideas Drawings

Life's Principles related to the organisms 'superpowers' and the function mentioned in this NTS.

- **Integrate development with Growth** – Combine modular and nested components
  The structure of the feather constantly repeats itself.
- **Be resource efficient** – Use low energy processes
  Apart from the process of growing the feathers, the process of reflecting light is completely passive, without any extra need for expending energy.
- **Be resource efficient** – Fit form to function
  The structure of the feather has evolved to this specific function.
- **Use life-friendly chemistry** – Build selectively with a small subset of elements.
  The whole structure is made of keratin and melanin, basic components of animal tissues.

Research References

Dakin, R. (2008). The role of the visual train ornament in the courtship of peafowl. *Department of Biology in conformity with the requirements for the degree of Master of Science* .

Fowler, E. (s.f.). *Pavo cristatus Indian Peafowl*. Obtenido de Animal Diversity Web: https://animaldiversity.org/accounts/Pavo_cristatus/

Kinoshita, S., Yoshioka, S., & Miyazaki, J. (2008). Physics of structural colors. *Reports on Progress in Physics, 71*(7).

Li, Y., Lu, Z., Yin, H., Yu, X. L., & Zi, J. (2005). Structural origin of the brown color of barbules in male peacock tail feathers. *PHYSICAL REVIEW, 72*.

Yoshioka, S., & Kinoshita, S. (2002). Effect of macroscopic structure in iridescent color of the peacock feathers. *FORMA-TOKYO-, 17(2)*, 169-181.

Zi, J., Yu, X., Li, Y., Hu, X., Xu, C., Wang, X., . . . Fu, R. (2003). Coloration strategies in peacock feathers. *Proceedings of the National Academy of Science*.

Research Excerpts

“Varying the lattice constant produces diversified colors. The reduction of the number of periods brings additional colors, causing mixed coloration.”

“He reported that the cortex surface layer of the barbule consisted of keratin, within which melanin rods of 1µm length were arranged in a plane parallel to the surface along the longitudinal direction. Below this plane, a total of 3–11 layers containing the melanin rods were arranged to form a 2D quasi-square lattice. The melanin rods were bound to each other by a keratin band. At the center of each square lattice, an air hole was located with increasing size toward the lower layer.”

“Although the multilayer system successfully explains the color of feathers, it does not predict the reflection in a wide angular range. Here we discuss the effect of the macroscopic structure in order to explain this character of the reflection. By the consideration of the large difference observed in the laser speckle patterns for two focusing conditions, it is suggested that the smoothly curved surface is related to the angular dependence of the reflection. Actually, the crescent shape in the transverse cross section causes the tilt of the multilayer to the incident light which results in the spread of the reflection in the plane perpendicular to the barbule axis.”

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8. NTS – Intertidal Starfish

Contact

Antón Salvador Ríos

Champion

Intertidal starfish, *Pisaster ochraceus*

Image of Champion

Natural History

Pisaster ochraceus is a species of starfish native from North America, being found anywhere from Alaska to Baja California, but more commonly in the Northeastern Pacific. (Ramirez, s.f.)

It can be found in rocky areas of the coast, from above the low-tide zone to 90m in depth. A very changing environment due to the difference between high tides and low tides, where this organism is faced with strong surges, big temperature changes, dilution by rainfall and dessication. (Ramirez, s.f.). That is because it's where mussels (their food source) live, and starfish, having reduce mobility, can't allow themselves to get too far from there. (Pincebourde, Sanford, & Helmuth, 2009)

It is a cold water species, so it needs a way to cool during these low tides. If its central core temperature rises above 35ºC its vital organs wouldn't be able to keep functioning and it would die. (Cornier, 2013)

Starfish don't have blood, but instead they use sea water instead. They extract nutrients of it by pumping surrounding seawater inside their bodies. (Sea Life Blackpool, 2018).

Function

Manage temperature on short timescales.

Strategy

When hotter temperatures, *P. ochraceus* increases its mass with sea water to heat slower.

Mechanism Description Text

P. ochraceus has a very extensive coelomic cavity that occupies all of its body. This cavity is filled with fluids, mostly sea water.

When the tide goes low, the starfish is subjected to heat stress, raising its temperature during this period (of approximately 6 hours).

If the starfish detects that the raise in temperature is too high, next high tide it will absorb cool sea water from the (it is theorized that this mechanism is activated by releasing some kind of metabolites that cause osmotic pressure). That way its mass will be higher, and thus its temperature will raise at a slower pace next low tide, as more heat is required to raise an equal amount of temperature. This is called improving its thermal inertia. It works well because the spaciousness of the coelomic cavity occupying most of the body of the starfish.

The organ regulating this change of volume is called the madreporite, acting as some kind of valvule that connects the opens from the exterior medium that opens into a system of canals that extend to the tube feet.

For this cooling mechanism, the cooler the water during high tide the better the cooling effect during the low tide. Also, higher temperatures during the low tide will cause a greater absorption of water in the subsequent high tide.

This increase in volume probably comes at the cost of energetic cost, impaired locomotion or other trade-off, in a way that makes *P. ochraeus* release the excess of coelomic fluid when the temperature during low tide becomes manageable again.

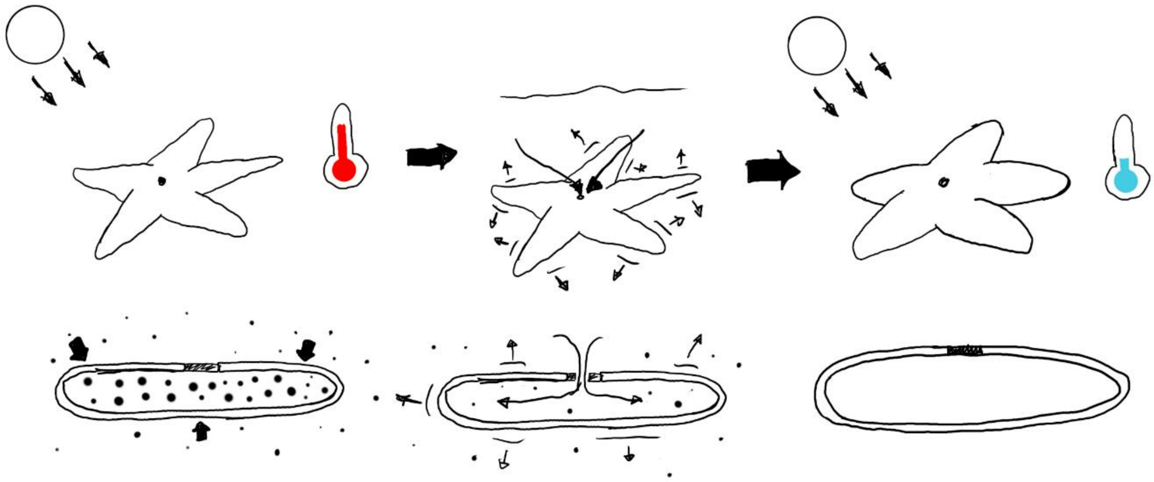
BDP = Biological Design Principle

To avoid heating up during low tides with high air temperatures, when *P. ochraeus* experiences a high temperature during a low tide, it releases metabolites that cause a difference in osmotic pressure between the inside of its coelomic cavity and the sea water in the next high tide.

This causes the madreporite to pump a certain amount (dependent on the experienced temperature and the temperature of the water) of cold water inside the body of the starfish, rising its body mass, so that the next low tide it will take more time to heat up.

When the temperature during low tides becomes moderate again, the process reverses and the starfish releases the excess fluid.

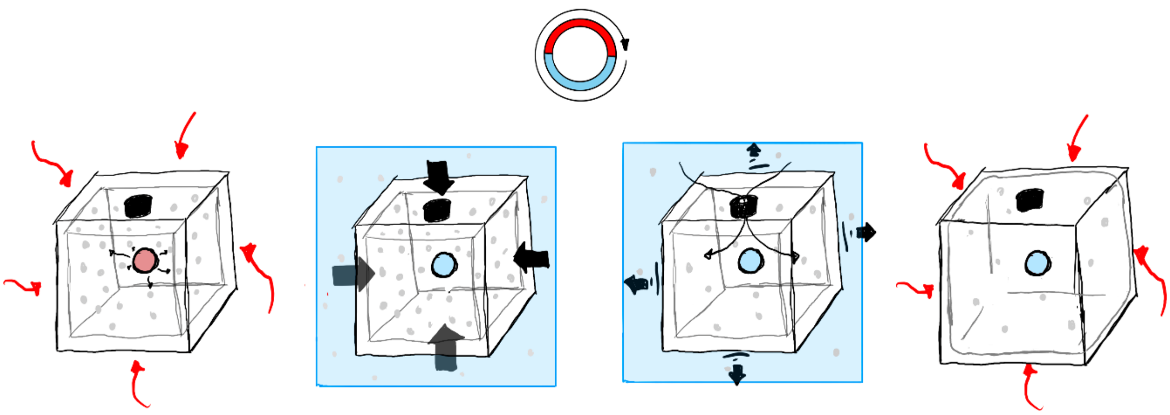
Biological Mechanism Drawing



Abstracted Design Principle

To avoid heating up during high heat stress short term cyclic situations, when this cycles starting to happen are detected, emit a response that cause a calculated imbalance between the system and the surrounding medium in the next low temperature part of the cycle, so that during this time the surrounding (cooler) medium will be pumped into the system until this imbalance is solved, thus increasing the net mass of the system and making it harder to heat up during the next high temperature part of the cycle.

Abstracted Design Principle Drawing(s)



Life's Principles related to the organisms 'superpowers' and the function mentioned in this NTS.

- **Adapt to changing conditions** – Embody resilience
  The starfish can be or not in high temperature environments, but it is prepared to face the scenario anyways.
- **Be locally attuned and responsive** – Use readily available materials and energy
  P. ochraeus uses the most available material it has, all around it, sea water.
- **Be locally attuned and responsive** – Leverage cyclic processes
  The starfish takes advantage of the tides happening in a cycling process, using the high tides to survive the low ones.
- **Be locally attuned and responsive** – Use feedback loops
  This mechanism is only activated when the temperature is too high, and when the conditions are acceptable again it is stopped.
- **Be resourceful with material and energy**– Use multi-functional design
  The coelomic fluid fulfils several life functions on the starfish, the cooling aspect is only one of them.
- **Evolve to survive** – Integrate the unexpected.
  The whole structure is made of keratin and melanin, basic components of animal tissues.

Research References

Cornier, Z. (29 de May de 2013). *Starfish sacrifice arms to beat the heat*. Obtenido de New Scientist: https://www.newscientist.com/article/dn23615-starfish-sacrifice-arms-to-beat-the-heat/

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Sea Life Blackpool. (2 de July de 2018). *7 Amazing Starfish Facts*. Obtenido de Sea Life Blackpool: https://www.visitsealife.com/blackpool/information/latest-news/7-amazing-starfish-facts/#:~:text=They%20have%20no%20brain%20or%20blood!&text=Seawater%20is%20pumped%20throughout%20their,its%20organs%20to%20function%20properly.

Research Excerpts

“Body temperature excess differed among treatments and was greatest in sea stars that experienced high Tw” (Pincebourde, Sanford, & Helmuth, 2009)

“This novel strategy is effective because sea stars possess a large, internal, fluid filled cavity (coelom) and are routinely surrounded by seawater that is cooler than air.” (Pincebourde, Sanford, & Helmuth, 2009)

“Exposure to high T_{body} activates a mechanism through which *P. ochraceus* accumulates a greater volume of coelomic fluid, resulting in a lower T_{body} during the next low tide. *Pisaster ochraceus* thereby exploits its thermal inertia as a means to slow heating during aerial exposure.” (Pincebourde, Sanford, & Helmuth, 2009)

“Our results indicate a tight interdependency between aquatic and aerial body temperatures in *P. ochraceus*. In particular, T_w physically influences maximal T_{body} by setting temperature at the start of aerial exposure periods.” (Pincebourde, Sanford, & Helmuth, 2009)

“Thermal stress is associated with production of metabolites that could induce an increase in osmotic pressure within the organism” (Pincebourde, Sanford, & Helmuth, 2009)

“The energetic cost of being relatively far from the mussel bed might, however, have imposed selection for sea stars to develop novel thermoregulatory strategies allowing easier access to prey.” (Pincebourde, Sanford, & Helmuth, 2009)

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