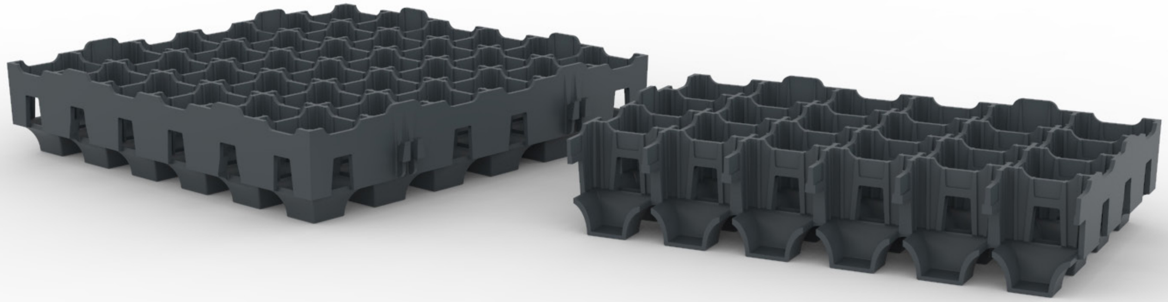
The Pavilion Roof System

Combining solar panels, heat pumps and green roofs to optimize sustainable rooftop use



Graduation Report Linde de Jonge

Master Integrated Product Design
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1. Abstract

This report contains the graduation project of Linde de Jonge in collaboration with Paviljoen 3, and aims to find a solution to reducing the eco-footprint of existing homes, by combining solar panels, green roofs and heat pumps in a modular fashion to be adaptable to the specific requirements of each household and complement the working of each individual system.

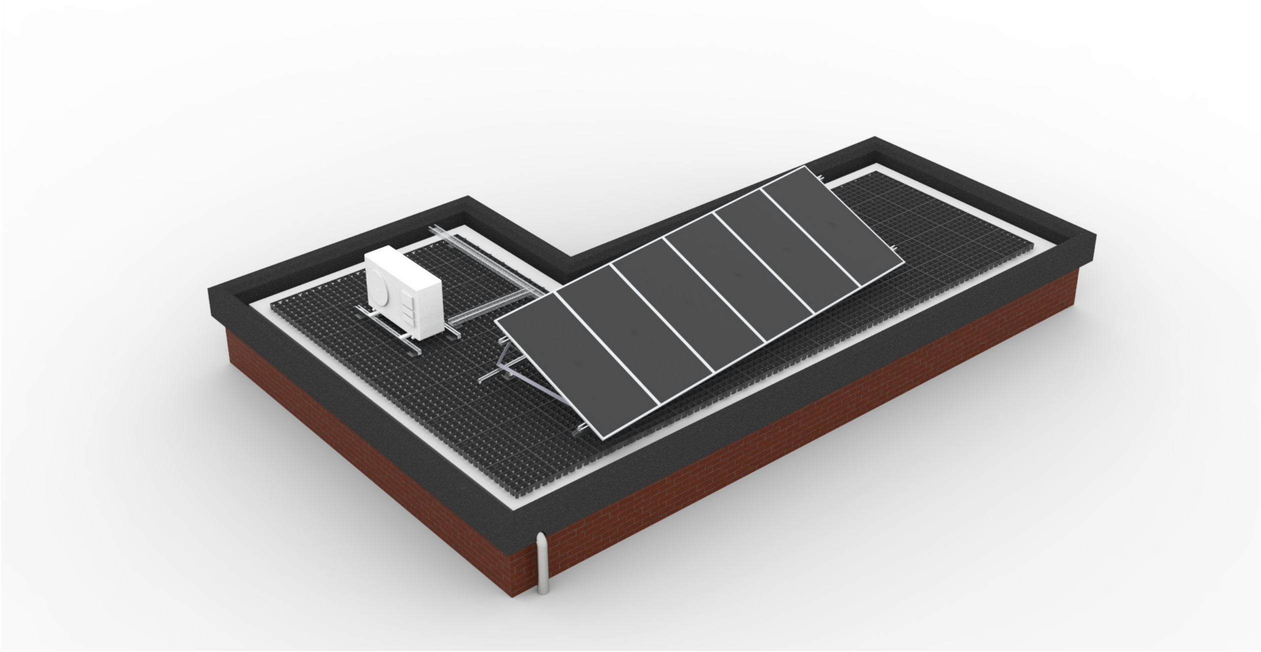
Method

User research, market analysis, creative sessions and observational studies have been implemented to support the iterative process towards a solution.
The creative process was divided in three cycles. The focus of the first cycle was to find a solution with high feasibility for the company, by combining products on the market and adding small but crucial design intervention to create a unified system for flat roof surfaces.

The second cycle aimed to create a solution suitable for tiled roofs, which is exceedingly common in the Netherlands, yet thus far incompatible with a green roof. The focus was on creating a solution which would enhance the exterior of the building, to increase the desirability of the design (an opportunity based on client research).

The two cycles resulted in two concepts with a very opposing solution approach. These concepts were presented to the company and a selection was made.

This selected concept was the start of the third cycle. In this cycle, the feasibility is established by detailing the embodiment of the system. Furthermore, the viability is illustrated by a future development roadmap.



Design

This project's main challenge can be summarized as finding the balance between:

1. introducing an entire roof-system to market;
2. without losing the flexibility in the wide range of products (PV, heat pump or green roof) available to fit the variance in client and household needs;
3. and with the least amount of in-house produced parts to fit the company's resources.

The solution of this project is an entire roof-system, consisting of market available components and components proposed to be developed and manufactured by the company Paviljoen 3, which are implemented into the system according to distinct development phases.

By combining existing products on the market, solely introducing components which are crucial for the viability of the roof-system and separating the innovation of system's components into separate phases, this solution diffuses the investment costs for P3, while enabling them to acquire empirical insights concerning the system, which they can apply in further system development. They can have intensive prototyping and experience using market-bought products, before they invest in launching their own product.

The design cycle ends with a final prototype of the developed components, and a company evaluation. The report concludes with a list of recommendations for the company to pursue further concept development.

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2. Introduction

The city of Amsterdam aims to increase the amount of sustainable energy generated per inhabitant and leave 'no rooftop unused' in the quest to be climate neutral as a city by 2050 [City of Amsterdam, 2020].

Households can lower their eco-footprint by decreasing their energy consumption or by generating sustainable energy. Solutions on the market for both approaches consist of: insulation, green roofs, heat pumps, solar panels and systems that provide sustainable water-housekeeping. These solutions are being widely (and mandatorily) implemented in new build homes. However, when applied to existing buildings, problems arise, because every system needs to be tailored to the widely ranging physical dimensions of the roof and energy needs of the building.

This project aims to find a solution to reduce the eco-footprint of existing homes, in collaboration with the company Paviljoen 3, by combining solar panels, green roofs and heat pumps in a modular fashion, to be adaptable to the specific requirements of each household and complement the working of each individual system.

Currently, aforementioned systems are installed in disregard to each other, thereby making it harder if not impossible to implement the other systems on the same roof later on.
This project has led to a solution that supports the combined installation of existing 'rooftop' solutions, the client is provided with a solution that will allow for future add-ons to further decrease the ecological footprint of the household.

Figure 1. A vision of 'no rootop left unused' by Rooftop Revolution.

3. Company

The client of this assignment consists of four separate companies: Paviljoen 3 (Pavilion 3), De Elementen (The Elements), De Bovenste Laag (The Top Layer) and De Engineur (The Engineer).

Paviljoen 3
The company of the brief. A 'think tank' started by Wouter Voskuijl and Benjamin Scheers. The goal of this initiative is to create solutions on rooftops to enable buildings through their energy transition in Amsterdam.

De Elementen
The Elementen is specialized in installation techniques. They install heat pumps, boilers, HRV (Heat Recovery Ventilation), etc. This would be the company to install the final product of this project.

De Bovenste Laag
De Bovenste Laag is a company specialized in painting, plastering, tiling, etc. All jobs that concern the onlay and finishing of walls.

De Engineur
De Engineur is a carpenter company that builds, remodels and renovates buildings, making custom solutions for companies or private properties.

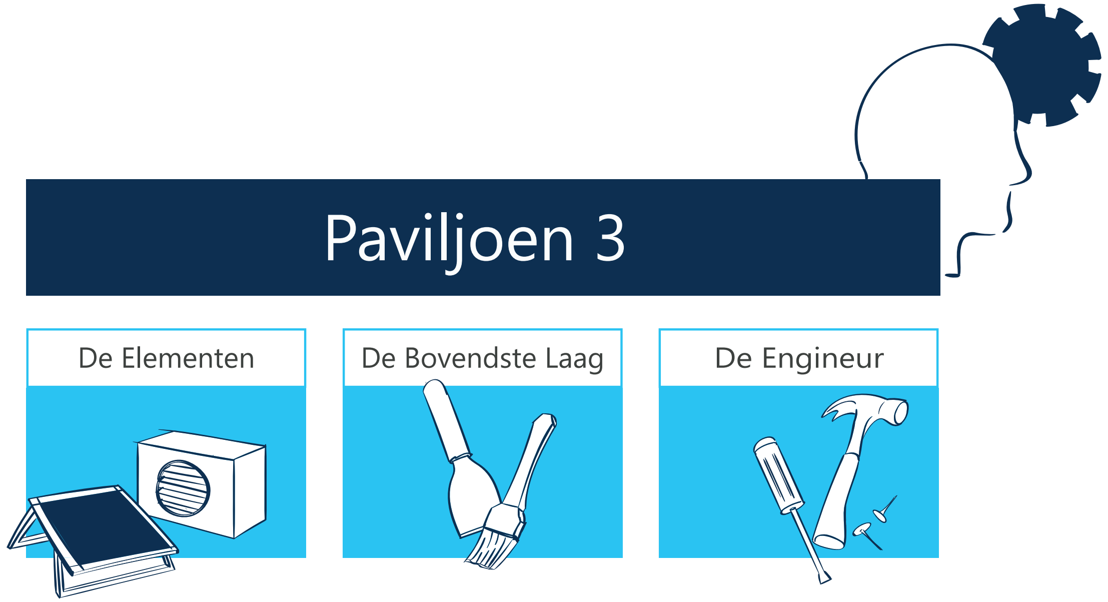


Figure 2. Company hierarchy.

3.1 Expertise

One strong benefit of these companies is that they are closely linked with one another. They can provide a service for their customers in which the communication and planning between carpenters, painters, intallers, plasterers, etc. is arranged for them. When mistakes are made by one of the parties, the process of building or remodeling can be resynchronized with all parties.
This service provides the company with a strong vantage point on the current market, because of the clear added benefit for the customer.

3.2 Vision

An important driver of this project is the vision of the collective companies. There is a strong desire to work towards a 'better world', both regarding social impact as environmental friendly developments. For example, De Bovenste Laag employs refugees and other minority groups with poor job prospects.

The takeaway of this vision for the project is that this attitude creates space to weigh social or environmental impact as requirements for the project. Well-argumented decisions can be made that put well-being before financial gain.

3.3 SWOT-analysis

A SWOT-analysis of the company has been done. An added aspect is the available skillset of the company. They are already experienced in installing heat pumps, are trained and licensed to install solar panels, but have no experience yet in placing green roofs. Therefore, the explorative study of green roofs in chapter 7 will be slightly more extensive.

STRENGTHS

- All-round expertise of all processes related to building, remodeling or renovating houses
- Service that entails communication and planning between different disciplines
- Strong communication with the customers
- Open to exceeding innovation fueled by strong motivation
- Strong connections/relationships with suppliers

WEAKNESSESS

- No name in installing green roofs
- Not a lot of/no experience in installing solar panels
- Not a strong name considering installation of solar panels and green roofs
- No experience in manufacturing products, so therefore no existing infrastructure for these type of developments

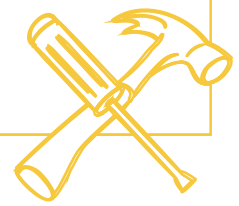
SKILLSET

Available:

- Installing solar panels
- Installing heat pumps

Missing:

- Installing green roofs



OPPORTUNITIES

- No competitors offering an all-rounded roof solution
- No competitors offering an information channel on optimizing roof surface
- City of Amsterdam is strongly working towards roof-solutions to support energy transition
- Investment costs for consumers for PV systems are decreasing

THREATS

- Many established companies as competitors, therefore hard to differentiate
- Net Energy Metering is tapered off by 2023
- Industry field that is not open to innovation
- Extremely diverse context, hard to design a fitting solution

Figure 3. Company SWOT.

4. Context

The environment of this project are the rooftops located in Amsterdam, the city in which the company is operative. One distinctive denominator of rooftops is the inclination (pitched versus flat), which is most probably going to have considerable consequences for the final design.

In this project focusses on flat rooftops, because of the following:

Flat roofs are most common

The square meters of flat rooftop comprise 75% of all the roof surface area of Amsterdam (RIVM, 2019). However, as can be seen in figure 5, a sizable part of the flat roof surface is located in the industrial areas of Amsterdam. The percentage of flat roof surface area in the residential area of Amsterdam is approximately 60% (Appendix A for calculations).

Inner-city's buildings

Next to the fact that flat roofs are more common, there is also a difference between the type of buildings under the type of rooftops. As can be seen in the figure, a big part of the pitched roofs are located along the canals of Amsterdam. These buildings are old, which has implications for the soundness of the structure. The solution of this project is most likely going to be heavy, and therefore these buildings are less appropriate.

Furthermore these buildings often fall under the Cultural Heritage Protection of Amsterdam, resulting in extensive restrictions to visual alterations of the building's exterior (Gemeente Amsterdam [A], 2020). And lastly, the buildings in the city centre of Amsterdam are often divided into multiple households per floor, resulting in a shared roof surface. Rented houses with a shared roof surface complicates the question of ownership and responsibility of the solution.

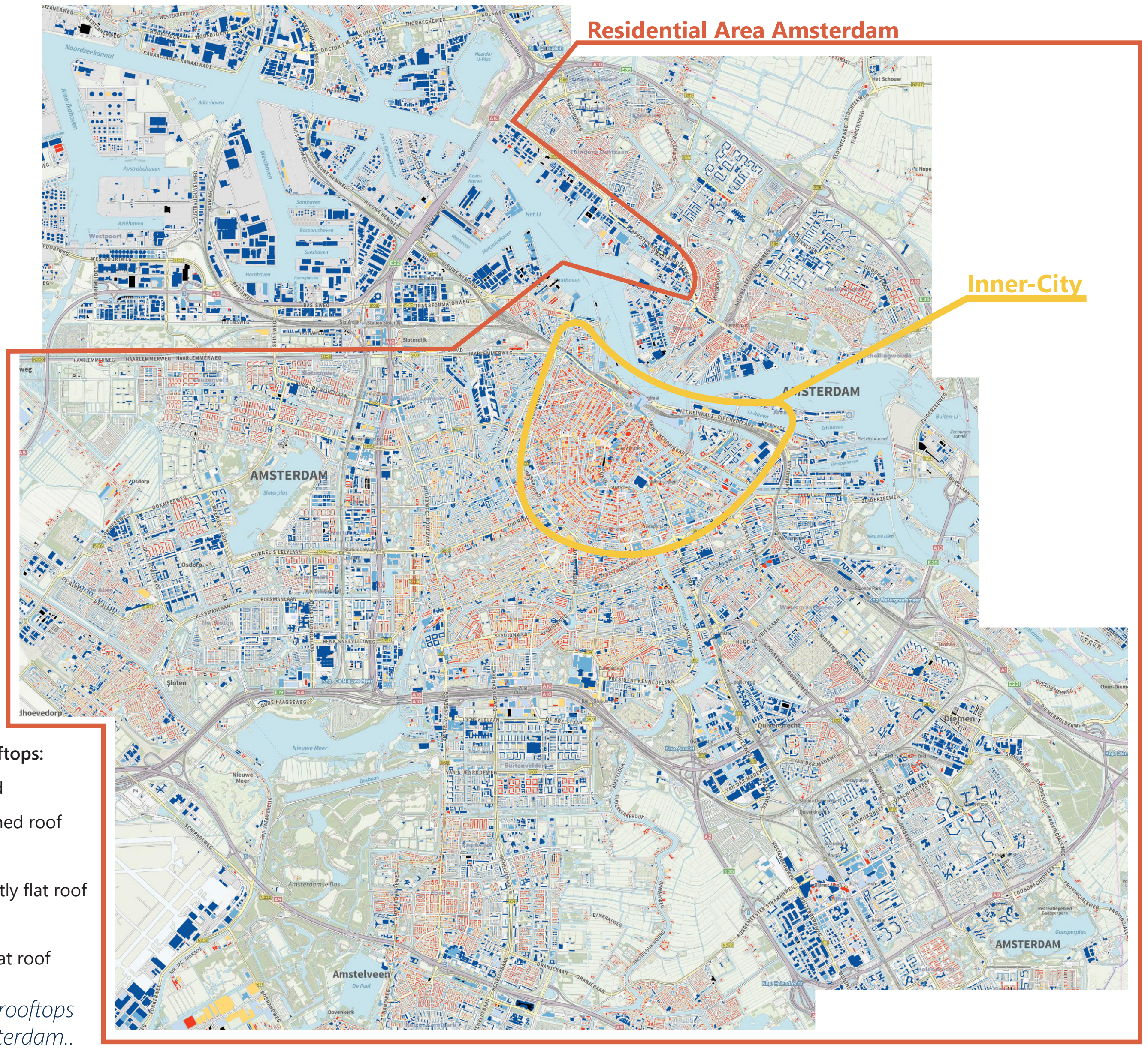


Figure 5. Analysis rooftops of Amsterdam..

5. Stakeholders

The company
Wholesalers/distributer
Manufacturors
Suppliers
Client
City of Amsterdam
Neighbourhood
Competitors

The market context of this project poses a great challenge. The construction industry is a market that is known to be conservative and resistant to innovation. Most knowledge is still transferred from expert (experienced plumbers and/or installers) to student (apprentice plumber and/or installer), which means there can be quite some discrepancy in methods and solutions by comparable experts.

This chapter will map the stakeholders of this project (figure 6), their interests in the outcome of this project and their relation.

Wholesalers/distributors

The company has strong relationships with established distributors of the systems, such as ThermoNoord, Atag and Ubbink.
These companies provide installers with systems for ventilation, heat and energy management. Furthermore they fulfill an informative role towards the installation companies, advising them in system selection and industry developments.

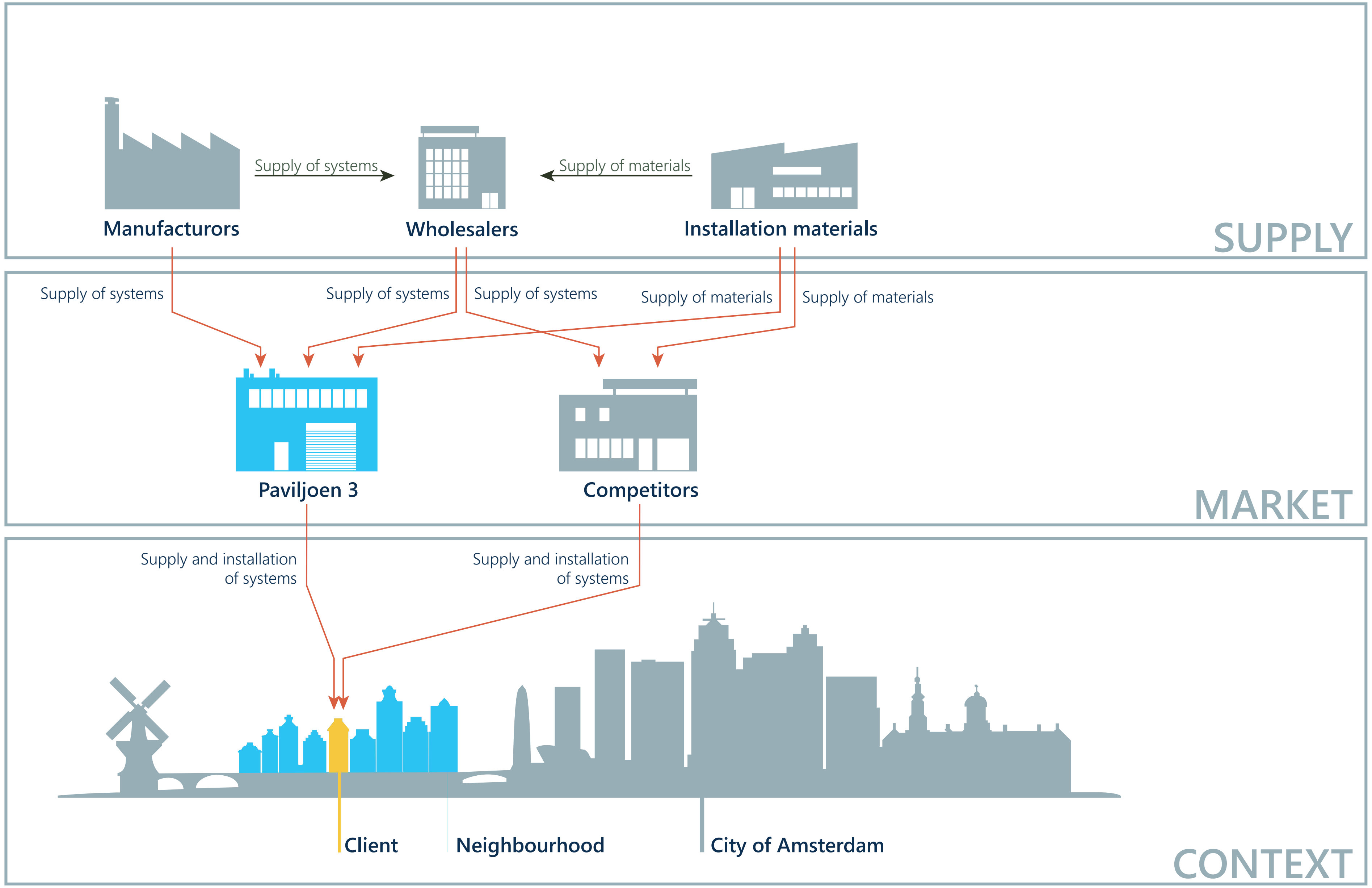


Figure 6. Project stakeholders and their relations.

Manufacturers of the systems
The installation industry is saturated by established, market leading manufacturers. There are two types of manufacturers:
1. Manufacturers that supply to distributors such as discussed above.
2. Manufacturers that sell to intallers directly.

Suppliers of installation hardware
Besides suppliers and manufacturers of installation technology, another industry is closely linked to this context; the manufacturers and distributors of installation hardware, for example companies such as Flamco or JMV. Utilizing existing mounting and securing systems on the market can greatly benefit the project, for it will decrease the required start capital for Paviljoen3. This makes these stakeholders quite interesting, because they could take the shape of future partners in design and/or sales.

Client
The potential clients of Paviljoen 3 are residents of Amsterdam with an 'appropriate'(to be determined) roof, and are interested to purchase their service and product. This interest can come from (a combination of) different drivers: financial gain due to lower energy bills or increase of property value, aesthetic increase of property, or ecological benefits of the solution.

City of Amsterdam
The City of Amsterdam has a clear vision for their city, although concrete plans are still pending. They want to leave 'no rooftop unused', and fully invest in solar and wind solutions to make the city energy sufficient [City of Amsterdam, 2020]. What makes the City of Amsterdam a strong stakeholder is that they provide and determine the permits and subsidies for the clients. They can decrease or increase the financial threshold of our target group. Aligning the project with their vision will help the market positioning.

Neighbourhood of the client
The neighbourhood of the client has two ways of influencing this project. Firstly, adjacent buildings have a view of the roof of the client, so they benefit an aesthetic solution. Regarding heat pumps, a common problem is that the sound caused by the product can disturb neighbours. A solution that eliminates this problem is in their interest.

Competitors
Because of the broad nature of the project; including solar solutions, green roofs and heat pumps, the competitive market is big. The main challenge is to convey the same level of expertise and professional knowledge compared to a specialized, monofocussed company, in all three fields. This while emphasizing the benefits of a more comprehensive approach.

Figure 7. Project stakeholders in the direct context.

6. Client

6.1 Current decision procedure

The current process, from initiative of the consumer to the purchase of a system, has been depicted in figure 8. As can be seen, many stakeholders influence the decision making process. In the lowest layer of the figure, the (time-)windows in which decisive features of the solution are selected have been approached.

At the start of the process, the client and possible energy advisor decide a general solution direction. A contractor that fits this direction is approached, further scoping the project within the expertise of the concerning contractor. The energy advisor, contractor and wholesaler advise the client on brands, models and subparts, accustomed to the client's situation. The industry developments are steered by the manufacturers (releasing products on the market) and wholesaler (inform on and analyse market needs).

This figure was shaped according to insights from an in-depth interview with installer and energy advisor P. Schram of SunisFree BV (Appendix B).

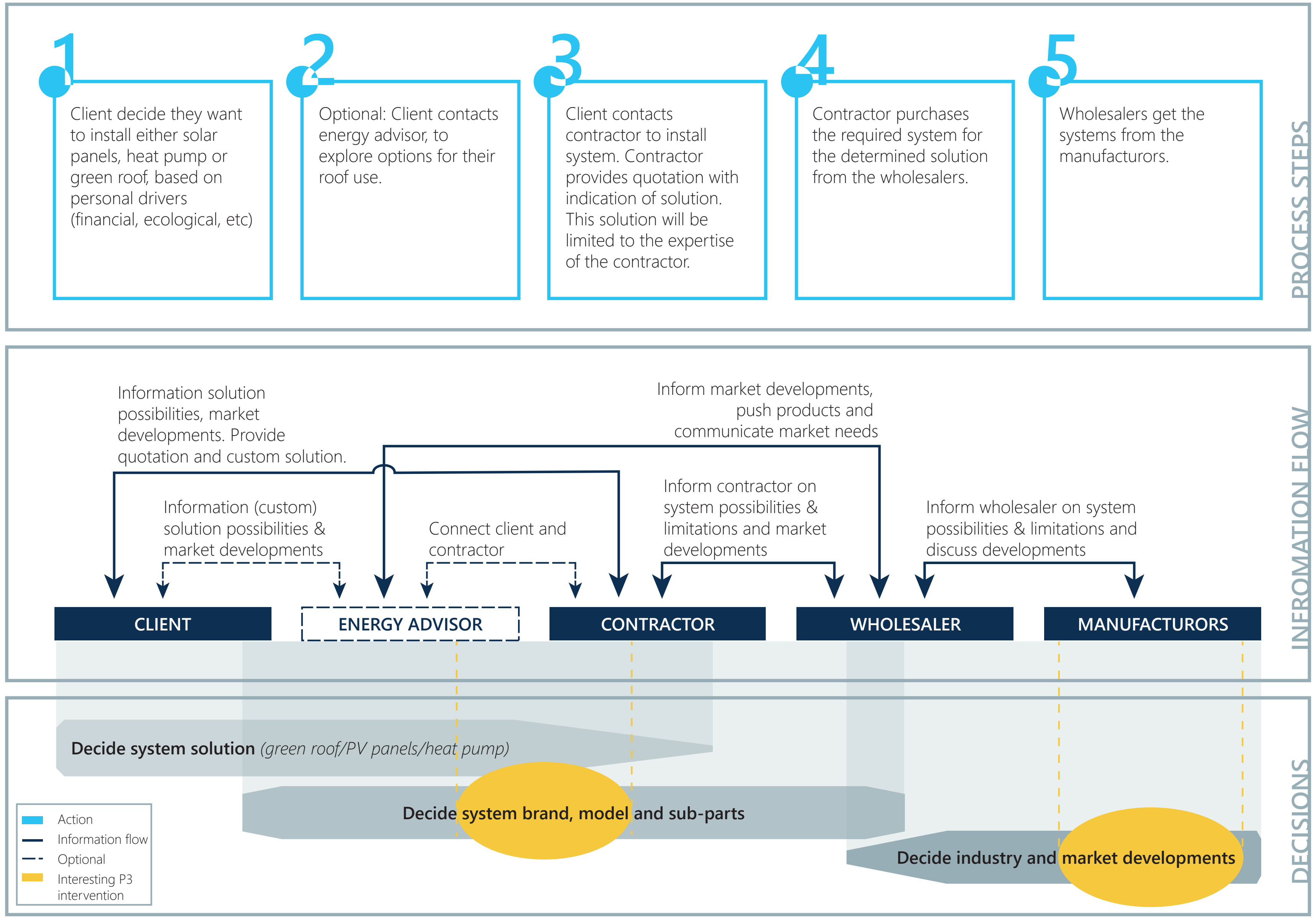


Figure 8. Current decision making procedure of the client.

6.1.1 Company intervention

The main insight is that there is a discrepancy between knowledge and the first decision towards a system as a solution. Most commonly the client contacts a contractor, who is experienced in either solar systems, heat management or green roofs. This has as effect that the decisive factor in system determination is the client, who possesses the least amount of expertise. In figure 8, yellow circles depict the interesting points for Paviljoen 3 to intervene in this decision making process. Either by providing the advising role of energy advisor and contractor with a comprehensive system approach, or by manufacturing a comprehensive solution for optimal roof use.

Market opportunity

This translates into a clear market opportunity due to a need of the consumers. When the consumer’s driver is to gain ecological benefits, they can opt for heat pumps, as well as solar panels or a green roof. Currently it is complicated to navigate through the possibilities and find the information required to determine the desirable (combination of) solutions for your specific situation.

If the company can provide a service that enables the consumer to plan an optimized use of their rooftop surface, taking several circumstantial factors into account, like orientation of the building, roof surface area, environmental needs for the municipal area etc., they would position themself distinctively in the current market.
The government provides subsidies for green roofs (§7.6), supporting this opportunity on a financial level for the consumer.

6.2 Client research

To gain a better understanding of the potential client of the solution, research was conducted using a questionnaire. The highlights will be discussed. For the questionnaire and the detailed results, see Appendix C.

Solar panels

An overwhelming 44% of the respondents are interested in buying solar panels, and 36% already owned them. The most important aspect was considered the environmental benefits (graded an 8,8). An interesting deviation is that the people who are doubtful about purchasing solar panels (16%), rated appearance and costs considerably higher than the positive consumers. Appearance was stated as the biggest drawback of a solar panel system.

Heat pump

The attitude towards heat pumps is more divided. 36% of the repondondents were interested, 20% not, 44% is doubtful. The environmental argument was again noted as the most important attribute of the product. Comparable as with solar panels, the costs we once again rated as a more decisive factor by the doubters compared to the positive consumer.

Green roof

52% of the respondents were interested in purchasing or already have a green roof. 36% is doubtful and 12% is not interested. The most important features were voted the benefits for the animals (graded an 8,6), the appearance (8,5), and the water collection (8,3).
The respondents cared less about the costs of the green roof compared to that of a heat pump or solar panels (graded 6,4 compared to 7,4 and 7,6 respectively). The people who are doubting, rated easy maintenance considerably higher.

System combination

When the systems are combined, the strong priority of the client is on solar panels (88%). The most important features are voted: positive effect on the environment, low maintenance and a decrease in monthly energy costs.

Conclusion

There is a strong priority of solar panels. The potential client cares about a solution which benefits the environment. It was often noted that aesthetics are the main drawback of solar panels and heat pumps. Especially for doubters, costs and aesthetics are important.

"In the ideal situation, my roof would provide living space for many birds and insects, and make a positive contribution for water storage."

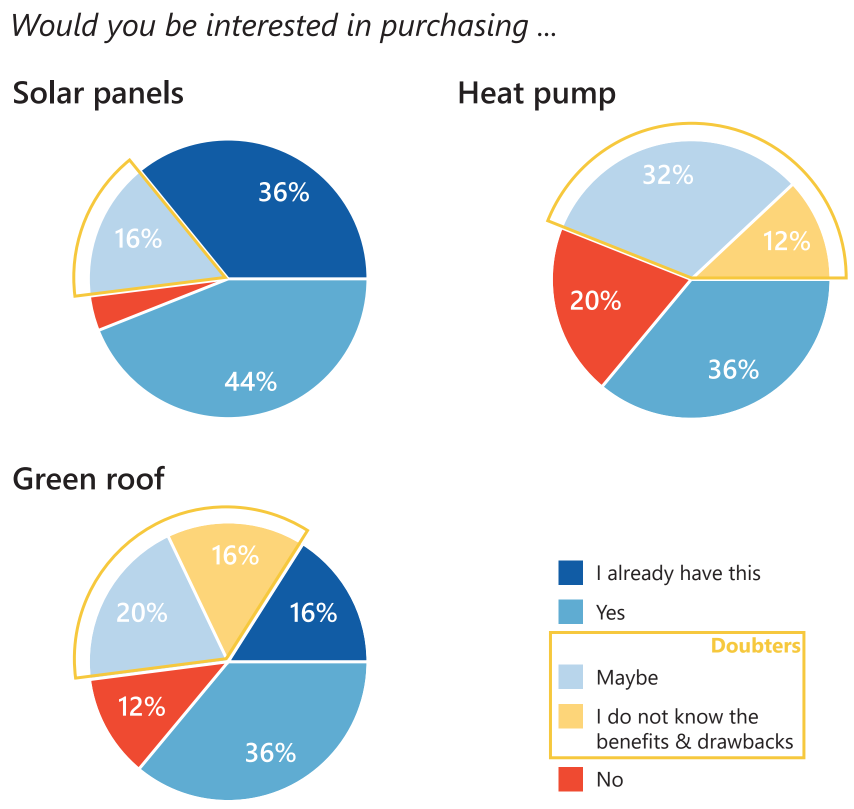


Figure 9. Result of the client research.

7. Green roof

This chapter will give an overview of green roofs, from standard build-up, to installation, maintenance and examples of available products on the market. It will start by explaining the archetype of a green roof.

7.1 Archetype green roof

The general physical arrangement of a green roof is depicted in figure 10.

On top of the surface of the roof, which must be watertight and show no signs of damages or weather weariness, a root barrier is situated to protect the roof from damages induced by the roots of the green roof. On top of the root barrier a drainage layer is placed. This layer ensures that water can be drained to prevent flooding and root rot of the green roof. (On pitched roofs a drainage layer is not a necessity, because gravity ensures the outflow of water.) On top of the drainage a filter cloth prevents the substrate from clogging the drainage system. This filter layer most commonly is made from a geotextile. The substrate is the growing medium, most commonly made from dirt combined with mineral clumps to support healthy plant growth. On top of the substrate layer the vegetation layer is situated.

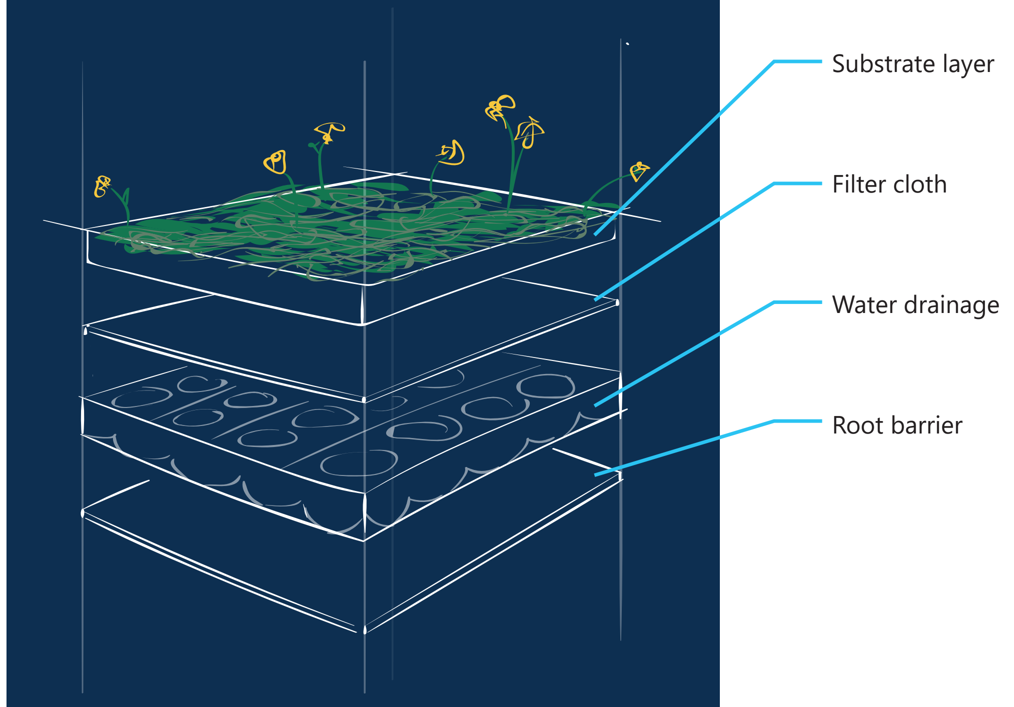


Figure 10. Archetype of a green roof.

This archetype is based on a combination of green roof build-ups from the following sources:
[Babylon Natuurdaken, 2013]
[Dakdokters (A), 2020]
[Groendak, n.d.]
[Growing Green Guide, n.d.]
[Powerhouse Growers Group, 2014]

7.2 Benefits of a green roof

Installing a green roof has multiple benefits for both the consumer and the roof's environment. In this project, the solution will harness these benefits, so for clarity, they are listed down in this chapter.

Decrease Urban Heat Island Effect
Cities can experience a temperature increase of 5 degrees Celius due to their paved and dark surfaces, called the Urban Heat Island Effect. The cooling nature of a green roof contributes to decreasing the Urban Heat Island Effect [EPA, n.d.].

Support biodiversity
The fauna of cities suffers from a shortage of 'green zones'. Green roofs offer a place for native insects, bees and birds to find food and shelter. Furthermore, they function as stepping stones, connecting bigger natural habitats such as parks and city forests [Dakdokters (A), n.d.].

Rainwater buffer
Cities are challenged regarding their water drainage, mainly because the paved surface area of cities is too large. If it rains, all water immediately flows directly into the sewer system of the city, which is then overloaded. Green roofs act as a buffer, retaining 60 to 80% more rainwater than regular roof surfaces [Dakdokters (A), n.d.].

Capture particulate matter and CO2
Plants can capture particulate matter and carbon dioxide from the air and release oxygen. The exact number differs greatly per roof, based on the vegetation that is used [Sempergreen (A), n.d.].

Longer lifespan of roof
A green roof reduces the damages caused by heat and UV radiation. This is because a green roof is cooler than a regular roof, and acts as a barrier for UV radiation. Installing a green roof can double or triple the lifespan of your roof. This will result in a cost recovery time of 8 to 21 years [Sempergreen, B]

Temperature regulation building
During the summer, a regular roof can reach temperatures of 85 degrees Celsius. A green roof keeps the temperature around 35 degrees Celsius. This big difference in temperature helps to maintain a cool atmosphere in the building. For commercial buildings this means they decrease the amount of air conditioning, and therefore a decrease in the energy consumption [Dakdokters (A), n.d.].

Higher efficiency of solar panels
The cooling effect of a green roof is also beneficial for the efficiency of solar panels. The efficiency can increase up to 8.3% when solar panels are used in combination with a green roof [Hui, 2011]. This benefit is highly interesting for this project.

Noise reduction
Paved surfaces of a city reflect sound, increasing the effect of noise pollution in cities. A green roof absorbs sound, achieving noise reduction. Research has shown that a green roof containing a substrate layer of 10 cm can achieve a noise reduction of 5 decibel [Dakdokters (A), n.d.].

Aesthetic value
A green roof can contribute to the quality of life in a city. Research shows that a green environment is essential for human health [University of Illinois College of Agricultural, Consumer and Environmental Sciences, 2011]. This benefit is not only interesting for the owner of the building, but for all the building owners in its proximity. Furthermore, it adds value to the property [Sempergreen (A), n.d.].

7.3 Types of green roofs

There are several types of green roofs. Five types of green roofs have been compared for this project:



Figure 11. Impression of a sedum, biodiverse and landscape roof.

Sedum green roof
Sedum plants are very easy to maintain and grow, and do not require a thick layer of substrate. Therefore these plants lend themselves well for lightweight green roof solutions. Sedum plants are not native to the Netherlands, and therefore city fauna is not able to benefit from the green roof.

Biodiverse roof
A biodiverse roof is a green roof that consists of several, mostly native plants, which can sustain the native fauna, such as bees and butterflies. This way, a biodiverse roof helps contribute to preservation of the biodiversity of an urban environment.

Landscape roof
A landscape roof retains a thicker substrate layer, which enables a bigger diversity of plants to grow, like grasses, herbs and small scrubs.

Shadow roof
A shadow roof is a green roof containing plants that thrive in shadow rich environments. This roof is of particular interest for this project, because it is suitable for the patches of roof underneath the solar panels.

Roof garden
The last category of green roof is the roof garden. This green roof is intensive in maintenance, but provides the user with an extra outside area on their building. However, the weight of this green roof makes it unsuitable for many buildings.

7.3.1 Types comparison

The most common distinction between these 5 green roofs is the required maintenance of the roof. These are divided in extensive, semi-extensive and intensive green roofs. Furthermore, it has implications for the thickness of the substrate layer, and thus inherently for the weight of the green roof, the vegetation, price, suitable roof types and water storage capacity. These implications have been plotted in figure 12.

	Sedum	Biodivers	Shadow	Landscape	Roofgarden
Maintenance	Extensive	Extensive	Extensive	Intensive	Intensive
Type of plants	Sedum	Native grasses, herbs, perennials	Shade plants	Perennials , small shrubs and lawns	Shrubs, trees, lawns
Price/meter *[in € ex. BTW]*	60 - 75	65 - 85	65 - 85	90 - 125	> 130
Thickness of substrate *[cm]*	5	8-15	8	13	> 20
Weight *[kg/m2]*	60-90	120 - 225	120	200	> 200
Water storage capacity *[L/m2]*	32 -150	40-150	40-150	70 -150	>70
Irrigation required	No	No	No	Yes	Yes
Other benefits	Easy and lightweight	Supports city fauna	Suitable underneath solar panels		Possible to grow vegetables

Figure 12. Different types of green roof compared.

This figure is based on information from the following sources:
[Dakdokters (A), n.d.]
[Vegetal I.D., n.d.]
[Sempergreen (B), n.d.]

7.4 Installation

There is a big difference between the installation procedure of a green roof when installing on a flat roof compared to a pitched roof. Above an inclination of 15 degrees, the roof is considered pitched [Breuning, 2020]. Both situations will be discussed separately in this chapter.

7.4.1 Installing a flat green roof

There are two ways of installing a green roof on a flat surface. The first is the conventional way, the second is a modular solution using green roof tiles.

7.4.1.1 A standard green roof

The standard way to install a green roof is as follows [Groendakcoach, 2020]:

Installation steps

1. Clean the roof surface
Make sure the roof surface is clean and has no damages.

2. Lay root barrier
If the roof surface is not root resistant, apply a root barrier foil.

3. Lay drainage and filter layer
Apply drainage layer. The specific way of installing differs per brand of drainage material. On top you can lay a filter layer if this is not integrated in your drainage layer product.

4. Lay separation profile (optional)
Due to weather changes, the green roof can expand and contract in volume. In order to protect your roof, it is advised to apply a strip of gravel between the edge of the roof and the green roof. There are special separation profiles on the market to ease the installation, making sure the gravel is contained and the green roof does not break down.

5. Lay substrate
There are different substrate options on the market. Either a substrate mix in bags is deposited on top of the drainage and filter layer, or the substrate is delivered in rolls that you apply on the roof.

6. Plant the vegetation
Also this step depends on the type of vegetation product is purchased. The options are:
A. Sowing seeds
B. Planting pre-grown plants
C. Applying pre-grown vegetation mats

7. Put down gravel
A raster has to be placed over the roof's rainwater drainage to avoid clogging. After this the gravel strip can be filled.

8. Irrigate
The last step of installation is to irrigate the green roof until it is fully saturated. If the green roof is installed during a dry period, this step needs to be repeated a couple of times.

7.4.1.2 A modular green roof

Another option to install a green roof on a flat roof surface, is by implementing vegetated tiles. There are several companies that offer pre-grown tiles that can be installed directly on the roof. The main benefit of this solution is the quick installation procedure and the immediate 'green' result.

For this project, the tiles of the company Sempergreen have been analysed. This tray contains ten to twelve different types of pre-grown sedum.

Sempergreen Sedumtray TE

Material	**recycled HDPE**
Size [cm]	**45 x 49,5 x 8,5**
Maximum slope	**15 degrees**
Nr. trays/ m2	**4,49**
Weight [kg/tray]	**18** (dry) **& 80** (wet)
Price euro/m2	**52,45**

The tile is delivered green, stacked on each other.

There are two ways to carry the tile.

The material of the tile is very thin, resulting in buckling when lifted.

The tiles is shaped to support drainage

The tiles interlock by overlapping the ridge over te side of the other tile.

The material is easily damaged. Two of the six tiles delivered were torn.

Figure 13. Analysis Sempergreen Sedumtray.

7.4.2 Installing a pitched green roof

When installing a green roof on a pitched surface, alterations must be made to the roof system as described. This is because the slope of the roof adds a shear pressure that causes the substrate layer to erode and collapse. Therefore, reinforcing systems have been developed to realize a green roof on a tilted surface. Furthermore, the need for a drainage layer is eliminated, because the waterflow is enforced by the pitch. See the images for examples of a products that enable a green roof under an angle up to 40 degrees; the Georaster.

Important note:
Currently, there is no solution for a tiled roof on the market, while these are very common in the Netherlands.

1

Place the grid of Georasters. This material support the substrate layer.

2

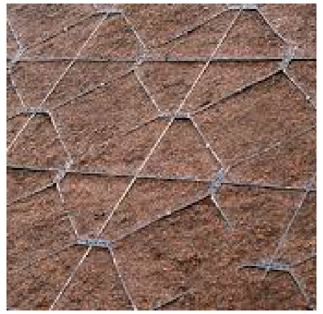
Start implementing the substrate layer (soil). This is pumped up though a big hose.

3

Even out the substrate layer using a rake, make sure it is evenly distributed.

4

Press down the substrate layer to give if cohesion, so it does not wash away easily.



5

Plant pre-grown plugs, suitable for the climate, substrate layer in inclination.

Figure 14. Installing hte Georaster on a pitched roof.

7.4.3 Installation challenges

Several challenges are identified, divided into before, during and right after installation.

Before

Not considering context
The plants of the green roof should be selected considering the weather of the location (wind, rain and sun), the slope and altitude of the roof. Failing to do so can cause plant death, leading to green roof erosion. [Kakonga, 2019].

Not matching drainage to vegetation
Different plant types have different water needs. When a vegetation type is selected, the drainage should retain enough to sustain the plant, but not too much to avoid root rot. [Lopez, 2020]

Roof construction
A green roof can be heavy, especially when saturated with water. Experts and construction engineers should be consulted before placing a green roof. [GreenRoofPlan, n.d.].

During

Protect inlet drain pipe
Drainage is crucial for the plants' health. Vast waterflow carries away the substrate layer or loose vegetation, causing the drain pipe to clog. There are products on the market to avoid this.

Fit around obstructions
A difficulty when installing a (modular) green roof is placing it around all obstacles on a roof without hindering their functioning. E.g. ventilation outlets can be relatively low, ending up in the vegetation layer, causing obstruction of the airflow.

Roof damages & priming
Before placing the first layer, the roof should be thoroughly checked for damages. During installation, tools, such as rakes, have to be handled with care, to prevent damages. Repairing a leakage is problematic after the green roof is installed.

After

Inadequate irrigation
After installation, the vegetation layer has to be intensively watered. The roots of the vegetation layer need to permeate the substrate layer to avoid erosion and plant decay.

7.5 Maintenance

Green roofs need to be maintained. In chapter 7.3.1, the maintenance requirements have been discussed briefly. In case of an extensive roof, such as sedum or bio-diverse roofs, it requires maintenance twice a year on average. This maintenance entails removing weeds, fertilizing, checking if the drainage is not clogged and during dry periods, it might be necessary to water the green roof [The Renewable Energy Hub UK, 2018].

Figure 15. Weeding as part of green roof maintenance.

7.6 Subsidies green roofs

Citizens of Amsterdam and organizations can apply for a subsidy for green roofs and/or facades, due to the benefits for the environment, the climate and water drainage (Gemeente Amsterdam [B], 2020). The following requirements to qualify for this subsidy are relevant for this project :

1. *The building (or boat) is situated in Amsterdam.*
2. *The part of the roof that will be used is older than 5 years.*
3. *The green roof has to last for at least 5 years.*
4. *The green roof is bigger than 30 m2 (combining roofs with surrounding buildings is allowed).*
5. *The green roof is capable of storing a minimum of 30 liters of water per m2.*

The subsidy amount will maximally cover:

1. *Up to a maximum of 50% of the entire costs of the green roof. The costs entail; all the required layers of the green roof (including a root protection layer and drainage layer) and the installation costs. Expenses for the construction of a roof terrace and regular maintenance will not be taken into account.*
2. *Up to a maximum of €30,- per m2 if the water storage capacity is between 30 and 50 L/m2.*
3. *Up to a maximum of €50,- per m2 if the water storage capacity is higher than 50 L/m2.*
4. *If over 50% of the surface area of the green roof consists of native grasses, herbs and shrubs, an additional €10,- per m2 can be requested.*
5. *The maximum amount per subsidy application is set on €50.000,-.*

8. Solar panels

The second system that this project will focus on are solar panels. This chapter will discuss the archetype and installation procedure of solar panels. The chapter will conclude with the requirements that arise due to the implementation of solar panels in the solution.

Additional research, including a comparison between technologies of PV panels and financial constructs to fund solar panels can be found in appendix D and E respectively.

Figure 16. The archetype of a solar panel.

8.1 Archetype solar panels

Solar panels are made up from the element silicon. When sunlight hits the solar panels, a DC (direct current) electricity is generated due to moving electrons in the panel. In order to create AC (alternating current) electricity, which is suitable to use in a household, the electricity from the solar panels first travel to an inverter. It is either possible to provide every solar panel with its own inverter, or there is a central inverter linked to all the solar panels combined. [EnergySage, 2018].

Depending on the installation (see §8.2), the solar panels are attached to a frame on the roof, and grounded and bonded. The most common dimensions for PV panels for residential use are 1.65 by 0.99 meters. For commercial use, so for example a system on a warehouse or a municipal building, the dimensions most commonly are 1.96 by 1 meter. [Energysage B, 2018] [Zonnepanelen. Net, n.d.]. The angle of the solar panels is advised to be around 35% to ensure optimal efficiency of the panels [Consumentenbond A, n.d.].

Solar panels 8.

8.2 Installation solar panels

Similar to green roof systems, there is a significant difference between installation of solar panels on a flat or a pitched roof. Both are interesting for this project, so will be discussed.

There are three scenarios of installation. These scenarios were established in the interview with P. Schram (appendix B):

1. Optimal scenario; *aim to have the maximum efficiency with the minimum of panels.*
2. Maximal scenario; *aim to have the maximum number of panels on the roof surface.*
3. Budget scenario; *aim to place the number of panels the client can afford.*

8.2.1 On a flat roof

When solar panels are placed on a flat roof, they are placed on a frame to angle them towards the sun. Most companies provide frames with standardized angles of 10 or 15 degrees [VanderValk Solar Systems, 2020], even though the optimal angle is 30 degrees [Siderea, 2020].

The easiest, and most common way to secure them is by using ballast. In practice this mostly comes down to placing concrete tiles on the supportive frame of the solar panels, as can be seen in figure 17.

The required weight of ballast is calculated per case, using the software supplied by the manufacturer of the panels (Schram, 2020). In practice, there may be instances where this calculation is not performed to standard. In some cases ballast is added according to the installer's experience.

Figure 17. Insights concerning solar panels of observational study 2, Appendix G.

8.2.2 On a pitched roof

The panels are placed directly on the roof, in the same angle as the roof. Five main steps have been distilled from the in-depth interview with P. Schram of SunisFree (Appendix B) and an observational analysis of Yanaki BV (Appendix F).

Figure 18. Insights concerning solar panels of observational study 1.

1. Erect the scaffold
In order to reach the roof, a scaffold is required. During most projects, the scaffold is erected and broken down on the same day. In theory, fall protection has to be installed next. However, in practice that it is often skipped with many projects (Yanaki, 2020).

2. Install roof anchors and frame
Roof anchors are stainless steel hooks that form the base of the mounting system. They can either be clamped on the roof tiles, or screwed into the supporting beams of the building. Extra roof anchors can be placed if the installer estimates this is necessary, e.g. at locations where wind forces are bigger (Schram, 2020). The mounting frame, two aluminium rails that will support the solar panels, is installed on the hooks.

3. Realizing the electrical circuit
In this step, all the wiring to finalize the circuit is installed. Depending on the system this could include all the microinverters, or one central inverter, and the grounding and bonding of the system.

4. Place the solar panels
The solar panels are placed on the rails using clamps which grip the aluminium border of the solar panel.

8.2.3 Installation challenges

During the installation of solar panels, mistakes can be made that compromise the future working of the system, or even create dangerous situations during use.

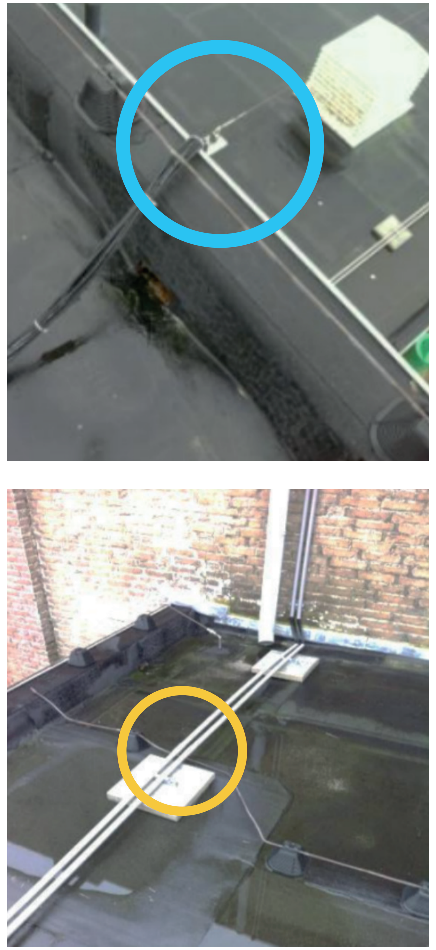


Figure 19. Faulty installed solar panels cables.

1. Working safely with fall protection.
Not every installation of solar panel. If the distance to the roof edge during installation and maintenance is shorter than 4 meters, fall protection (either permanent or temporary) is required [Skysafe, 2020]. In many cases, there is not enough space on the roof to keep this distance. In both the flat and pitched roof observational studies, a lack of fall protection was recorded.

2. Mapping the shade of the roof
If one panel is partly covered by shadow, it will compromise the entire solar system. A micro-inverter could be used to optimize the solar system's efficiency [van der Wilt (B), 2019]. Even when working with advanced models to optimize efficiency can be compromised by inaccurate modelling of objects and 3D space on and around rooftops [Georgiou, 2020].

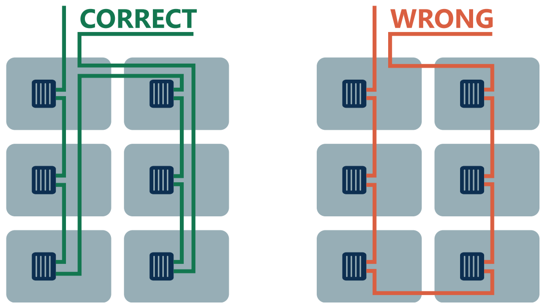


Figure 20. Schematic layout of cable management.

3. Cablemanagement:
Concerning cablemanagement, the following points are important:

i. Avoid induction loops in the system (figure 20). [Van der Wilt (F), 2019]
ii. Keep cables as short as possible; This will result in less energy loss and cheaper system costs. [Van der Wilt (E), 2019].
iii. Avoid placing cables over sharp angles (figure 19); This will short circuit the system over time [CTS, 2019].

4. Distance to roof edge
It is required to place the solar panels at distance from the roof edge to minimize wind loads [Van der Wilt (E), 2019], following the guidelines of Eurocode NEN-EN 1991-1-4, and is dependent on the width, length and height of the building [Zonnepaneel-info, n.d.].

5. Lighting conductors
When there are lightning conductors present on the roof, PVs or cabling should not be placed over lightning conductors without preserving safe distance or equalizing the circuits (see figure 19 for an example of an installation fault). [CTS, 2019].

6. Grounding the system
It is important to ground the PV system, not only to redirect lightning but also to avoid shocks from the system when repairing or maintaining the system [Van der Wilt (F), 2019]. Unfortunately, this is often neglected in practice [CTS, 2019].

7. Distance from roof surface
The panels must be dinstanced from the roof surface, to provide airflow underneath the panels. Placing the panels too close to the roof surface can not only affect the efficiency, but could cause fire hazards [Van der Wilt (E), 2019].

8. Over- or under-torquing
When installing, an observed fault is over- or under-torquing screw terminals and fasteners, which can lead to loose connections or stress on module frames [Brubaker, 2020] [Comstock, 2020].

9. Interrupting water flow
Another installation error is when panels or cables are placed in such a manner that they disrupt the water flow and block drainage, resulting in leakages [Thomas, 2019].

8.3 Standard ballast requirements

On flat roof surfaces, solar panels are weighed down using ballast. The required ballast to secure the panels safely is dependent on the angle of the solar panels, the wind region, the height of the building and the landscape type (ranging from rural to urban).

Amsterdam is located in a wind region of an average of 27,5 m/s. The required ballast in kilograms per square meter of solar panels installed specific to Amsterdam can be found in figure 21 [Zonnepaneel-info, n.d.].

Required ballast on flat roof in Amsterdam
in kg/m2 solar panel

Height of the building	Angle of the PV panels 20°	30°
>5 meters	16,1	17,9
>10 meters	16,1	17,9
>20 meters	17,7	19,7

Figure 21. Standard ballast for rooftops in Amsterdam.

8.4 Maintenance

Maintaining solar panels is a relatively easy job. The panels need to be cleaned to ensure proper working. The frequency depends on the environment of the system (whether it is dusty or surrounded by trees for example), and can range from twice a year to once every five years The consumer is also able to do this themselves. [Schram, 2020].

It is advised to have a routine inspection of your panels at least every five years. The system is checked on damages, microcracks and other aspects that could affect the system's efficiency [SolarMarket, 2019].

With proper maintenance, solar panels have a life expectancy of 25 to 30 years [Richardson, 2020].

9. Heat pump

For this project, the last interesting technology to be analysed is heat pumps, due to the possibility to install the outdoor part on the roof and the expertise and experience of the company. A factor that complicates the implementation of heat pumps in the given context is that many houses in Amsterdam are not insulated upto a standard where heat pumps can provide sufficient warmth to sustain the household. In this case it is necessary to implement a hybrid heat pump [HIER (B), n.d.]

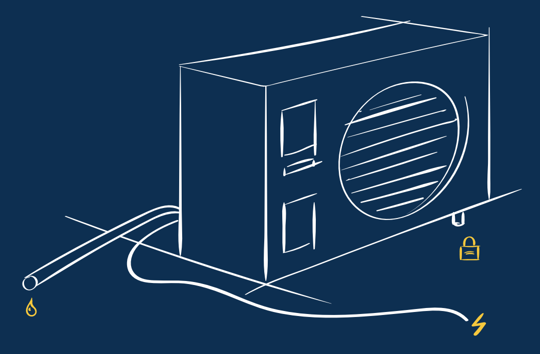


Figure 22. The archetype of a heat pump.

9.1 Archetype heat pump

For this project the scope is limited to roof-installations. The specific technology of heat pumps that are appropriate to install on a roof are air-water heat pumps or solar heat collectors. Both come in a wide range of sizes and set-ups. For this project, the characteristics of the outside unit is relevant. These outside units are also varied in their physical features. However, they share the following common denominators:

1. Electricity need
The ventilator and pump of the heat pump need electricity to work. Therefore a cable traject needs to be installed on the roof.

2. Refrigerant supply
Next to an electrical supply, the heat pump needs a supply traject for the refrigerant liquid. This pipe is insulated, most commonly with the insulation as an outer layer (unprotected).

3. Roof anchoring
The heat pump needs to be secured to the roof. This can either be done by securing it to the roof using bolts, or by using ballast.

9.2 Benefits and drawbacks

For the consumer, there are several advantages and drawbacks when opting for a heat pump.

Benefits:

1. Sustainable addition to a house, reducing the energy required.
2. The return of investment period is 7 years (for hybrid heat pumps) or 13 years (for air-water heat pumps)
3. [Valliant, 2020]. After this period you start profiting from the system. Some air-water heat pumps are able to cool during summer time [HIER (B), n.d.].

Drawbacks:

1. There can be sound nuisance caused by the heat pump.
2. The insulation measures required to ensure the effect of the heat pump are expensive. Moreover, a balance ventilation is required. [HIER (B), n.d.].
3. Both the outdoor and the indoor unit take up a lot of space.
4. Many of the outside units are not considered aesthetically pleasing. However, there are developments to try and make the outside units smaller, more attractive, or discrete [Warmtepomp-info, 2018].
5. The insulated piping for the refrigerant liquid is unprotected. It is easily damaged and eaten by birds. This is harmful for both the system's efficiency as the birds.

Figure 23. A heat pump installed on a green roof, in a casing to muffle the nuisance.

9.3 Types of pumps

For the project we will distinguish between two types of heat pumps:
1. Standard heat pumps
2. Heat pumps for a pitched roof

Within these category types there is still a wide variety of products. However, the determination of which heat pump is appropriate is greatly dependent on the specific needs of the user and context (read rooftop & building), while the common denominators (§9.1) stay the same. Therefore, the design of this project will attempt to be multi-suitable for different types of sizes and brands, and focus on smart integration of the common denominators. The other option, to create a solution that only supports one specific type of heat pump, would not be viable on the market.

9.4 Installation heat pumps

The two types of heat pumps differ in installation methods. They will be discussed separately. They do share a number of installation requirements:

1. The heat pump's base must be installed on a flat and level surface.
2. The system should not obstruct drainage.
3. If necessary install vibration dampers between the heat pump base and floor.

9.4.1 On a flat roof

Outside units of standard heat pumps are installed by securing the unit to montage beams (recycled plastic beams) to increase stability and placing these on the roof. There is some inconsistency in application of ballast. Some companies state no ballast is necessary., others follow the guideline of using the same amount of ballast as the weight of the heat pump (average of 70 KG) [VSK, ThermoNoord, 2020].

The outside unit can also be anchored to the roof using bolts. This method is more secure, but can also cause leakages in the roof surface.

Mounting materials
There are several products on the market to support easy heat pump installation, such as:

1. Special roof anchors with integrated leakages prevention.
2. Special frames to level and secure.
3. Systems to muffle and dampen.

Figure 24. Images to give an impression of the heat pump installation set-up.

9.4.2. Installation on a pitched roof

There are several heat pumps on the market that are developed specifically for pitched roofs. A good example is the Ubbink Decorio (figure 25). Installing these systems is more extensive than an installation of a flat roof. A part of the roof needs to be altered to receive the system. However, cable management, fall-protection, maintenance features and appearance improvements are integrated.

Furthermore there are frames on the market that enable installation of standard heat pumps on a pitched roof.

Figure 25. Heat pump specifically developed for pitched roofs.

9.4.3 Installation challenges

Several installation challenges of a heat pump are identified.

Blocking roof drainage
The support beams and cables of the heat pump should not obstruct the water drainage of the roof.

Too long refrigerant supply
The refrigerant supply pipe should be kept as short as possible to optimize the system's efficiency.

Sharp corners in cables
Sharp corners and loops should be avoided in the cabling of the heat pump.

Not properly anchoring cables
The cables should be anchored or ballasted, so they do not move with heavy winds and rainfall.

Not providing enough stability
The montage beams of the heat pump can be cut too short, resulting in low stability.

Be installad under an angle
Heat pump must be installed horizontally. This can be challenging if the roof surface is sloped.

Lack of proper clearance
When placing the outside unit of the heat pump, a rough meter should be kept clear around the unit to permit airflow to and from the unit. [Demers, 2020]. This installation error was also noted at observational study 2, where solar panels were adjacent to the outside unit of an AC.

Observational study
Leonardostraat, Amsterdam

Chaotic cabling

Ballast of cables

No proper clearance for airflow

No protection for birds

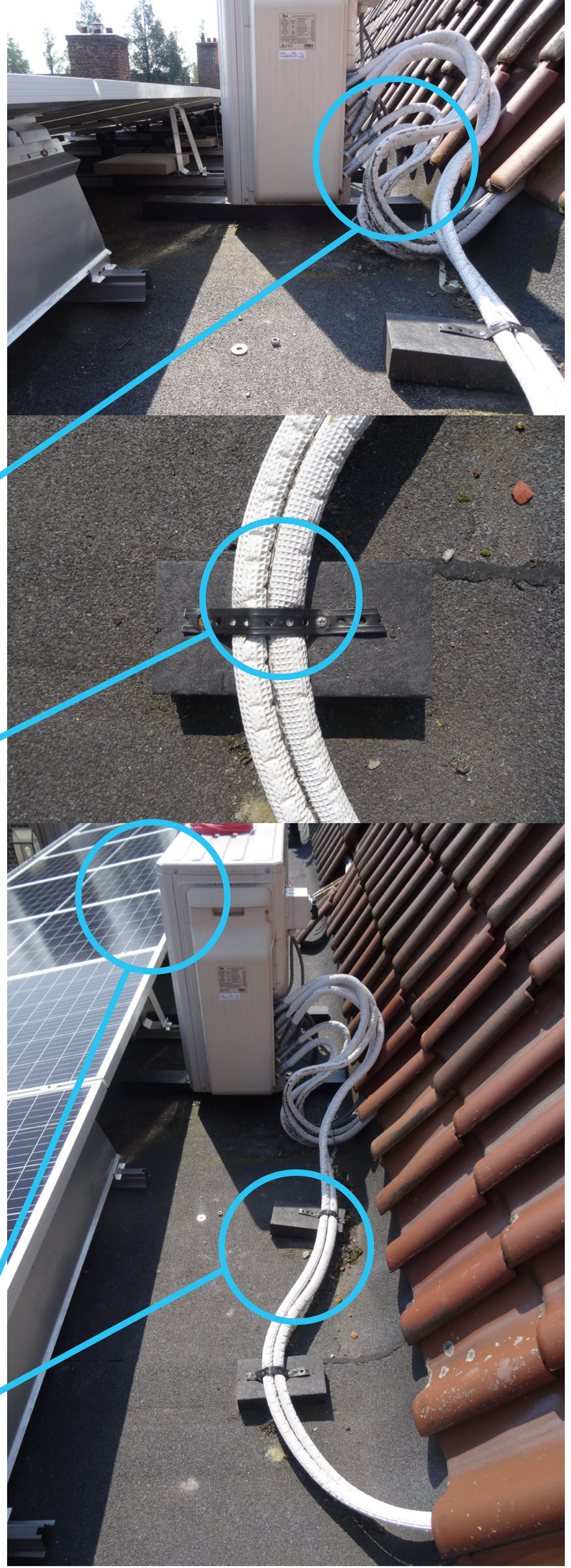


Figure 26. Insights concerning the heat pump gained in obsservational study 2.

9.5 Maintenance

The maintenance of the heat pump mostly consists of check-ups of proper working. This includes airflow tests, cleaning and damage checks. This instills the need to access all piping, the wiring and the outside module on a yearly basis [Turpin, 2017].

10. System combination

Figure 27. Picture taken on client location of the company of an inverted roof with heat pump.

Currently, there are no solutions on the market which smartly integrates solar panels, heat pumps and green roofs. However, combining these systems to optimize roof use and system efficiency is a viable solution to help households with their energy transition. Especially in urban areas, where square meters are valuable, energy demand is high, and the lack of green areas is crippling both the drainage system and the city's fauna, significant gain can be achieved by smart use of the available roof surface. This chapter discusses the opportunities and challenges that arise when these systems are combined.

Free orientation solar panels

A challenge of this project is the flexible orientation of solar panels towards the sun. Depending on the client's and household needs, the solar panels are either placed following the borders of the roof (maximal scenario), or oriented to the sun, i.e. south (optimal or budget scenario) (Schram, 2020). This means the solution should allow for free orientation of the panels relative to the roof's borders.

Combine and order cable management

Both heat pump and solar panels have cables running to a passage in the roof surface. There is no integrated solution for cable management on a green roof, while this could avoid system damages. An added benefit is to provide a solution which protects the cables of the heat pump from birds and erosion caused by weather.

Added aesthetics

One of the biggest reservations potential clients have regarding purchasing solar panels, is that these systems will ruin the exterior appearance of their home. However, their main appreciation of green roofs is their aesthetically pleasing look (chapter 6.2). The solution can take advantage of this green roof feature to make solar panels more attractive.

Maintenance en repair

When combining the systems, they should remain accessible for maintenance and repair. It could happen that the roof surface needs repair or maintenance. This can become a challenge when implementing a green roof, which the solution should strive to tackle.

Utilize the weight of the green roof

Both solar panels and heat pumps need ballast to be secured to the roof. A green roof contains a thick layer of substrate: employing the weight of the green roof as ballast for the other system is a convenience when integrating these systems. A thing to keep in mind is that this introduces a new force to the green roof. Suddenly there will be a force pulling the layers upwards.

Scalable and modular solution

Every rooftop is different in size, layout and inclination. To enable the company to manufacture one product, which suits most of their clients, the solution should be modular and scalable. With scalability, the system could also become scaleable over time. This enables the client to gradually invest in their rooftop's functions.

Inverted insulation

A well known misconception of a green roof is that it insulates your home. A green roof does not add additional insulation to your home, due to its minimal R-value. (A green roof does cool your roof surface during warmer days, and therefore cools your house.) However, if extra insulation is desired, an insulated layer can be added on top of your outer roof surface. This is a well-known practice in the Netherlands, applicable to flat roof surfaces, called an inverted roof (omgekeerd dak). The insulation layer is secured by a ballast layer, typically consisting of gravel or concrete tiles. The combination of these systems provide the opportunity of integrating a layer of insulation, which could be secured by the weight of the system itself. In figure 27, an example can be seen of an inverted roof, taken when observing the company.

11. Ideation

This chapter will discuss the concept criteria, the ideation and its results. It concludes with the concept selection.

11.1 Concept criteria

Based on the research insights from literature research, interviews, observational studies, company discussions and creative sessions, concept criteria have been established to guide the concept development. The criteria list is the foundation for the List of Requirements (chapter 12.4), and are divided into 5 categories: the system, the client, the company, the government & market and project drivers.

The system

The system should...

- C1.1 combine solar panels, green roof and heat pumps.
- C1.2 maximize efficiency of roof use
- C1.3 be scalable in size
- C1.4 be scalable over time
- C1.5 keep component accessible for maintenance and repair

Client

The client needs a system which...

- C2.1 allows for costumization to their specific needs
- C2.2 primarily focusses on PV panels
- C2.3 is visually pleasing/adds to the appearance of their house
- C2.4 is non-invasive to their roof structure
- C2.5 is affordable
- C2.6 is easy to maintain

Company

The company needs...

- C3.1 a system which is easy to install (standard is 2 people) and minimizes human error during installation
- C3.2 to start with a small design intervention
- C3.3 to make use of available products on the market
- C3.4 to have low investment costs
- C3.5 to have the potential to scale the solution up to a product line
- C3.6 a system which is suitable for the biggest number of houses in their targetmarket
- C3.7 a system which is plug and play, and does not require big alterations to the roof
- C3.8 to be able to prototype and develop gradually before investing in manufacuting
- C3.9 to combine intallation procedure of solar panels, heat pump and green roof (cheaper and quicker)
- C3.10 to inform and convince the client to install an eco-roof

Market & Government

The system should...

- C4.1 have a competitive advantage on the market
- C4.2 be up to safety standard
- C4.3 be visisble from the street

Project drivers

I want to...

- C5.1 be able to work out to a detailed level, with available information
- C5.2 be able to create a biodiverse roof surface, instead of sedem
- C5.3 allow for prototyping

11.2 Ideation structure

The ideation on the design challenge has been divided into three cycles.

Cycle 1
The focus of the first cycle was to find a solution with high feasibility for the company, by combining products on the market and adding small but crucial design intervention to create a unified system for flat roof surfaces. The cycle started with a create session, which can be found in Appendix H.

Cycle 2
The second cycle aimed to create a solution suitable for tiled roofs, which is exceedingly common in the Netherlands, yet thus far incompatible with a green roof. The focus was on creating a solution which would enhance the exterior of the building, to increase the desirability of the design (an opportunity based on the client research).

Resulting concepts and selection
These two cycles resulted in two concepts with a very opposing solution approach. These concepts were presented to the company and a selection was made, using the concept criteria as guidance. In this discussion, further requirements for the concept were identified.

Cycle 3: Final concept
This concept selection was the start of the third cycle. In this cycle, the feasibility of the selected concept is by detailing the embodiment of the system. Furthermore, the viability is illustrated by a future development roadmap.

In the coming chapter we will discuss the results of the cycles and the concept selection. For the complete ideation during cycle 1 and 2, see Appendix I and J respectively.

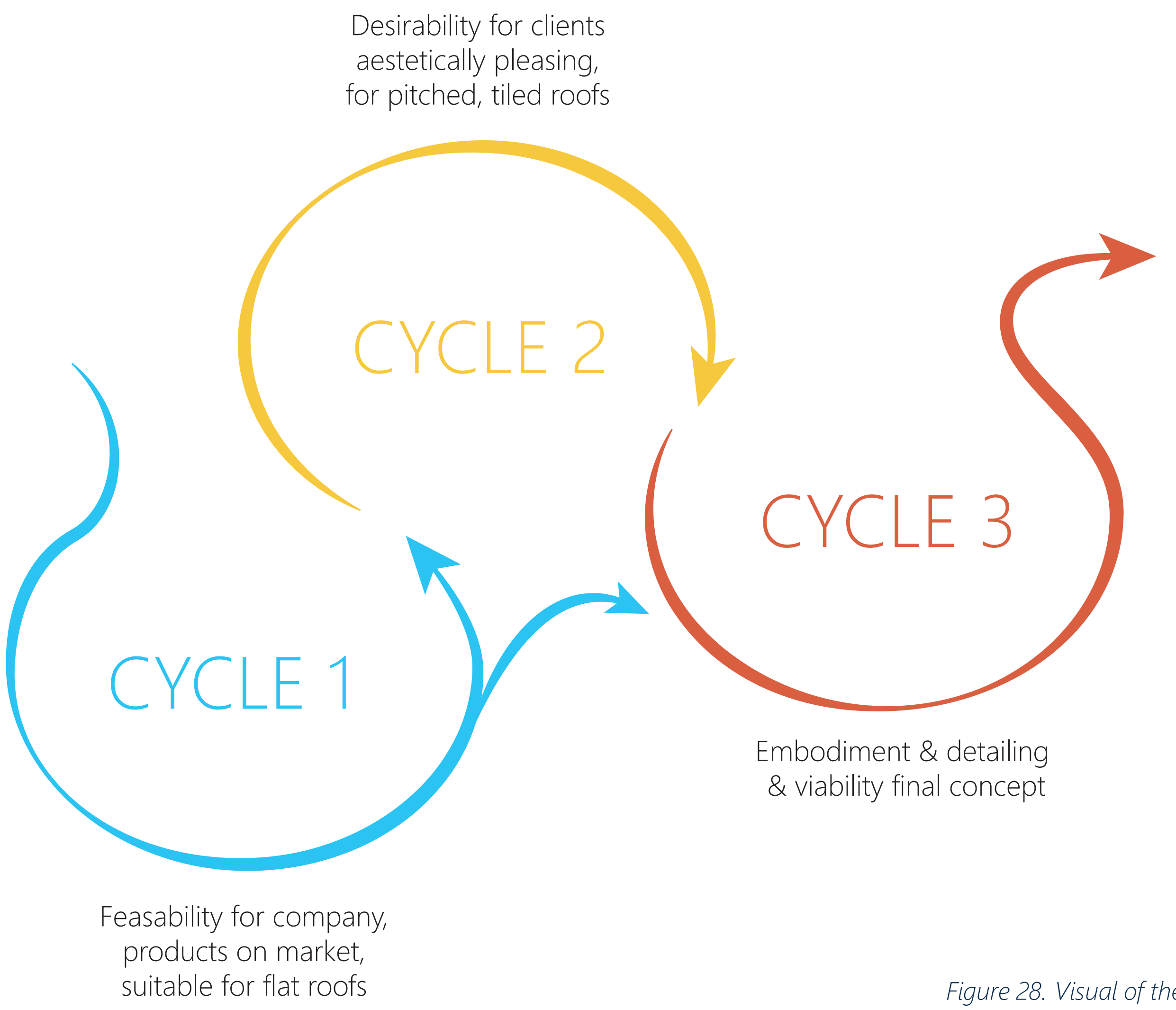


Figure 28. Visual of the design cycles.

11.3 Result cycle 1

11.3.1 Market opportunity

There is no universal anchoring mechanism for the wide variety of solar panels and heat pumps on the market. The anchoring of these systems is further complicated when combining it with a green roof. Every installation project requires an appropriate system selection combined with custom alterations by the company to install solar panels, heat pumps and green roofs as combination. This concept provides a raster build from existing tiles on the market as a platform to install other systems to. By creating a common, generic connector between the green roof and other systems, installation is simplified.

The company does not have experience in developing products on scale, nor does it have great starting capital for product development. This concept enables the company to start prototyping system configurations using existing products on the market. Only minimal design intervention to link the systems to the green roof needs to be developed. This results in low start-up costs and a quick time-to-market for the company. Starting with existing products, enables the company to start prototyping and developing their own product, while already operating professionally. The company does not have a lot of experience with installing solar panels and green roofs, so this concept enables them to develop their product and gain experience simultaneously.

11.3.2 Vision

Create a scalable solution for the company to install heat pumps, solar panels and a green roof, using products on the market and respecting the company's expertise and limitations, for flat rooftops

Figure 29. Impression picture of solar panels on a flat green roof.

11.3.3 Concept

The product is built up from three components. The grid, the connectors and the systems.
The grid is composed of tiles available on the market, currently used to reinforce driveways and parking lots. The tiles are attached to each other, resulting in a grid that supports the green roof and provides a way to secure the connectors. The connectors will connect the systems, solar panels and/or heat pumps, to the grid. By using the grid and connectors to attach the systems to the green roof, ballast or roof anchors become obsolete. Furthermore, it provides configuration freedom to direct the solar panels towards the sun.

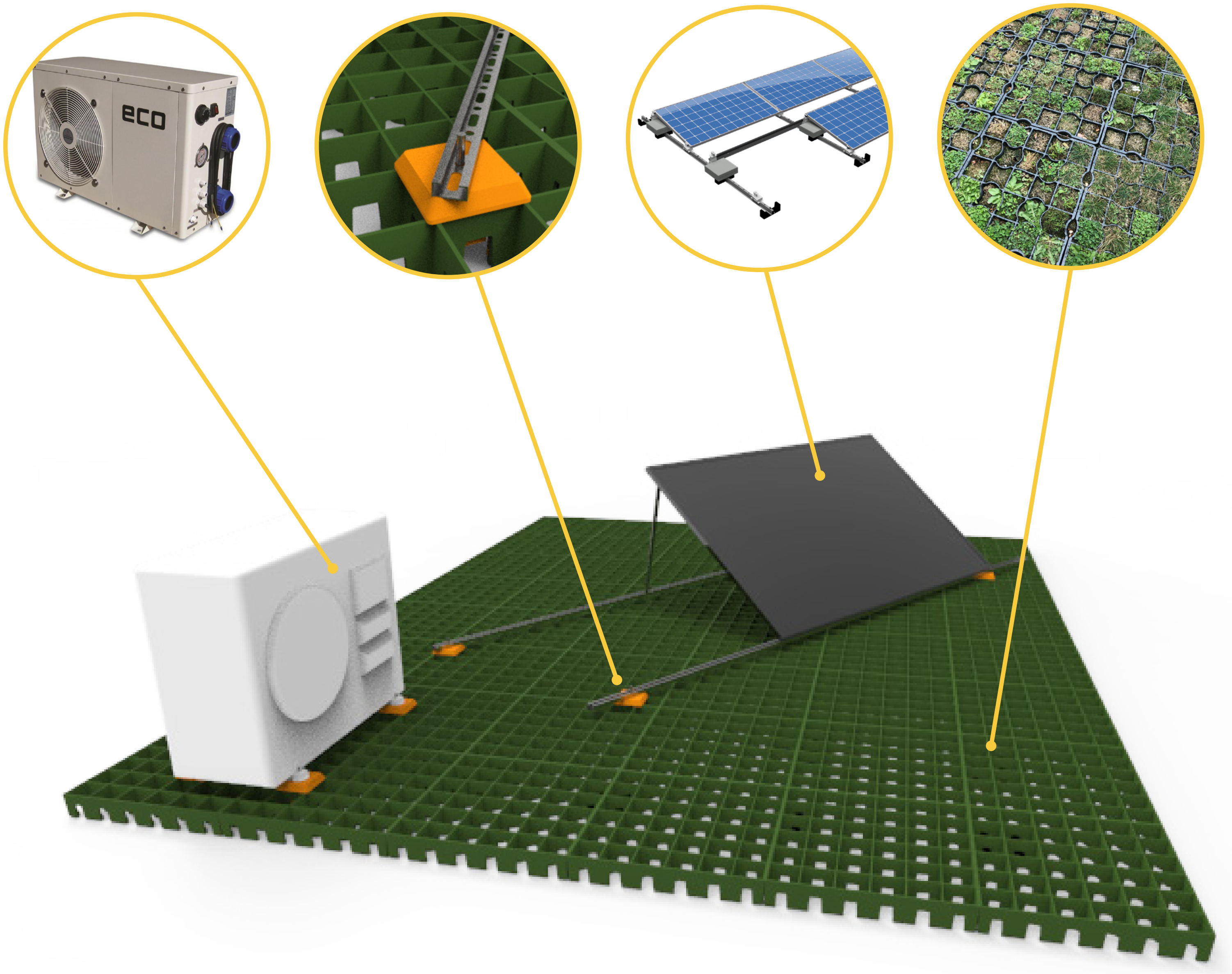


Figure 30. Concept of cycle one, with focus on the heat pump, the anchors, a solar panel and the grid tiles

11.3.4 Installation

1. Placing the grid
Firstly, the grid is installed on the roof. Installation can be done by one person, but is preferable done by two persons. The grid will be laid to cover the biggest surface area as possible, avoiding obstacles such as chimneys or venting outlets. Before laying down the grid the consumer can opt to apply a layer of insulation.

2. Placing the connectors
After the grid has been laid, the placing of the connectors can be measured out. This depends on the systems that will be installed and the desired orientation of these systems. For solar panels, this means they need to receive the maximum sun hours a day and be oriented towards the sun. For heat pumps this means sheltered from the wind, away from edges and with a minimum distance of a meter from objects to ensure air circulation.

3. Installing solar panels and/or heat pump
The connectors can either be directly attached to a designated support system of the solar panels, or to Flamco rails, onto which solar panels can be installed. This depends on the type of solar panels which are used, which is to be determined with the consumer.
The heat pump is installed in the same way. It can either be installed directly to the connectors, or rails can be placed in between to attach the connectors to the heat pump. In further development, the opportunity to place vibration absorbers between the connectors and the heat pump at this stage of installation can be explored to minimize noise pollution.

4. Installing green roof
After the installation of the systems, the green roof can be installed. The layer of substrate will be applied to fill up the grid. After this mats of sedum can be placed, plants can be plotted or seeds can we sown, depending on the preference of the consumer.
If extra ballast is required, standardized concrete stones for garden patios (which have the same dimensions as the grid tiles) can be used on top of the grid instead of sedum on strategic spots.

5. Install cabling
After the green roof is placed, the cables of the solar panels and the heat pumps can be installed. Connectors can be used to support cable management products.

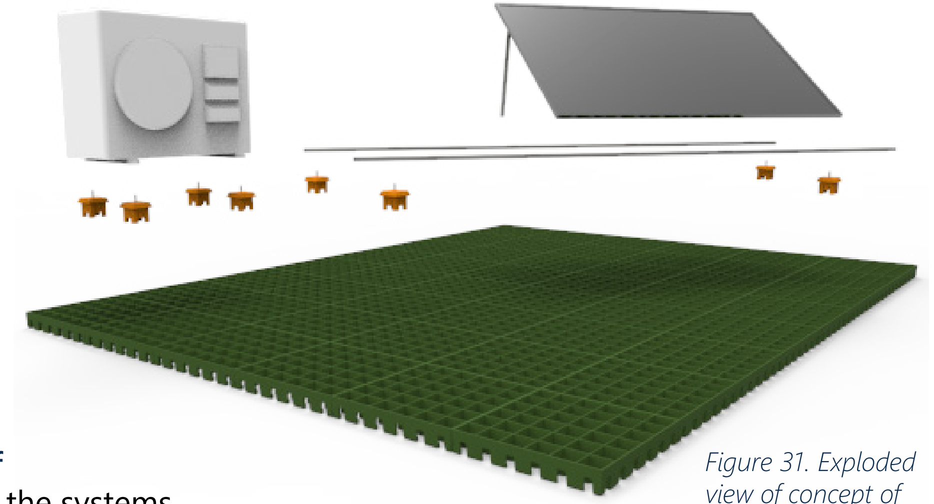


Figure 31. Exploded view of concept of cycle one.

11.3.5 Maintenance

The system allows the solar panels, heat pump, cables and green roof to remain accessible for maintenance. By using cable management to run your cables above the green roof surface, the cables remain accessible for maintenance. The roof surface remains walkable. The grid reinforces the green roof, while also distributing the weight to avoid point load.
The solution is also scalable over time. It enables the consumer to firstly only install solar panels and green roofs, and later on install a heat pump using the already installed grid.

11.3.6 USPs

- Uniform fixation method for all components.
- Biggest green roof area possible (good for nature and roof).
- Standardizing installation methods of different systems.
- Possibility to re-organize, expand or remove part of the system.
- Minimize human error during installation.

11.3.7 Development challenges

- Make sure that the attachment of all the systems are up to safety standards.
- Placement connector pieces.
- Keeping it simple

11.3.8 Costs

The material costs of this concept are estimated to be around the €7600. These are the costs for 6 solar panels, the framework to install these panels, a heat pump and 25 square meters of green roof, including the grid tiles.

Calculation for 25 square meters of roof with 6 PVs	€/piece	#	€/installation
Tiles	11,38	25	284,5
Heat pump installation	5000	1	5000
			0
Solar panels (6x)			
Panels			
Trina Solar Honey 340wp (1698 x 1004 x 35 mm)	137	6	822
Frame			
Alu voor voet ValkPro+ P/L10° midden	4	4	16
Alu voor voet ValkPro+ P/L10° zijkant	4,85	4	19,4
Alu achter voet ValkPro+ L10° midden	6,22	4	24,88
Alu achter voet ValkPro+ L10° zijkant	6,73	4	26,92
Verz dakdrager L=1500x1,5mm + koppelstuk 87mm	11,17	4	44,68
Verz achterplaat ValkPro+ P10° L=1560mm (1300-1500mm)	13,35	4	53,4
1,067 11,63 10,47 Verz zijplaat ValkPro+ L10° universeel.	11,63	2	23,26
Schroeven, bouten etc			15
Flamco rails	8,55	6	51,3
Green roof			
Sedumtray indicatie	50	25	1250
Connectors			
Developed by Paviljoen3	7,33	10	73,3
Total		€	**7631,34**

Figure 32. Cost calculation of concept of cycle one.

11.4 Result cycle 2

11.4.1 Market opportunity

The interest in ecological solutions for household provision has been increasing over the last decade. Subsidies from the government motivate home-owners to invest in solar panels or comparable systems which help to make their houses more eco-friendly. That many homeowners are interested in purchasing solar panels, heat pumps or a green roof was also confirmed in research performed for this project. Solar panels are especially popular, and the benefits for the consumer are clear. Heat pumps and green roofs are considered interesting, but the advantages for the client are not always apparent.

Besides high investment costs and unclear advantages, one of the main reasons to not purchase either solar panels or heat pumps, is because they diminish the aesthetic value of the consumer’s home. Appearance is an important decisive factor in the purchase of these systems, especially with the number of pitched roofs in the Netherlands, with the surface visible from street level. In the current market, this want of the user is clearly visible in the manufacturer’s effort to create either aesthetically pleasing or camouflaged systems (heat pumps which look like chimneys, solar panels that look like roof tiles). However, when you are combining these types of systems on a roof, they still look random and out of place.
For Paviljoen3, there lies opportunity in offering a combination of the three systems that does not diminish the appearance of the house, but instead adds to it. This concept is developed specifically for pitched roofs, to maximize the advantage of the design.

11.4.2 Vision

A modular system, adaptable to the specific wishes of the home-owner, to combine solar panels, a heat pump and green roof on a pitched roof. With special attention for the aesthetic unity of the installation, it adds to the house’s appearance.

Figure 33. Impression picture of a pitched green roof with solar panels.

11.4.3 Concept

By using different configurations of solar panels and green trays a design can be co-created with the home-owner. They can mix and match the amount and situation of solar panels, green trays and heat pumps, taking into account the desired look and systems optimal performance. Different configurations can be made in geometrical shapes that cover part of the tiled roof. This roof surface is approached as an extension of the garden, and designed with the same care. The systems do not look like they have been randomly dumped on the roof, but are part of an integrated design.

Figure 34. Concept result of cycle 2, with special attention for the heat pump, the sedum trays and standard roof anchors.

11.4.4 Installation

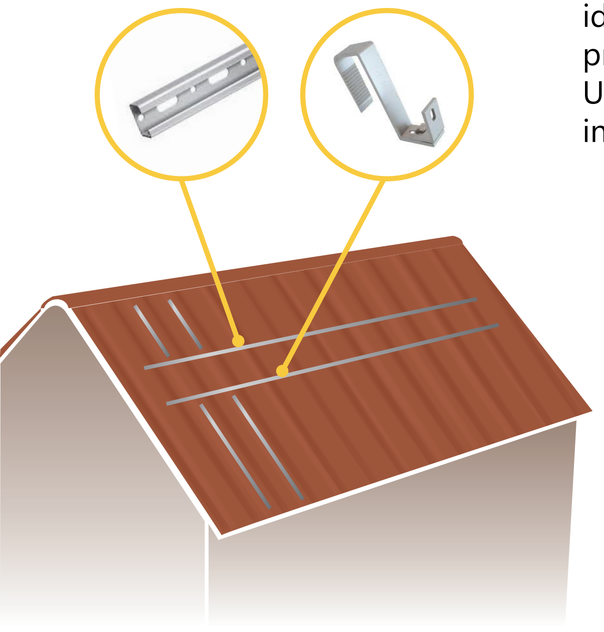
1. Plan the design
As the first step in installation, the consumer and company make a custom design plan for the roof. Firstly, the optimum number and position of the solar panels are determined. Then the position of the heat pump and green roof can be chosen.

2. Installing rails
The product is installed without compromising the existing roof structure. The installation process is almost identical to the current installation process for solar panels on a tiled roof. Using roof-anchors as support, rails are installed on the roof.

3. Installing solar panels and green roof
To these rails, solar panels and green trays can be installed. Heat pumps can be installed using existing support structures on the market.

4. Installing cabling
Cabling and optional irrigation can be added using cable management on the market.

5. Adding a decorative border
Once everything is installed, the home-owner can opt for a decorative border to visually bind the systems together, together with a corresponding heat pump casing.



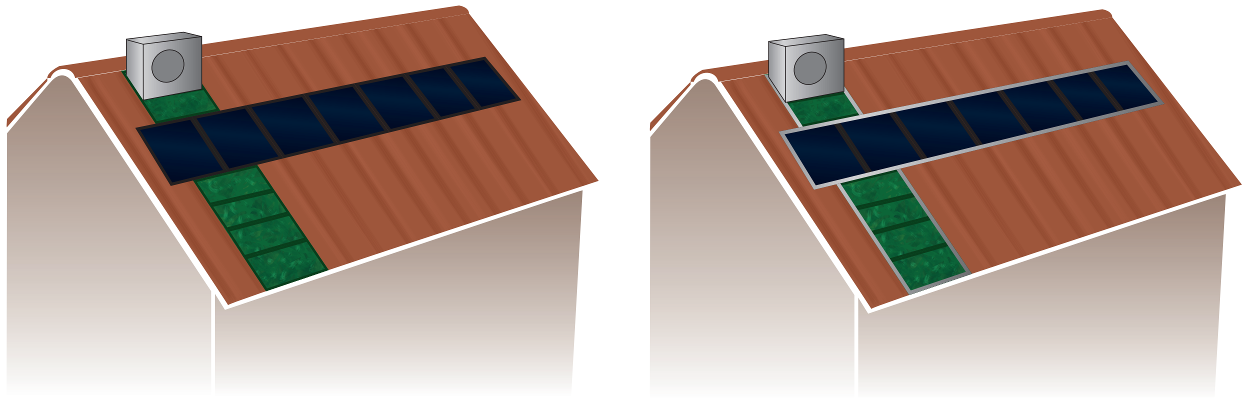


Figure 35. Installation of concept result of cycle 2, using standard roof anchors and Flamco rails.

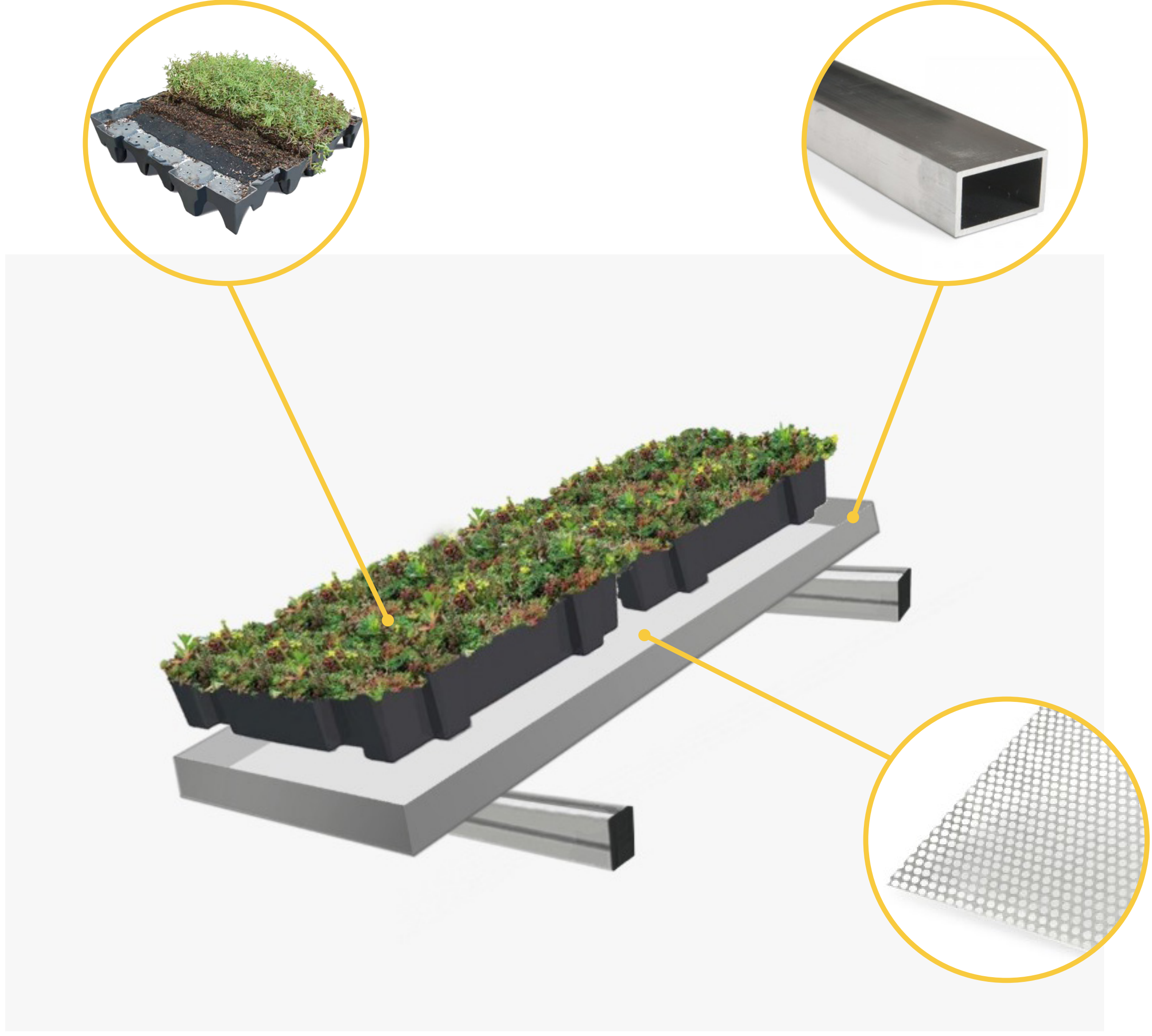


Figure 36. Proposed configuration of the green roof tray, consisting of standard sedum trays, standard aluminium profiles and perforated aluminium sheets as bottom.

11.4.5 Maintenance

The maintenance of the systems on a pitched roof should, just as current solutions, be done by a professional. The casing of the heat pumps still allows for maintenance access. The modular nature of the system allows for easy replacements and additions to the system.

11.4.7 Development challenges

- Providing the possibility for creativity and system flexibility while using standardized elements.
- Attachment and anchoring methods of the different elements.
- Interference of the components (solar panel performance, cabling, etc.)
- Weight limitations of the roof structure
- Shape of the green trays to ensure proper drainage.

11.4.8 Costs

The material costs of this concept are estimated to be around the €8400. These are the costs for 6 solar panels, the framework to install these panels with roof anchors, a heat pump with casing and 4 square meters of green roof, including the green trays.

Calculation for 6 PVs and 4 sq. m of green roof (8 trays)				
Heat pump				
Heat pump		5000	1	5000
Casing		400	1	400
Mounting platform				100
Solar panels (6x)				
Panels				
Trina Solar Honey 340wp (1698 x 1004 x 35 mm)		137	6	822
Frame				
Clickfit EVO set rij van 6 panelen portrait zwart				149,7
Dakhaak Universeel	1008040		12	
Module Klem Universeel zwart	1008020		14	
Montagerail Eindkap zwart	1008060		4	
Montagerail 6130mm	1008106		2	
Green roof				
Sedumtray indicatie		50	25	1250
Trays (aluminium 500 x 1000 mm)		65,31	8	522,48
Border (80 x 20 x 2 mm)		11,77	3	35,31
Bottom (1000 x 50 mm)				24,42
Versterkingshoek (60 x 60 mm)		1,79	2	3,58
Rivets (popnagels)				2
Connectors				
Flamco rails		8,55	6	51,3
Total			**€**	**8360,79**

Figure 37. Cost calculation of concept result of cycle 3.

11.4.6 USPs

Providing visual unity for the roof
The different components on the roof are shaped into one system. By designing a visually pleasing system, with common physical attributes, a random and messy appearance is avoided.

Freedom of design for customer
This product does not only approach the combination of the system as a technical problem, but also as an aesthetic opportunity. The systems are used comparable to how tiles, plants and garden features are used in landscape design. The design can be customized per client; shape, scale, configuration, type of systems.

Non-invasive installation
De construction can be added without making alterations to the existing roof structure. By using standard roof-anchors, it is attached to the roof tiles. Expansion, replacements or removals can be done easily and quickly.

Solar panels as starting point
Research for this project showed that the consumers prioritize solar panels over heat pumps and green roofs. They are mostly interested in investing in solar panels. This solution builds on that. The consumer firstly decides on solar panels and can after this opt to add green roof to enhance the appearance of the installation. They can add as much or as little green trays as they desire, with the possibility to add extra green trays over time. This, together with the non-invasive nature of the product, lowers the threshold to install a green roof.

11.5 Concept selection

For this project, concept 1 is selected to continue with. In order to compare and select the concepts, the list of concept criteria was used. The detailed concept evaluation can be found in Appendix N. The criteria can be divided in client needs, company needs, market and governmental needs and project drivers.

Client

For the user, a system which is scalable in size, scalable over time, and fits their specific ‘roof-situation’ is desirable. Both concepts provide this. The two benefits of concept 1 is that the roof is easier to maintain (for it is on a flat roof) and placing solar panels on top of a green roof results in a higher efficiency (which is not proven for a green roof adjacent to solar panels, as in concept 2; this might even complicate the airflow underneath the panels). The downside is that a system on a flat roof cannot be seen from the streetlevel, and therefore the system cannot contribute to the aesthetic enhancement of somebody’s home.

Company

For the company, the focus is on developing a solution which is easy to install, is plug-and-play and has low investment costs (hence using small design interventions with market-bought components). Both concepts provide this, but concept 1 excels in the possibilities for the company to prototype and develop a product line gradually, adding and improving their system through the years.
The concepts have also been discussed and compared with the company, and concept 1 was preferred. The need for easy de-installation in case of human error or repair came apparant in this discussion.

Market and government

For the market and government, there is not a very big distinction between the concepts. Concept 1 ensures maximum efficiency of roof use, because the system covers the entire roof with green roof, which is beneficial for the city’s drainage system. Furthermore, concept 1 allows for the installation of a bioroof (substrate layer between the 8 and 15 cm), which is beneficial for the city’s fauna.
Concept 2 is visible from street level, which is beneficial for the image of the city.

Project driver

Due to personal interest, concept 1 has a slight preference. Firstly, because it allows for a bio-roof. This is a big benefit for the city’s nature, for bees, butterflies, other insects and birds can use these as a refuge. A regular sedum roof does not match the native fauna of the city and therefore renders quite useless for it. Furthermore, it is expected that this concept can be worked out to a more detailed level and prototyping than concept 2. The context of a flat roof requires less integration of the concept with the roof (fastening and such), and therefore requires less assumptions before reaching a proof of concept.

12. Final concept: The Pavilion Roof

This project's challenge can be summarized as finding the balance between:

1. introducing an entire roof-system to market;
2. without losing the flexibility in the wide range of products (PV, heat pump or green roof) available to fit the variance in client and household needs;
3. and with the least amount of in-house produced parts to fit the company's resources.

The solution of this project is an entire roof-system, consisting of market available components and components proposed to be developed and manufactured by the company Paviljoen 3, which are implemented into the system according to distinct development phases.

By combining existing products on the market, solely introducing components which are crucial for the viability of the roof-system and separating the innovation of system's components into separate phases, this solution diffuses the investment costs for P3, while enabling them to acquire empirical insights concerning the system, which they can apply in further system development. They can have intensive prototyping and experience using market-bought products, before they invest in launching their own product.

An additional benefit of minimizing the design intervention is that you minimize the ready-to-market time of the system. This translates into a minimal period before the company can start generating revenue.

In the coming chapters, firstly the system's architecture will be explained, appointing all the system components for future reference. Hereafter, the envisioned system evolution will be detailed, per component. The subsequent chapters will focus on the first 3 development phases, as described on the right hand side, in detail.

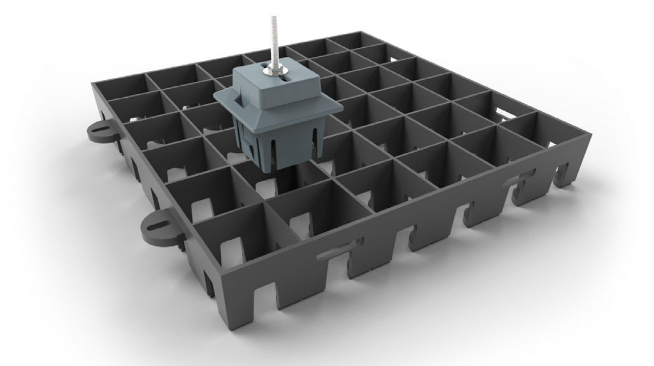


Figure 38. The Flowblock and anchor.

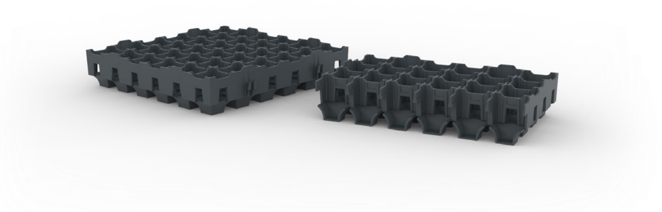


Figure 39. The P3 Tile.

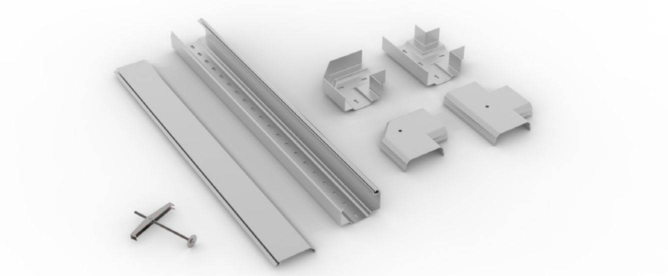


Figure 40. P3 Cable management.

THE 3 PHASES

PHASE 1
For this project, the first step of developing a viable roof system has been determined as introducing a connection between the green roof and the other systems. This will be done by repurposing the Flowblock, a semi-pavement grass tile, and introducing an anchor which secures to these tiles .

PHASE 2
The second step of the system development has been identified as introducing a grid tile with improved functionalities compared to the Flowblock (see chapter 14).

PHASE 3
The third phase will focus on cable management which fits the existing productline (see chapter 15).

12.2 Basic system formation

In order to effectively communicate the envisioned development of the system, a clear overview and preliminary function description of the system components is given in this chapter. In chapter 13.1, the components will be further specified, in respect to the initial stage of the system.

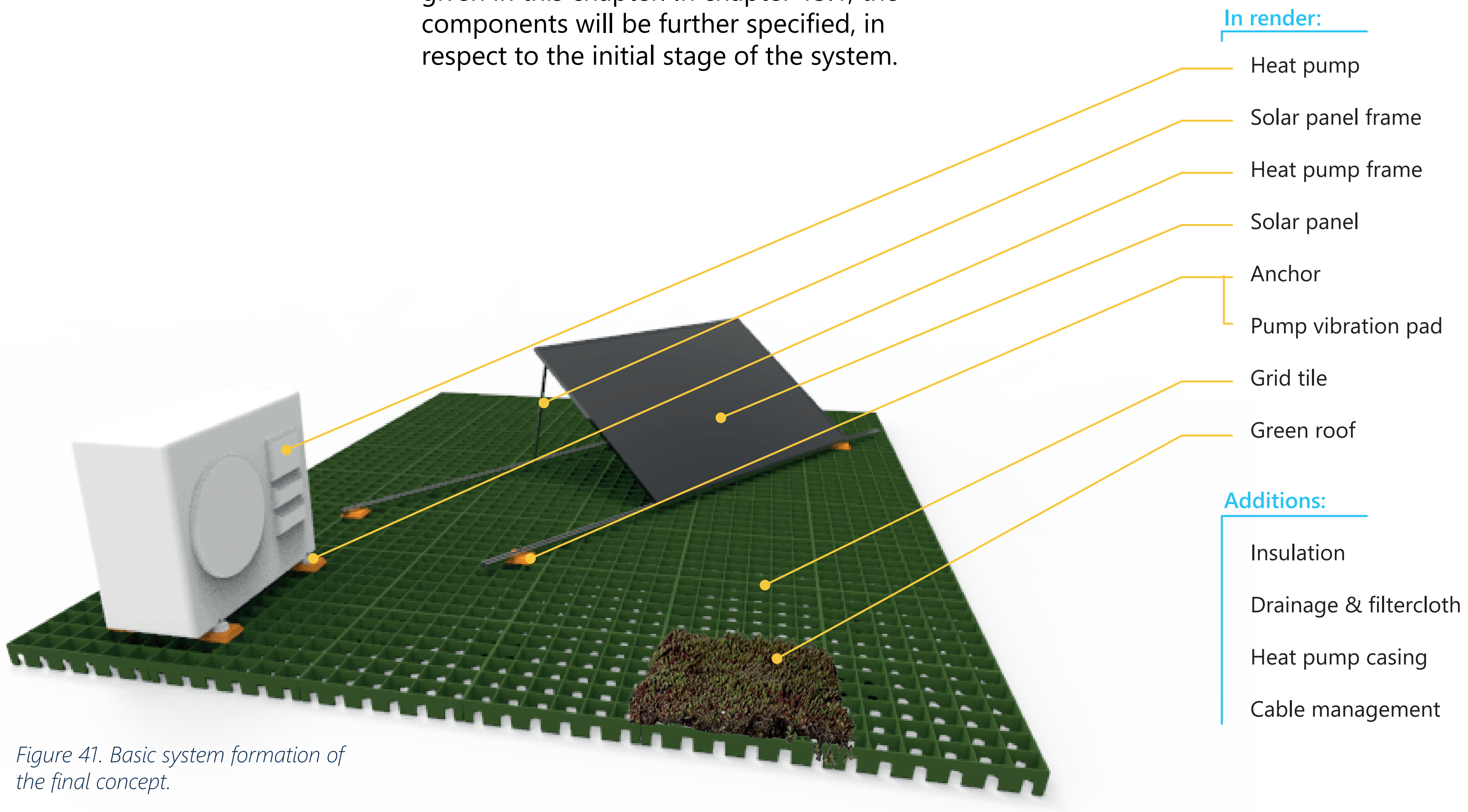


Figure 41. Basic system formation of the final concept.

Grid tile
The system will be supported by a grid framework as base. All system components will be attached to or contained by this grid.

Green roof
The grid tile will contain the green roof. This will consist of a substrate layer in the grid, and a greenery layer on top.

Drainage & filter cloth
The system needs a drainage layer with filter cloth in order for the green roof to survive.

Anchor
The anchor functions as the connecting feature between the grid and the other components.

Solar panel & its frame
The amount of solar panels in the system should be scalable and possible to orient reely towards the sun. The system also includes a component which supports the solar panels in the desired angle. The frame is attached to the anchors.

Cable management
Both a heat pump and solar panels include a lot of cables going from the system to an inlet on the roof surface going into the house.

Pump vibration pad
In order to decrease noise disturbance due to vibrations on the roof, it is advised to install a rubber pad between the anchor and the frame supporting the pump. It is a simple, straightforward solution.

Heat pump and its frame
The type of heat pump which is used is dependent on the household. In order to standardize the attachment of different heat pumps to the anchors (placed in distance increments constrained by the grid) a heat pump frame as common denominator is required. This frame can also support other household systems with outside units, such as AC.

Insulation (optional)
If extra insulation is desired, an insulated layer can be added. This can be placed in similar fashion as an inverted roof (omgekeerd dak). However, instead of adding an extra ballast layer, typically consisting of gravel or concrete tiles, the weight of the system itself will secure the insulation.

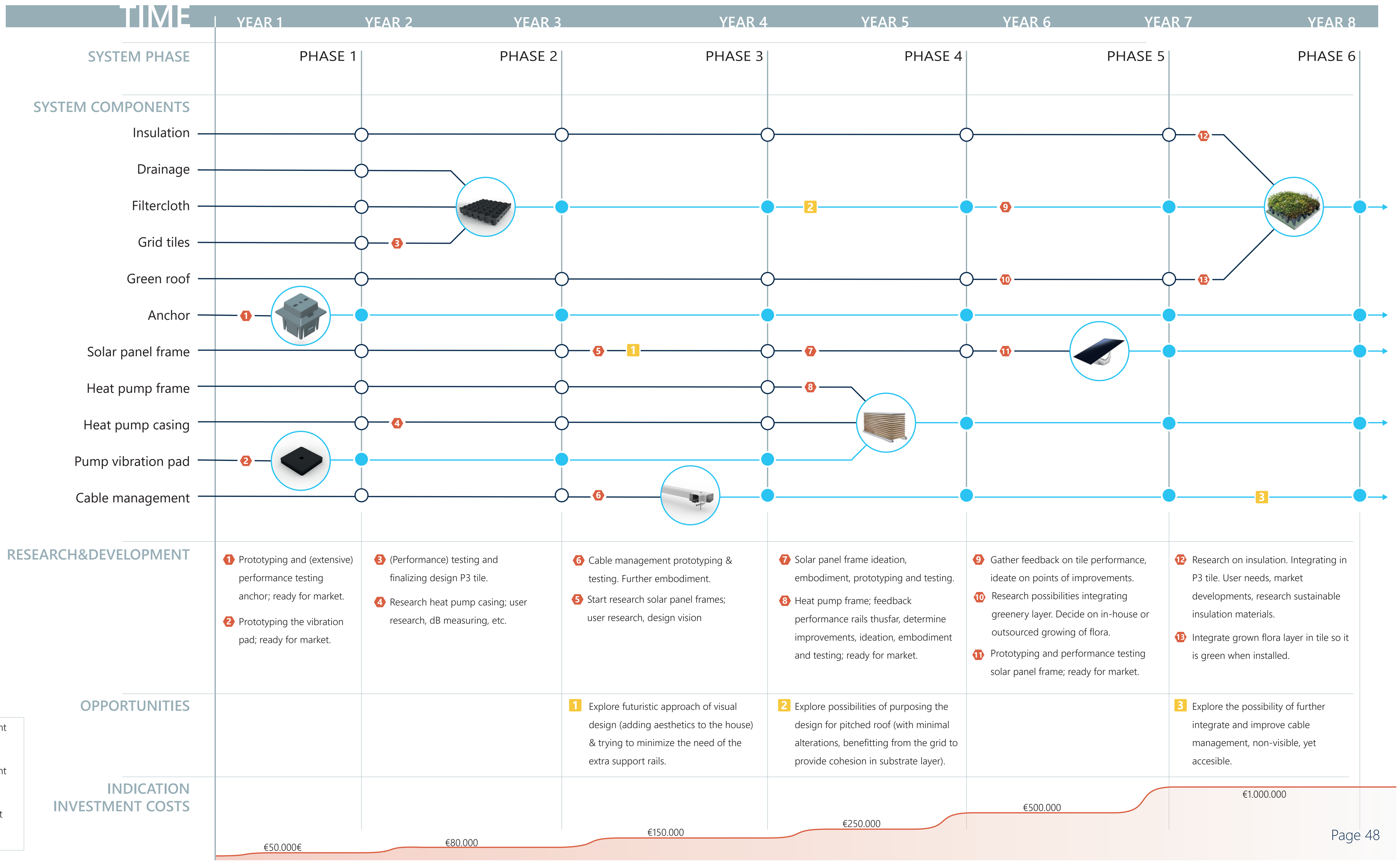
Heat pump casing (optional)
If the heat pump cannot be placed out of sight, a heat pump casing can be used to enhance the appearance of the heat pump's outside unit.

12.3 Future development roadmap

One of the unique selling points of this concept is that it enables the company to gradually develop a product line for an entire roof system. They do not have to develop all system components simultaneously in order for the system to perform.

The development roadmap on this page depicts the system's evolution, including the required component developments and interesting opportunities. The result is different phases of the system, which all are ready for market. The long-term vision is a system with most components engineered and manufactured by Paviljoen3.

For this project, the steps of Phase 1, Phase 2 and Phase 3, introducing the anchor, the pump vibration pad and the green roof tile will be embodied.



- Storebought component (dark line)
- P3 component (light line)
- Storebought component (open circle)
- P3 component (filled circle)
- Research&development
- Opportunity

Figure 42. The future development roadmap.

12.4 List of Requirements

As a result of the different phases of this design, the List of Requirements for the system and its components is divided in Phase 1, Phase 2 and Phase 3. It is categorized per component. On the right hand side it refers to the chapter where more information on the subject is available.

Once established, the requirements remain relevant over the course of the phases, only updates or additions to existing requirements are mentioned.

	Phase 1	Phase 2	Phase 3	
Req. no.	Requirements	Requirements	Requirements	Chapter
1. System				
	The system schould ...			
	Requirements for the entire system, non-part specific			
R1.1	maximize efficiency of roof usemaximize efficiency of roof use			C1.2
R1.2	be scalable in size			C1.3
R1.3	be scalable over time			C1.4
R1.4	allow for costumization client specific needs			C2.1
R1.5	primarily focusses on PV panels			C2.2
R1.6	is visually pleasing/adds to the appearance of the house			C2.3
R1.7	is non-invasive to the roof structure			C2.4

Figure 43. List of Requirements: System.

Figure 44. List of Requirements: Grid tiles.

Req. no.	Phase 1 Requirements	Phase 2 Requirements	Phase 3 Requirements	Chapter
2. Grid tiles				
	The grid tiles schould ...			
	Function			
R2.1	Provide a grid to attach the anchors to.			§11.3.3
R2.2	Support the substrate layer.			§10
R2.3	Enable configurations of a grid which is scalable			§10
R2.4	Enable configurations of a grid, flexible in shape			§10
R2.5	Secure the solar panels to the roof as ballast			§8.3
R2.6		Interlock to keep them tighly adjacent		§11.3.4
R2.7		Interlock to counteract upward forces caused by wind pressing on the PV panels		§10
R2.8		Interlock non-permentantly, to enable one-tile replacements		§13.8
R2.9		Include a bottom to enable easy replacement and de-installation		§13.8
R2.10		Have an incorporated drainage layer		§13.8
R2.11		Have an incorporated filter layer		§13.8
R2.12		Have an incorporated root barrier layer		§13.8
	Installation			
R2.14	Be installable by two people			C3.1
	Maintenenance			
R2.15	Be removable in order to acces roof surface for maintenance	Enable easy de-installation to give acces to the roof surface for maintainance		§10
R2.16	Be removable, in order to enable one tile replacements	Interlock non-permentantly, to enable one tile replacements		§10
	Manufacturing & Materials			
R2.17	Consist of a product on the market requiring minimal design alterations	Be easy to manufacture, to minimize production costs		C3.4
R2.18		Be manufactured using a method suitable for upscaling		C3.5
R2.19		Be designed to fit the existing anchors		§12.1
	Aspirations			
A2.1	Support or allow temporary fall protection to be used	Support permanent fall protection to be installed		§8.2.3

Figure 45. List of Requirements: Green roof.

Req. no.	Phase 1 Requirements	Phase 2 Requirements	Phase 3 Requirements	Chapter
3. Green roof				
	The green roof schould ...			
	Function			
R3.1	Provide the same, or comparable quality in, layers of a conventional green roof: Root barrier, water drainage, filter cloth, substrate/growing medium			§7.1
R3.2	Provide a substrate layer for sedum plants (>5 cm)	Provide a substrate layer for native plants (>8 cm)		§7.3.1
R3.3	Be suitable for a roof up to an angle of 15 degrees			§7.4
R3.4	Provide proper drainage to sustain a green roof			§7.1
R3.5	Retain at least 30 liters of rainwater per square meter			§7.6
R3.6	Be scalable to roof size			§10
R3.7	Include a filter cloth			§7.1
	Installation			
R3.8	Be installable by two people			C3.1
	Maintenance			
R.3.9	Be accesible for maintenance with a frequency of twice a year			§7.5
	Manufacturing & Materials			
R3.10	Have a lifespan of 25 years (corresponding with the expected lifespan of PV panels)			§8.4
	Aspirations			
A3.1		be suitable for pitched roofs up to an angle of 40 degrees		§7.4.2
A3.2		be suitable for tiled roof surfaces		§11.4.1

List of Requirements 12.4

Figure 46. List of Requirements: The anchor.

Req. no.	Phase 1 Requirements	Phase 2 Requirements	Phase 3 Requirements	Chapter
4. Anchors				
	The anchors schould ...			
	Function			
R4.1	Have an option/add-on to absord sound nuisance caused by the heat pump			§9.2
R4.2	Support multiple solar panel frames from the market			C1.1
R4.3	Support different dimensions of heat pumps			C1.1
R4.4	Fit in all holes developed of the Flowblock (there is a 5 mm difference between holes located in the centre of the tile opposed to along the edges)			§13.2
R4.5	Withstand a force of 36 kg (half of the ballast of a solar panel)			§8.3
	Installation			
R4.6	Be able to fasten and loosen during installation, to minimize consequences of human error			§11.5
	Maintenenance			
R4.7	Be replaceable over time			§11.5
	Manufacturing & Materials			
R4.8	be simple to manufacture in order to have minimal production costs			3.3
R4.9	have a lifespan of 25 years (corresponding with the expected lifespan of PV panels)			§8.4
	Aspirations			
A4.1	provide solution for over- or under torquing of fasteners			§8.2.3

List of Requirements 12.4

Figure 47. List of Requirements: Solar panel frame.

Req. no.	Phase 1 Requirements	Phase 2 Requirements	Phase 3 Requirements	Chapter
5. Solar panels frame				
	The solar panels frame should...			
	Function			
R5.1	Be a storebought product			§11.3
R5.2	Be flexible in number of solar panels to suit each household's need			§8.2
R5.3	Combined frame for multiple solar panels in order to safe material costs/efficient installation			§8.2
R5.4	Allow the solar panels to be freely oriented in (x and y) per case, for maximum efficiency			§8.2
R5.5	Be suitable for solar panels of size 165 by 99 cm			§8.1
R5.6	Provide a pitch of 10 and 15 degrees (market standards)			§8.2.1
R5.7	Allow for a proper electrical circuit installation			§8.2.3
R5.8	Support the use of microinverters			§8.1
R5.9	Not unnecessarily lengthen cables			§8.2.3
R5.10	Not obstruct proper water drainage of the roof			§8.2.3
	Installation			
R5.11	Be installable by two persons			C3.1
	Maintenenance			
R5.13	Allow for cleaning of the PV panels			§8.4
	Manufacturing & Materials			
R5.14	Have a lifespan of 25 years (corresponding with the expected lifespan of solar panels)			§8.4
R5.15	Allow easy grounding of the system			§8.2.3
	Aspirations			
A5.1	support solar panels of different sizes, starting with 199 by 99 cm			§8.1

List of Requirements 12.4

Figure 48. List of Requirements: Heat pump frame.

Req. no.	Phase 1 Requirements	Phase 2 Requirements	Phase 3 Requirements	Chapter
6. Heat pump frame				
	The heat pump frame should...			
	Function			
R6.1	Be comprised of storebought products			§11.3
R6.2	Support different models of heat pumps			§11.3
R6.3	Secure to heat pump and enlarge the support area to improve stability			§9.3.3
R6.4	Provide a flat and level surface for the heat pump			§9.3.3
R6.5	Not obstruct proper drainage of the roof			§9.3.3
R6.6	Not translate the vibrations of the heat pump to the roof to decrease nuisance			§9.2
	Installation			
R6.8	Be installable by two persons			C3.1
	Maintenenance			
R6.9	Allow for maitnenance of the heat pump			§9.5
	Manufacturing & Materials			
R6.10	Have a lifespan of 25 years (corresponding with the expected lifespan of PV panels)			§8.4
	Aspirations			
A6.1	improve the aesthetics of heat pumps			§6.2

Figure 48. List of Requirements: Cable management.

Req. no.	Phase 1 Requirements	Phase 2 Requirements	Phase 3 Requirements	Chapter
7. Cable management				
	The cable management should...			
	Function			
R7.1	Be comprised of storebought products			C3.3
R7.2	Hold the refrigerant supply and electical wiring of the heat pump and solar panels			§9.3.3
R7.3	Provide accessibility to refrigerant supply and electrical wiring for maintenance			§9.5
R7.4			Protect the insulated piping of the refrigerant supply from damage & birds	§9.2
	Installation			
R7.5	Be installable by two persons			C3.1
R7.6	Be easy to install			C3.1
R7.7			Sequence: Be partly installed, install the wiring and then finish (close)	
	Maintenenance			
R7.8	Require no maintenance			C2.6
R7.9	Allow for partial/local repairs			C1.5
	Manufacturing & Materials			
R7.10	Have a lifespan of 25 years (corresponding with the expected lifespan of PV panels)			§8.4
R7.11			Be easy to manufacture by the company	C3.4
	Aspirations			
A7.1	Improve insulation of the refrigerant supply			§9.2

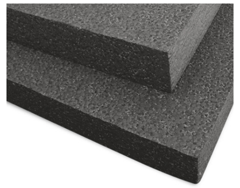
13. Phase 1

13.1 System formation

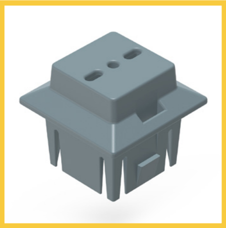
The result of the first phase of this system can be found below. The system consists mostly of available products on the market, which are used and repurposed to create an entire roof system which is scalable and flexible to the requirements per roof. All products are store bought except the anchor and pump vibration pad (yellow), which will be the first products developed by Paviljoen3.

Grid tile
The grid tile which is used in the system of Phase 1 is the Flowblock, by DrainProducts. More information on this product, including strengths and weaknesses, can be found in chapter 13.2.

Drainage & filter cloth
The first layer of the system will be a drainage layer with integrated filter cloth. There is a wide variety of these products on the market.



Insulation (optional)
The company can apply insulation underneath the system if this is desired by the client. They can use standard insulation materials used for inverted roofs.



Anchor
The anchor of this system will be the first design introduction of Paviljoen3. Chapter 13.3 will explain the functionalities of this part.

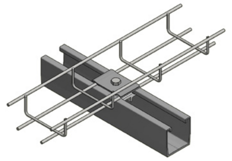
Green roof
The green roof, consisting of the substrate layer and greenery layer will be store bought as well. For the greenery layer the company has three options, which might be discussed with the client. It can be sown, planted using plugs or sedum rolls can be used. Advised is to use the sedum rolls. They provide immediate aesthetics and are affordable (25 euro / square meter).

Solar panel & its frame
The solar panel and frame for this system phase will consist of standard solar panels, and the available Van der Valk systems. Van der Valk has several systems which provide incremental angles, are scalable, high quality and familiar to the company. The only addition to these frames are two aluminium profiles connecting two rows of anchors, to which the system can be attached.

Pump vibration pad
The pump vibration pad will also be developed and manufactured by Paviljoen 3. This can first be done per job, to later scale up to larger production sizes which can be outsourced.

Heat pump and its frame
The frame of the heat pump is kept rudimental. It consists of four anchors and four aluminium profiles.

Heat pump casing (optional)
If the outside unit of the heat pump is placed in sight, a heat pump casing can be made or bought. In Phase 1, this optional addition will be dealt with per client case.



Cable management
The cable management will be store bought. Van der Valk has a solution which can be installed on the anchors directly.

13.2 The Flowblock

The system of Phase 1 re-purposes a product already on market; The Flowblock. The Fowblock is a semi-pavement tile, used for lawns and drive-ways. It enables vehicles to drive over grassed areas.

The Flowblock has the following assets:

1. Suitable for heavy duty traffic, therefore extremely durable and hard-wearing.
2. Interlocks with a connection made to withstand heavy duty traffic.
3. Pressure distribution, which is desirable to protect the roof surface.
4. Made from recycled material and fully recyclable.
5. Allows for greenery to grow, with 90% of open surface area for plant growth.

The Flowblock will be used to support the green roof, and to provide a grid to install the components of the system to. This last function will be performed in combination with the anchor (see the next chapter).

Several tiles were analysd before the Flowblock was selected. These analysis can be found in Appendix K.

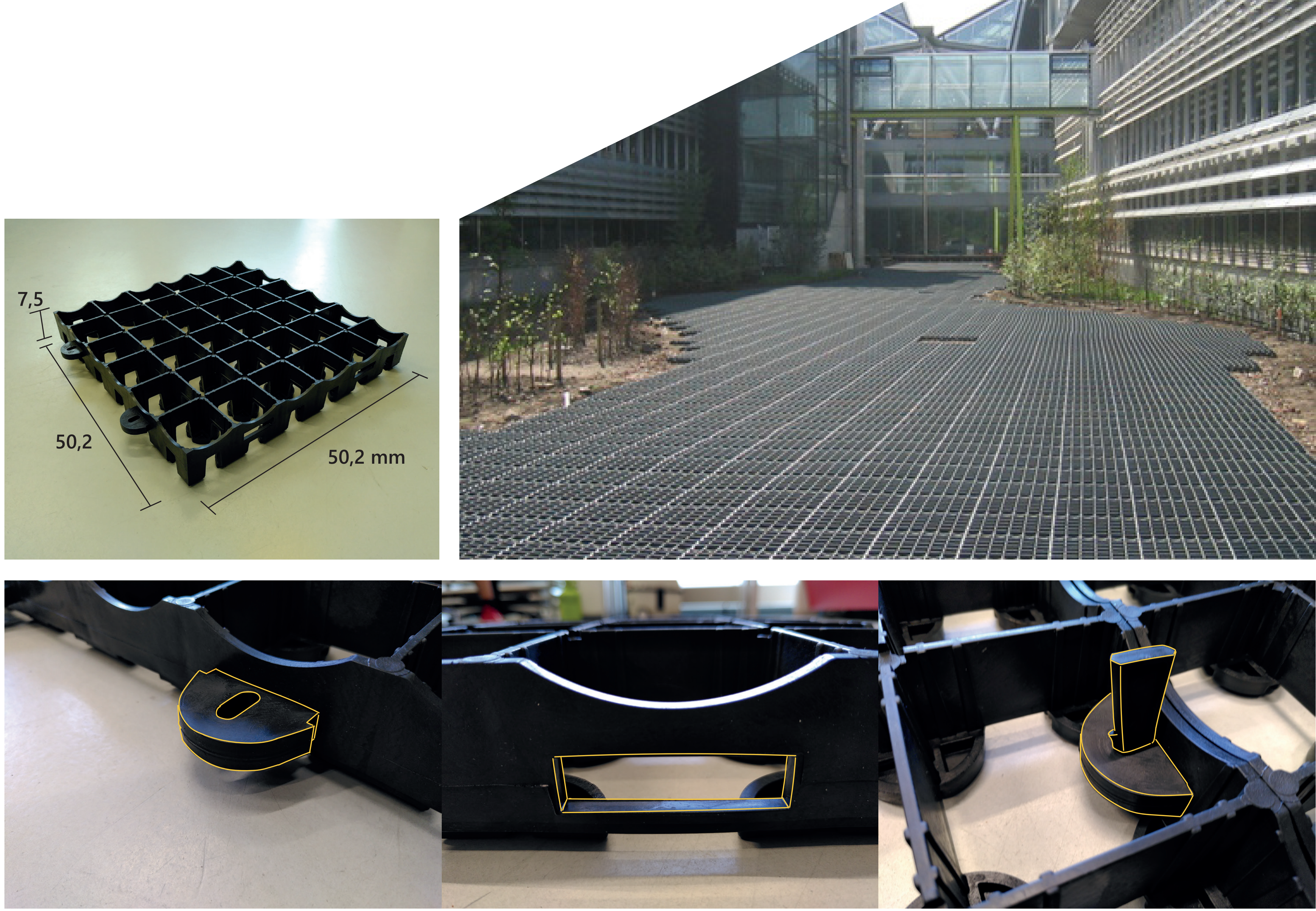


Figure 49. The Flowblock by DrainProducts.

13.3 The anchor

The anchor will be the first product to be developed by Paviljoen3. The anchor locks in the grid tiles and provides a platform to which products can be installed.

13.3.1 Working principle

The anchor consists of two parts, the anchor itself and a plug, combined with a store bought M8 bolt, nut and washer. In the exploded view on this page the configuration of these parts can be seen. When tightening the bolt, the plug is pulled into the anchor, causing the anchor to expand. The working principle is comparable to an expansion bolt.

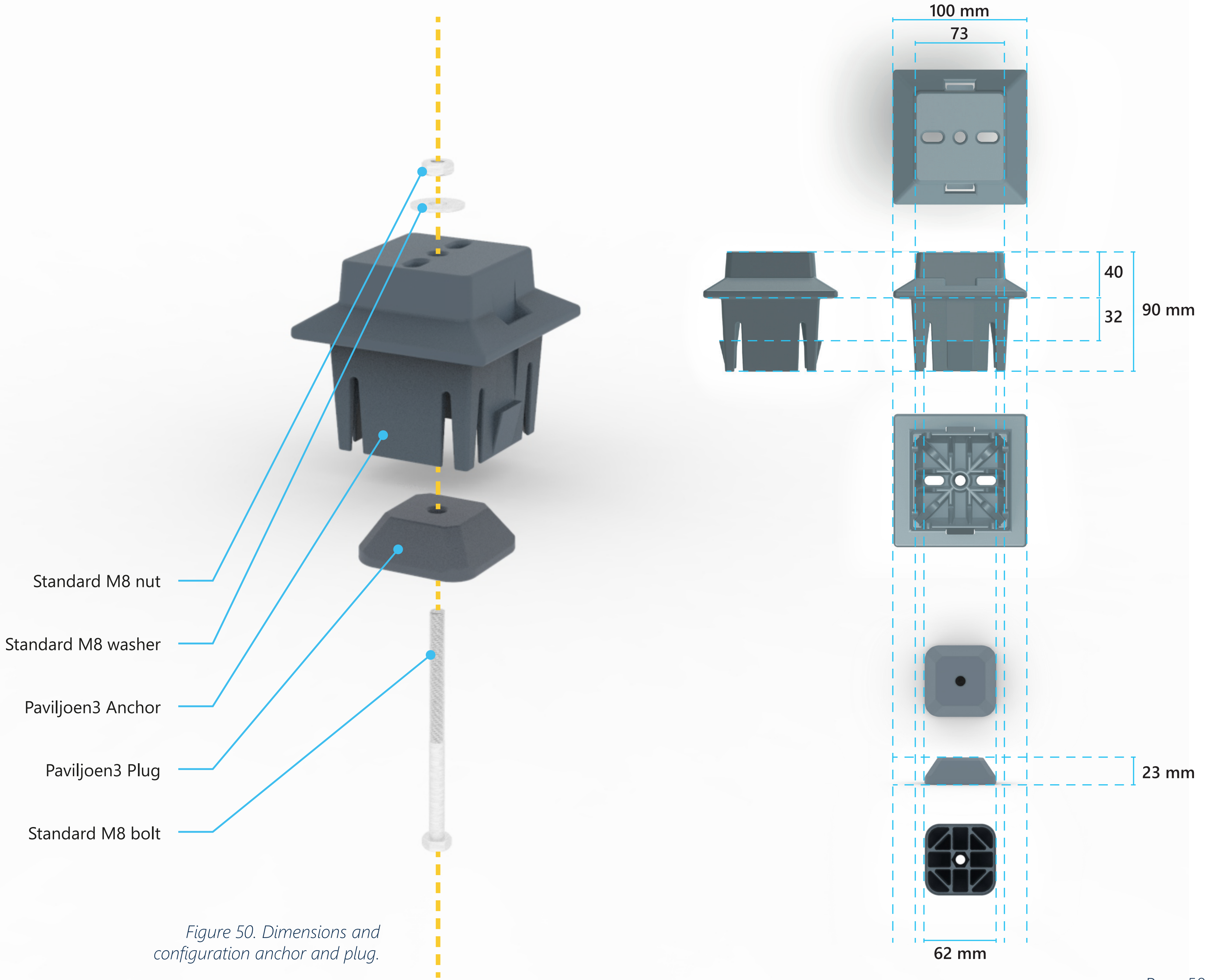


Figure 50. Dimensions and configuration anchor and plug.

13.3.2 Installation

To install the anchor, it is placed in one of the grid holes of the Flowblock. The hooks on the side of the anchor lock behind holes in the Flowblock. By tightening the nut, the plug is pulled up and the anchor expands. The hooks in combination with the friction force as a result from the expansion secure the anchor.

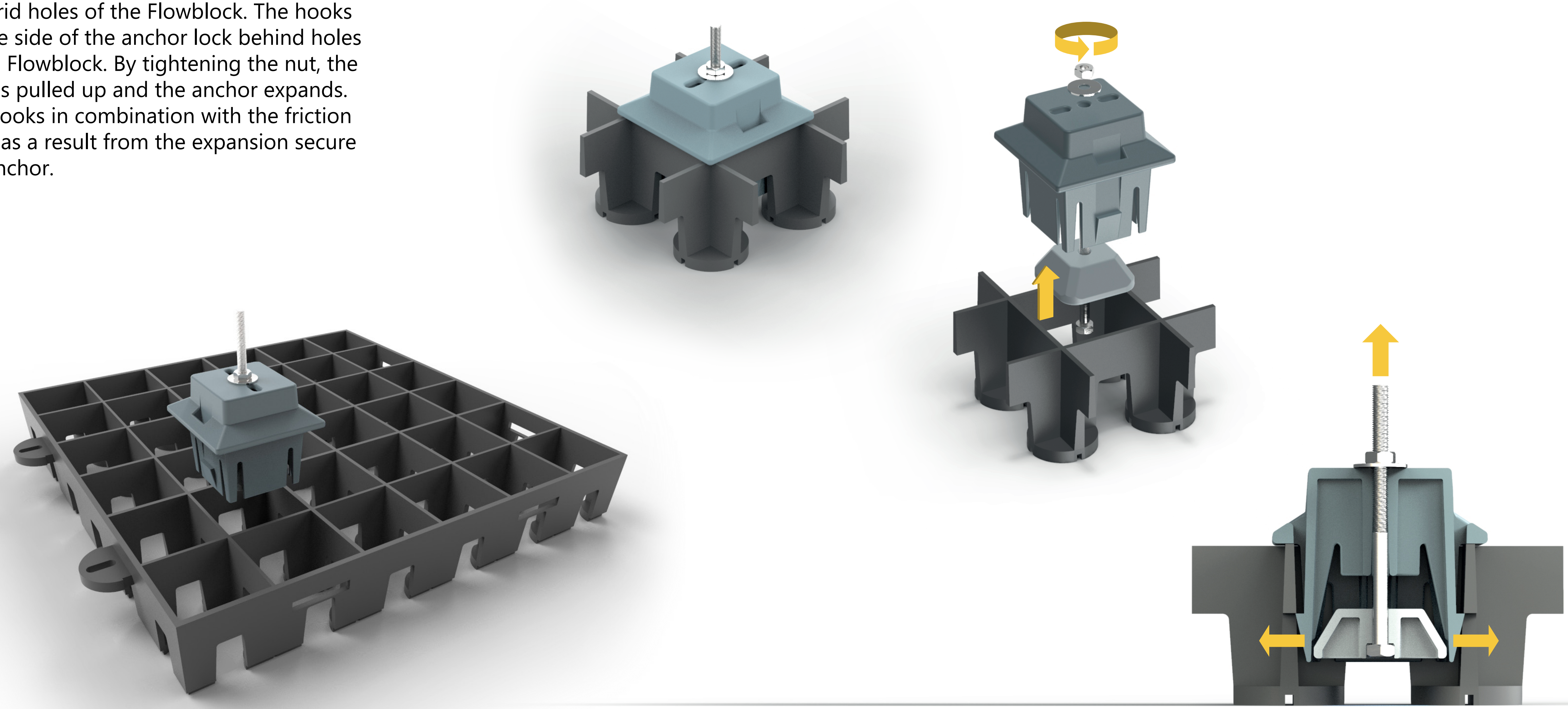


Figure 51. Installing the anchor in the Flowblock.

13.3.3 De-installation

One of the main requirements of the anchor is that it should be de-installable (R4.6). This is to minimize the consequences of human errors during installation. It often happens that during installation a previously installed part needs to be moved or replaced. By making the anchor de-installable it is possible to go back and tweek the configuration of the system without consequences. Another benefit is that you can replace them when defective, or remove them if you want to reach your one of the underlying layers (roof surface, insulation, drainage) for maintenance or repair.

The anchor is de-installable by simply loosening the nut, releasing the pressure applied by the plug. However, especially after some time, the anchor or the plug can get stuck by material deformation or friction. In this case, the anchor has three features which ease de-installation:

1. Pressing the hooks:

During installation, the anchor is still relative accessible. It is still possible to reach the hooks from the side and press them in. Therefore the anchor is designed with two hooks (instead of the possible four), so the installer is able to press both hooks inwards while pulling out the anchor (indicated by blue).

2. Prying the hooks:

After the installation of the green roof, the anchor's hooks are no longer accessible from the side, since the Flowblock is filled with substrate. Two holes are placed in the top of the anchor, indicated in yellow, to make it possible to pry the hooks using a standard screwdriver.

3. Hammering the plug:

In case the plug does not go down to release pressure, but is stuck due to material friction, the installer can hammer on the plug, using a standard screwdriver and hammer. This can be done through two holes at the top of the anchor indicated in red.

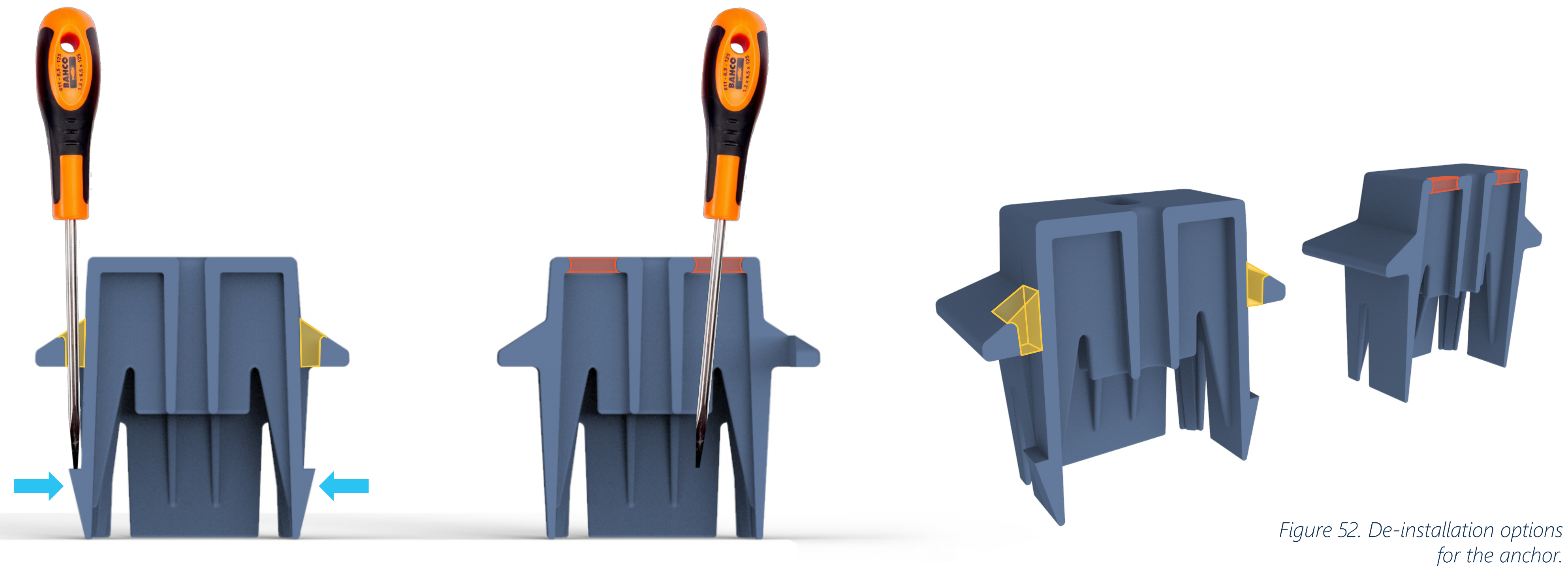


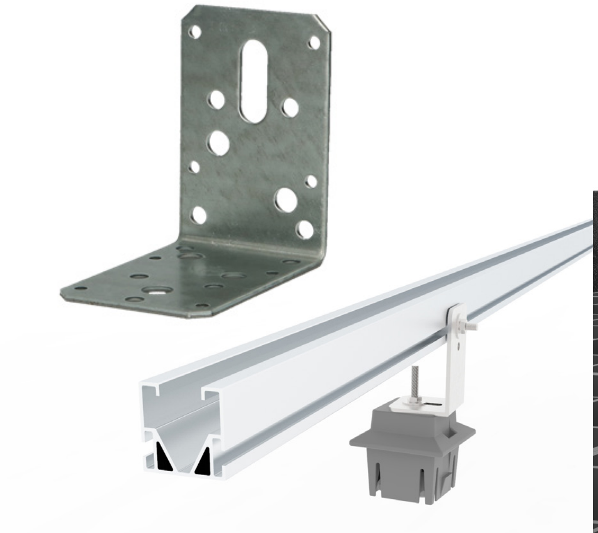
Figure 52. De-installation options for the anchor.

13.3.3 Installing systems to anchor

The anchor has a vertical bolt which pulls the plug in when fastened. The screw thread at the end of this bolt can be used to attach other components to.

Solar panel frame
The rails for the solar panels are attached by installing a stainless steel angle to the bolt, to which an aluminium profile is attached. The only requirement of the angle is that st is adjustable (meaning it has elliptical holes), to compensate for the constrictions of anchor placement due to the Flowblock grid.

Heat pump frame
The heat pump frame is proposed to be composed of Flamco rails. These are installed to the screw thread using a standard nut. The heat pump can be installed using standard hammer head bolts and slide nuts. All materials are galvanized, and therefore suitable for the outside use.



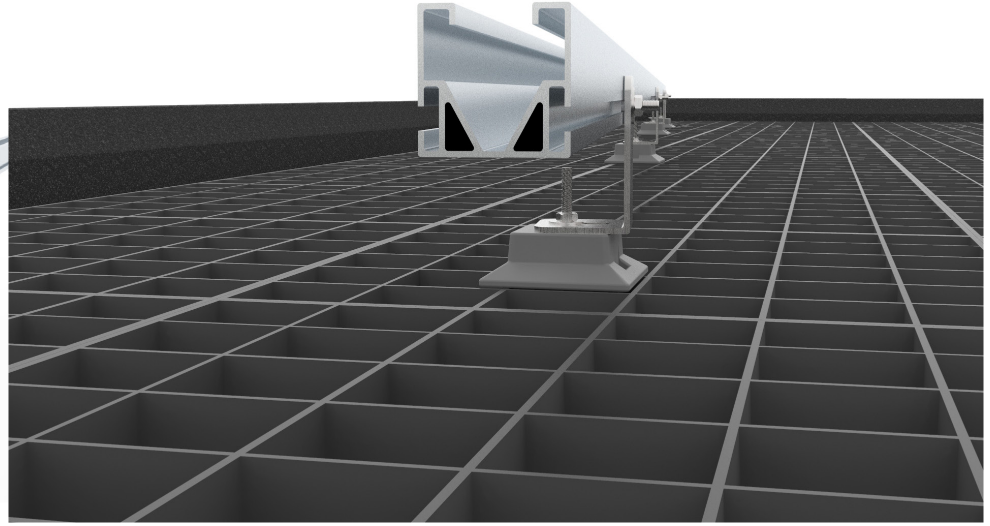
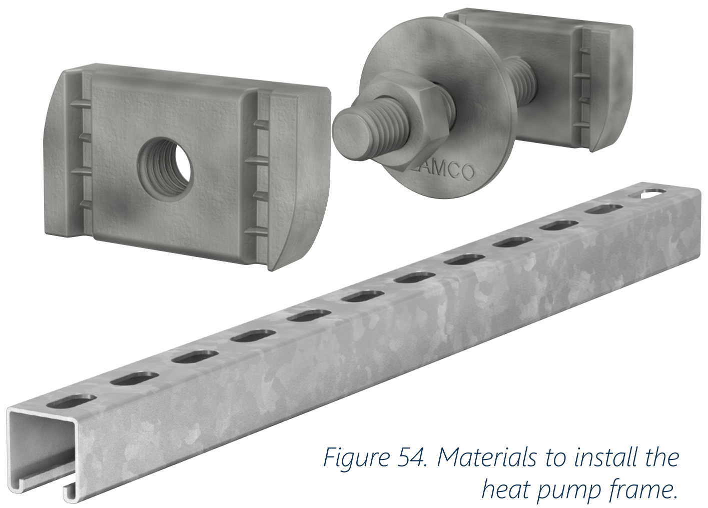


Figure 53. Materials to install the solar panel frame.



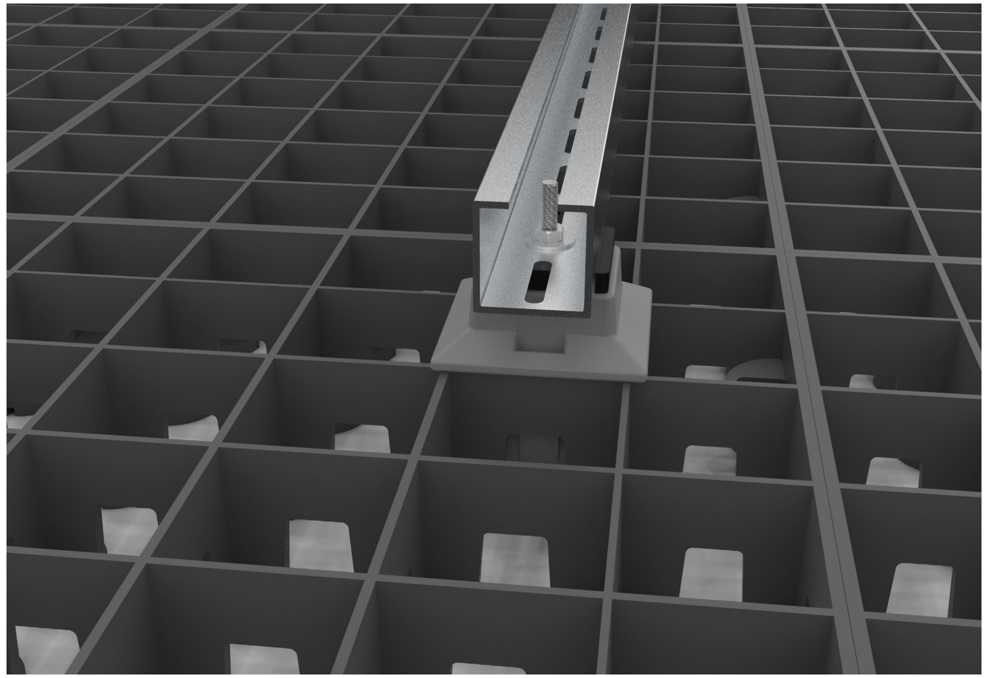


Figure 54. Materials to install the heat pump frame.

13.3.5 Manufacturing

The anchor and the plug will be injection molded in recycled High Density Polyethylene (corresponding with the material of the Flowblock). This material was chosen due to its tensile strength, toughness, strength and costs, all meeting the requirements of this part.

The anchor and its plug are designed to be straightforward to manufacture. Both parts only need two-part molds. The plug is a rudimental part. The anchor is slightly more complicated, due to the hooks on the side of the product. Normally, this feature would require a three-part mold.

However, placing the holes in the top of the anchor, which support the de-installation of the anchor (see chapter 13.3.3, step 2), enables the anchor to be made by a two-part mold. The female mold includes an insert which creates the hole and the female mold detail for the hooks.

Furthermore, all the walls of the parts are sloped to support the mold release, and the thickness of the walls are appropriate to be injection molded with HDPE.

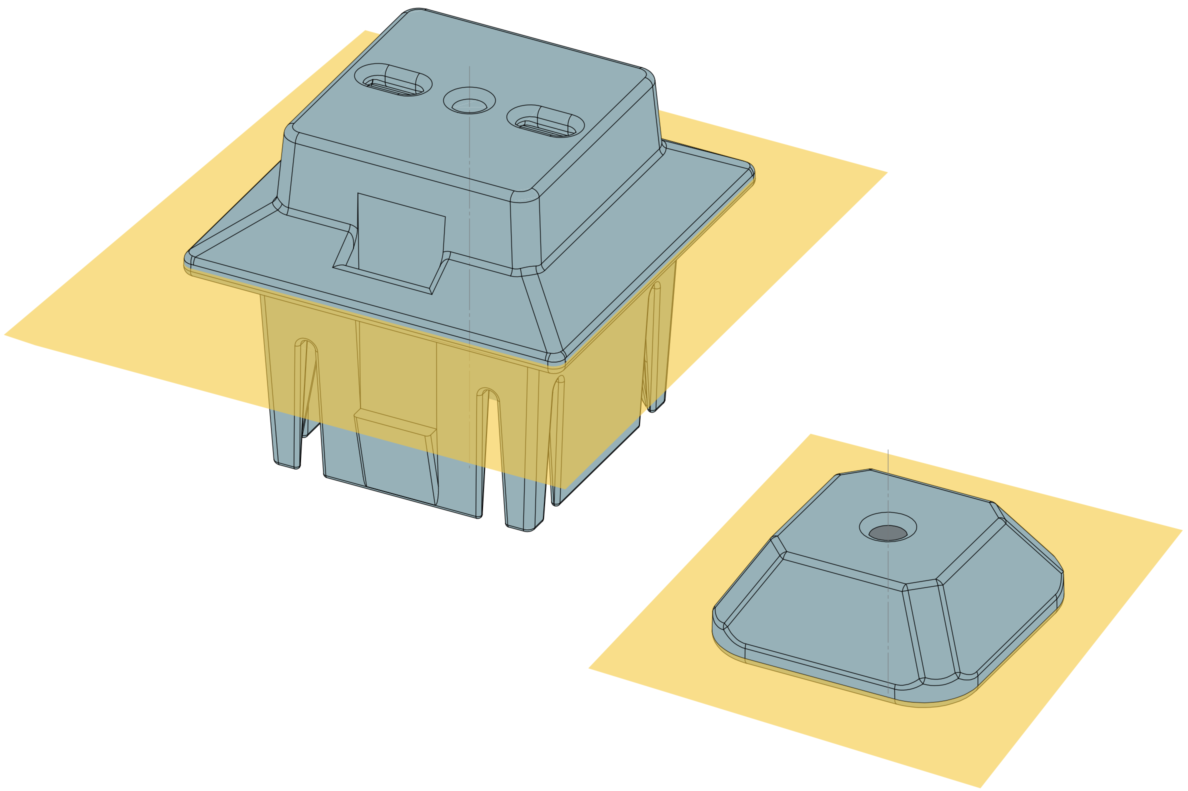
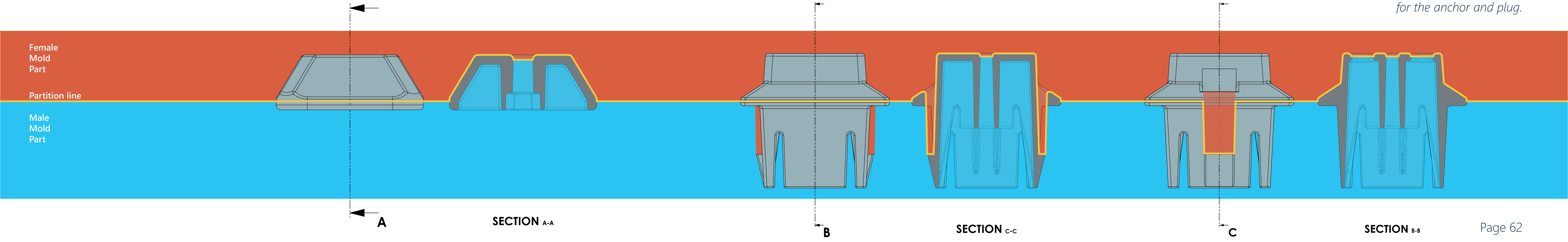


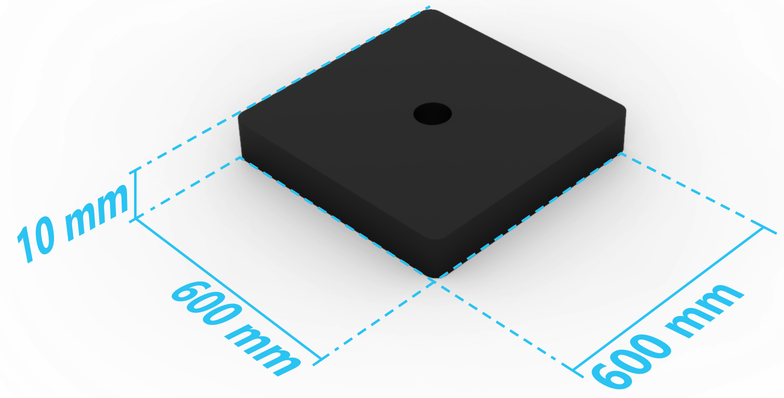
Figure 55. Manufacturing molds for the anchor and plug.



13.4 The pump vibration pad

This phase of the system has one other addition developed by Paviljoen3: the heat pump vibration pad. One of the drawbacks of a heat pump is the sound nuisance it can cause. This drawback also emerged as a common worry in the client questionnaire. A simple intervention the company can perform to absorb the vibration caused by the pump is placing rubber pads between the heat pump frame and the

Advised is to make these pads costum per client case, because for every system they install they will only need 4 pads. The pads are easily manufactured by hand. Simply put, it is excessive to create a whole production line for this part.



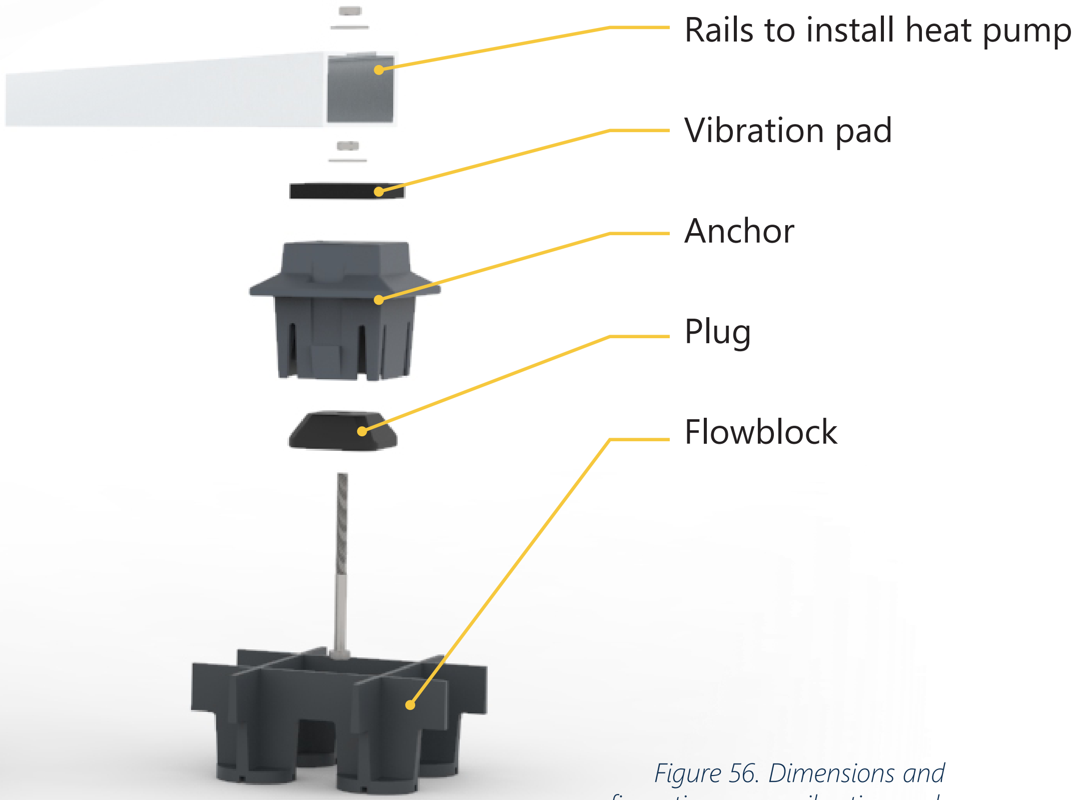


Figure 56. Dimensions and configuration pump vibration pad.

13.5 Costs

13.5.1 System costs

For the project, an excel file has been created for the use of the company, which approximates the material costs of the system, excluding tax, with the number of square meters of green roof, the number of solar panels and the number of heat pumps as input. The excel can be found in Appendix L. To illustrate, a roof system with an average of 40 square meters of green roof, 12 solar panels and 1 heat pump is estimated at €10.767,39. This includes all materials of installation, of which the store bought items are added as a link.

The biggest costs of the system are the biodiverse vegetation layer (€2198), the solar panel system (€2866,39) and the heat pump (€4017,35).

13.5.2 Manufacturing costs

An estimation for the manufacturing and investment costs of the anchor and the plug have also been acquired at the company QDP, in Duiven, the Netherlands. This company was selected because they provide low volume manufacturing of injection molded parts. The investment costs for the mold are estimated to be a little over €3600 for the anchor, and €2000 for the plug, based on the material, weight and dimensions of the parts.

The combined costs, including return of investment costs of the mold, material costs of the part and set-up costs for the manufacturing company for a production volume of 2000 parts would result in a price per part of €3,26 for the anchor and €1,72 for the plug. For more information on, see Appendix L.

These low production costs could be driven up by unforeseen complications in the mold shape, and shipping costs, for the concerning company's production facility is in China.

The costs of the pump vibration pads have been calculated to be 36 cents a piece (Appendix L).

13.6 Installation system Phase 1

The installation of the system will be as follows:

Preparation:
1. Clean the roof surface
2. Implement insulation layer (optional)

Green roof installation (Part I):
3. Lay root barrier foil
4. Install the drainage layer
5. Install the Flowblocks

Solar panel installation:
6. Secure the anchor
7. Install the rails
8. Install the solar panel frame
9. Place the solar panels

Heat pump installation:
10. Place the anchors
11. Install heat pump frame
12. Place the heat pump

Cable management:
13. Place the anchors
14. Place the cable baskets
15. Secure with centre clamp
16. Place the wiring
17. Secure the wiring

Green roof installation (Part II):
18. Implement substrate layer
19. Implement vegetation layer
20. Place gravel
21. Irrigate

Each step will be discussed in this chapter.

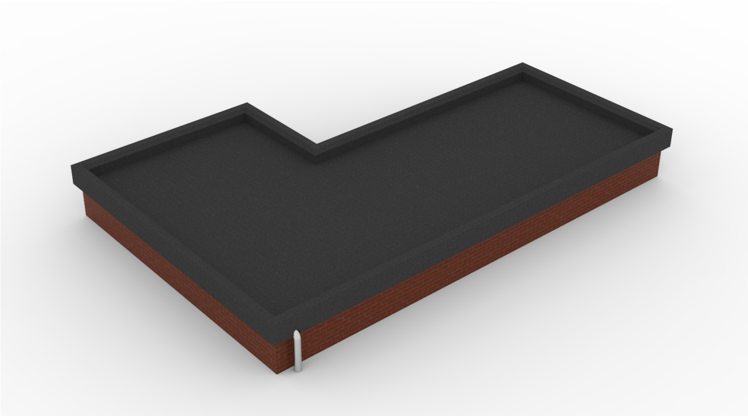


Figure 57. Clean the roof surface.

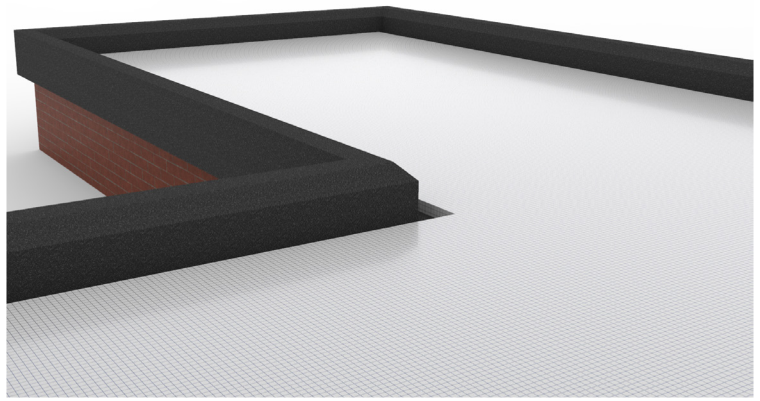


Figure 58. Implement insulation.

13.6.1 Preparation

1. Clean the roof surface
As with normal installation of any rooftop system, the first step is cleaning the roof surface. Check for damages on the roof surface or any indication of leakage. These have to be solved before the system can be installed. If the roof surface is old or in bad shape, it is advised to apply a new layer of bitumen or EDPM before installing the system, to avoid later costs of de- and re-installation when roof surface maintenance is due.

2. Implement insulation layer (optional)
The client has the option of including an insulated layer. This will decrease the energy requirements of the household. This will be implemented in the same method as an inverted roof, as discussed in chapter 10 and 13.1.

13.6.2 Green roof installation: Part I

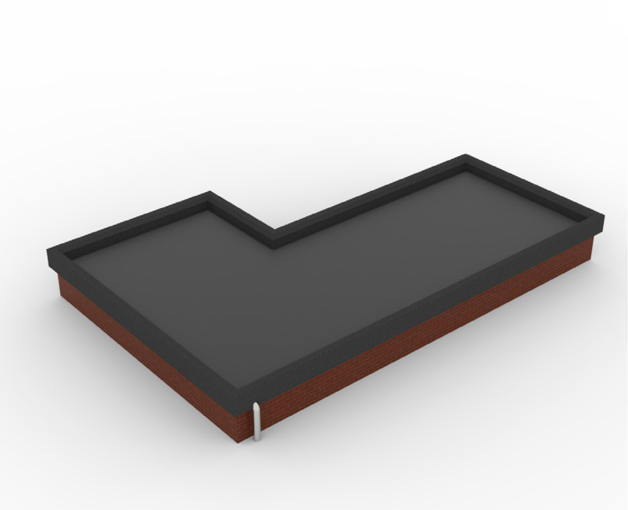


Figure 59. Lay root barrier foil.

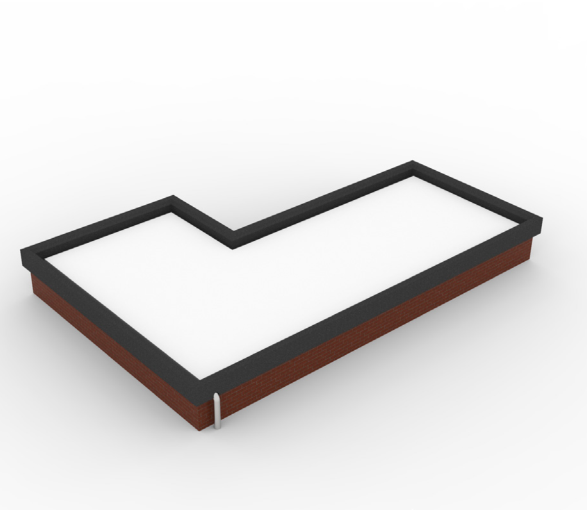


Figure 60. Install drainage layer.

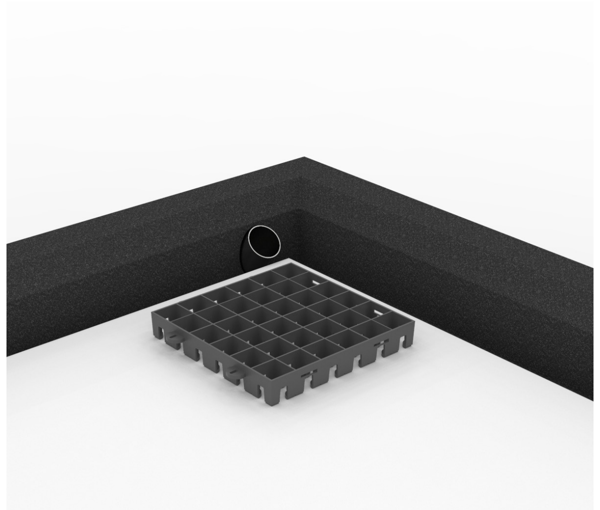


Figure 61. Installation first Flowblock.

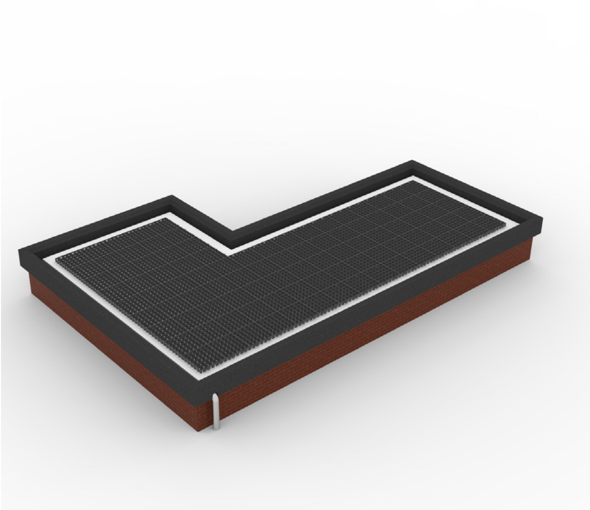


Figure 62. Installation all Flowblocks.

3. Lay root barrier foil
The first layer of the green roof will be a root barrier. This layer will protect the roof surface from damages by the plant roots.

4. Install the drainage layer
The drainage layer has to be implemented to ensure water drainage and avoid root rot. If a filter cloth is not integrated in the drainage layer, this has to be laid down next.

5. Install the Flowblocks
After the drainage layer, the Flowblocks can be installed. Starting at one corner of the roof, the entire grid is placed. Advised is to lay all the blocks down with the wedges placed by hand, before locking them down. This allows for small adjustments before the layer is locked by pushing the wedges through.

13.6.3 Solar panel installation

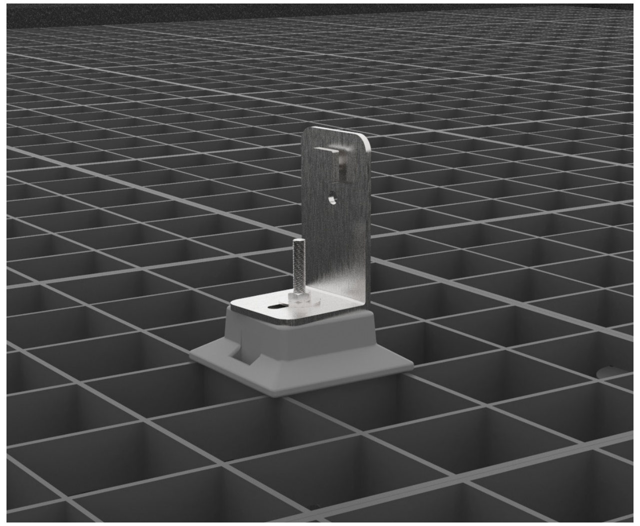


Figure 63. The anchor with steel angle.

6. Secure the anchor
If solar panels are included in the system, the first step is to install the required anchors. Stainless steel angles are installed to the screw thread of the anchors, to support the rails of the next step.

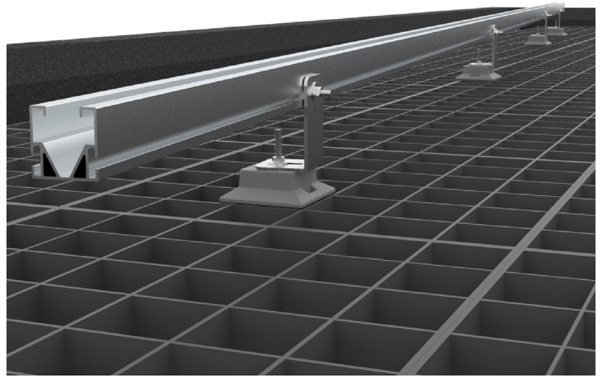


Figure 64. The angle attached to the rails.

7. Install the rails
Rails will be installed to the anchors along the length of the installation. This is needed because the anchors can only be placed corresponding to the distance increments of the holes of the Flowblock. Depending on the orientation of the solar panels on the horizontal plane, these increments do not always coincide with the distance of the solar panel frames (which is equal to the width of a solar panel).

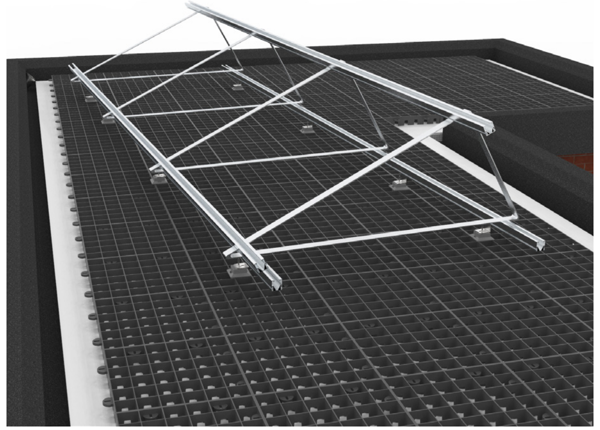


Figure 65. Install the solar panel frame.

8. Install the solar panel frame
The solar panel frames can be installed to the rails. Many frame brands are suitable, but de VanderValk solar systems are recommended. Their frames have been found to be compatible with this system set-up.

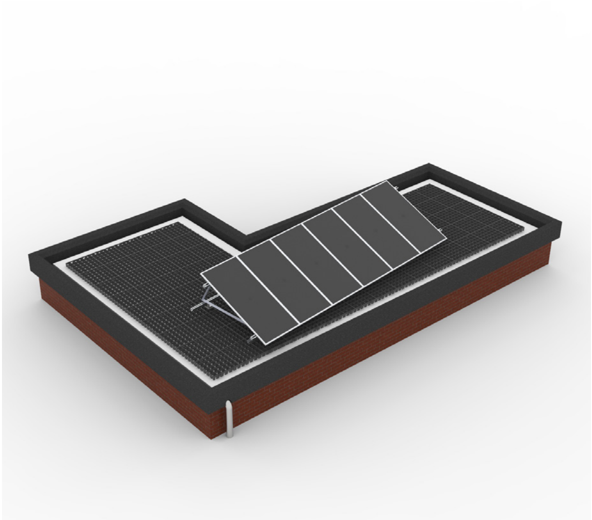


Figure 66. Place the solar panels.

9. Place the solar panels
Lastly, the solar panels can be installed. If the system includes a heat pump, the electrical wiring of the circuit will be done after. Otherwise, step 7 to 9 can be skipped and the cable management can be installed next.

13.6.4 Heat pump installation

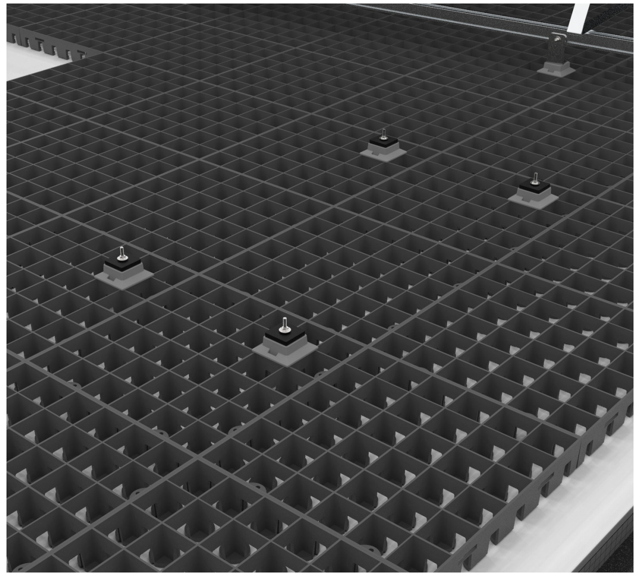


Figure 67. The anchors with vibration pads.

10. Place the anchors
If the system includes a heat pump, the first installation step is secure in the anchor, including a vibration pad.

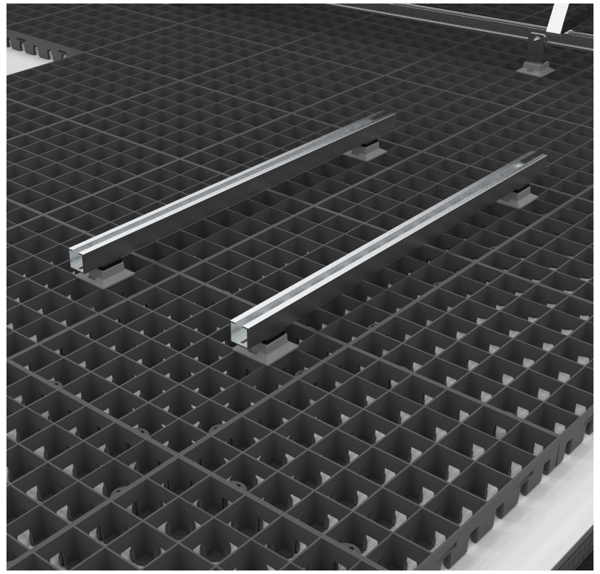


Figure 67. The heat pump frame installed.

11. Install heat pump frame
On the anchors, two rails are installed to serve as the heat pump frame. These will be installed parallel to the front of the heat pump. Suggested is to use standard Flamco rails.

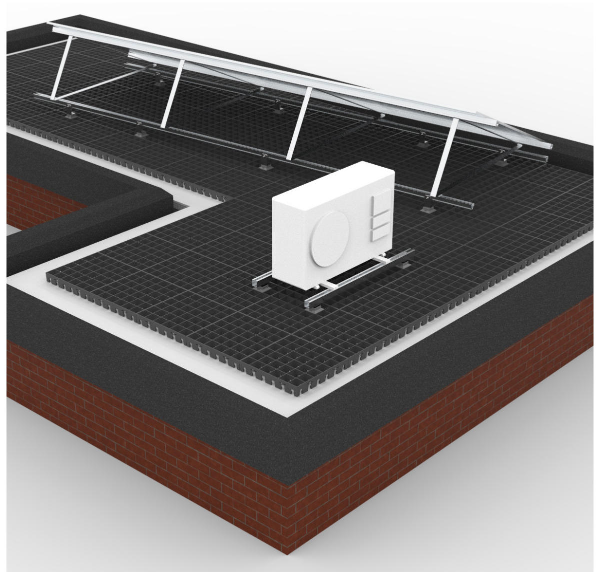


Figure 68. Place the heat pump.

12. Place the heat pump
On these rails, the heat pump can be installed. After this step, the installation of the cable management of the solar panels can be combined.

13.6.5 Cable management installation

13. Place the anchors
Conform the distance indication by the VanderValk CableCare system, place the anchors to support the standard cable baskets.

14. Place the cable baskets
On the anchors, place the cable basket with the screw thread in the middle of the basket.

15. Secure with centre clamp
Secure the cable basket to the anchors by using the standard galvanized centre clamps of the VanderValk cable care system. The clamp is compatible with the anchor.

Figure 69. Galvanized centre clasp.

16. Place the wiring
After the cable management is secure, the cables of the heat pump and/or the solar panels can be run through.

17. Secure the wiring
The last step of the cable management is securing the cables to the basket. This is typically done by tie-wrapping the bundle of cable to the baskets. This action remain the same for this system.

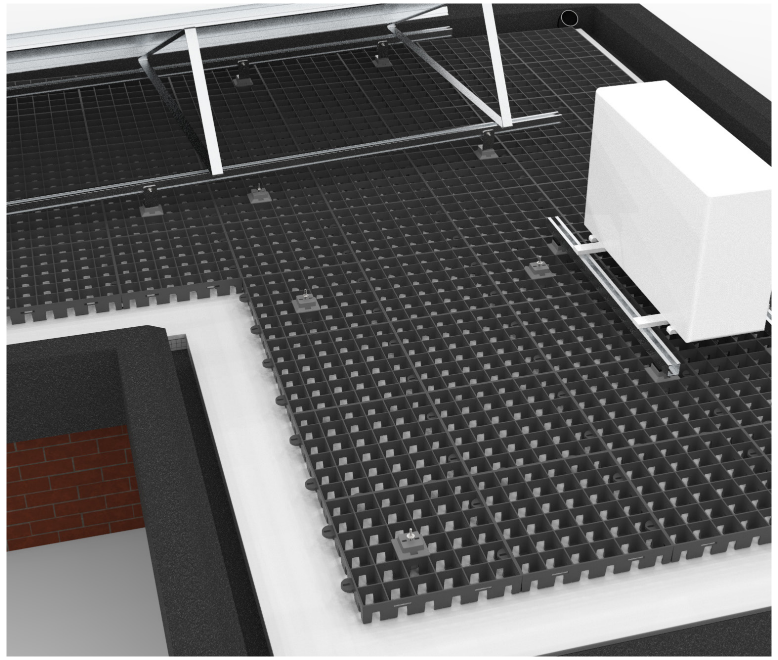


Figure 70. The anchors placed to support cable management.

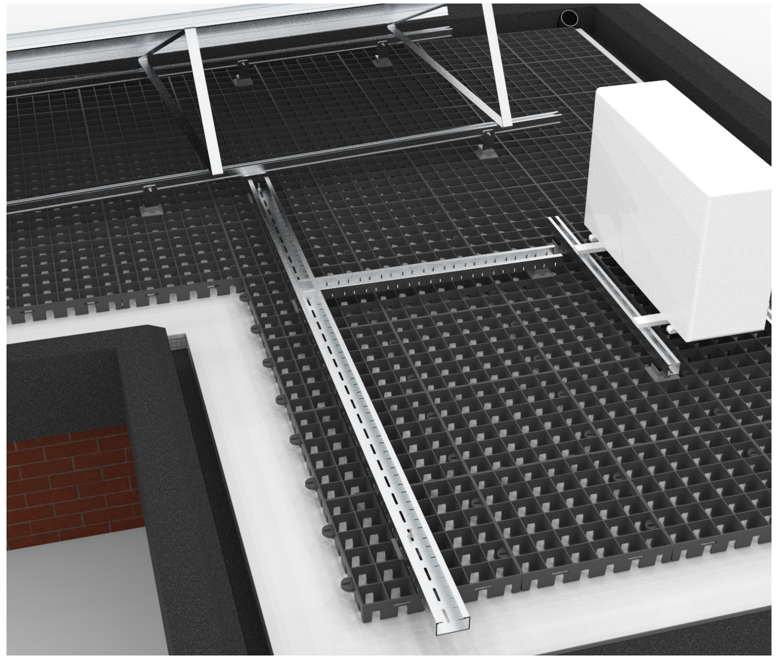


Figure 71. The VanderValk CableCare installed.

13.6.6 Green roof installation: Part II

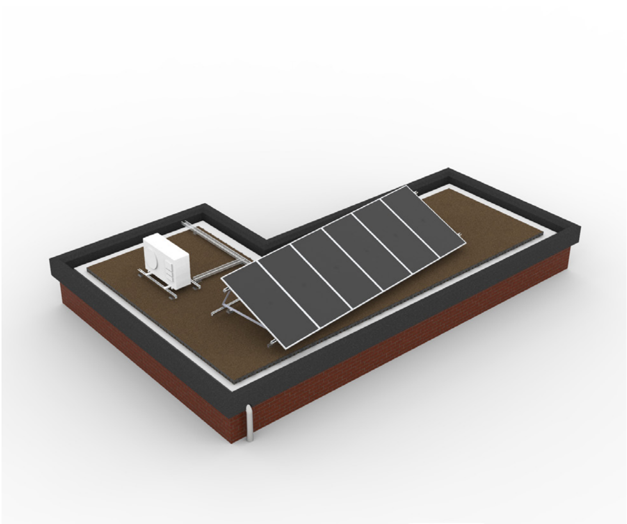


Figure 72. Implement the substrate layer.

18. Implement substrate layer
After the heat pump, solar panels and cable management is installed, the Flowblocks can be filled with the substrate layer. Depending on the size of the project, the substrate can be carried to the roof using a scaffold elevator, a standard moving lift or 'blowing' from a truck-mounted hopper using a compressor pump and a hose [GrowingGreenGuide, n.d.]. The substrate layer can be spread out using a standard rake.

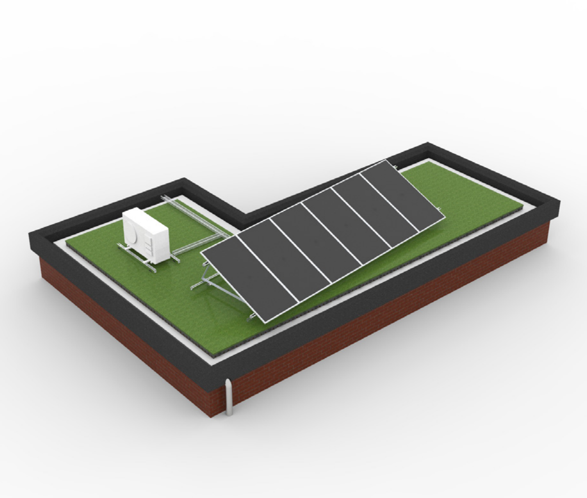


Figure 73. Implement the vegetation layer.

19. Implement vegetation layer
To implement the vegetation layer the client has three options (as discussed in chapter 7.4.1.1). They can sow seeds, plant pre-grown plants or apply a pre-grown vegetation mat.

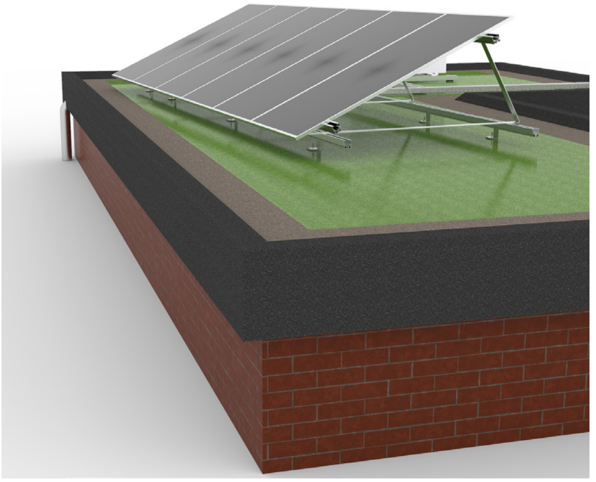


Figure 74. The roof edge filled with gravel.

20. Place gravel
The outer edge, between the Flowblocks and the roof border, is filled up with gravel. This protects the layer underneath and improves drainage of the roof.

21. Irrigate
The last step of placing the entire system is irrigation. This will ensure the plants survive and grow.

13.7 System alterations

Due to the use of available products on the market, compromises have been made in the functioning of the system. These compromises will be translated into innovation opportunities in chapter 13.8, but in this chapter alterations which can be made to this phase of the system to enhance performance will be discussed.

Add bottom to tiles

The weight of the green roof is not fully utilized, because the Flowblock does not have a bottom. It can not be assumed that the weight of the substrate layer counts as ballast, for when the Flowblock would be lifted, the substrate layer would fall through. Therefore, only the weight of the Flowblock itself can be counted as ballast in Phase 1 of the system. There is a direct link between the number of solar panels and the required square meters of Flowblock. This is depicted in figure 75. If the ratio of roughly 1 square meter of solar panel to 1 square meter of Flowblock (i.e. # solar panel : # Flowblock< 1:6,35 (depicted as a red line in the figure), alterations to the Flowblock have to be made.

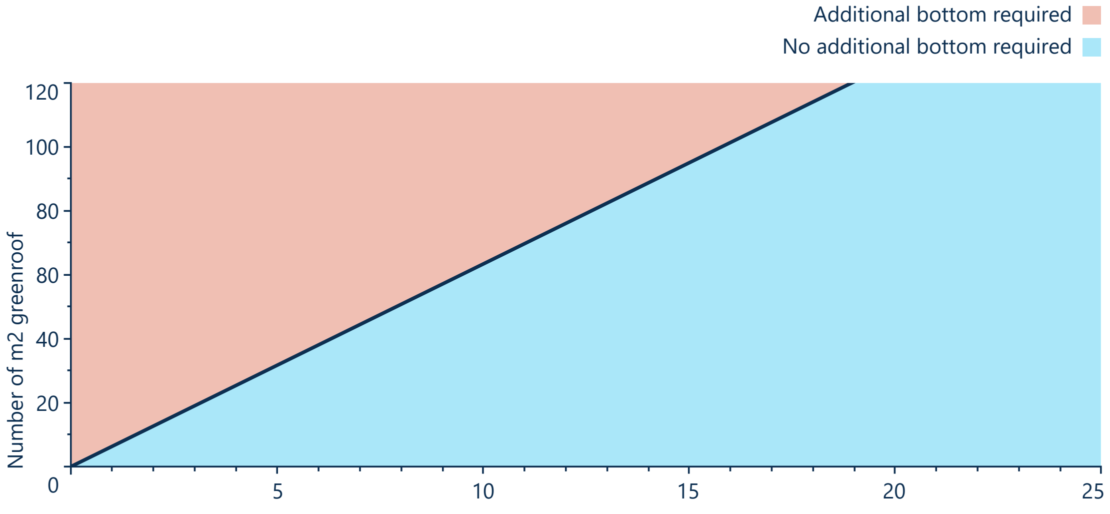


Figure 75. Ratio Flowblcks to PV panels to meet ballast requirements.

The suggested alteration is placing small squares of HDPE sheet in the cups of the Flowblock (depicted as blue squares in figure 76). They would not have to be attached for they will be held down by the substrate layer. This method is preferred over adding material to the outside of the tile, for protruding objects (such as screw heads) will damage the roof surface. Several suggestions were discussed with the company and this was the preferred option.

A Maple program is written to calculate the minimum number of tile alterations required to ballast the solar panels up to safety standards, subjected to the square meters of green roof and the number of solar panels of the specific client case (Appendix M).

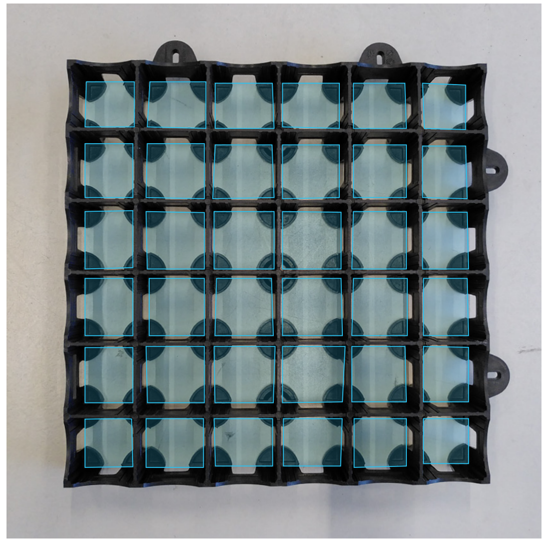


Figure 76. Indication of bottom squares added to the Flowblock.

Tile de-installation

The Flowblocks have a permanent locking system. When local repairs or roof maintenance is due, the connections will have to be sawn. This is not without risk, for in the process the roof might get damaged.

Gravel instead of vegetation

It is possible to use the system without implementing a green roof. There are two options. The first one being that you install empty Flowblocks within the safe ratio of 1 square meter of solar panel per 1 square meter of Flowblock. Another option is that a bottom is added as discussed earlier, after which a tile can be filled with gravel. This allows for an installation in which the Flowblock is not visible, and the life expectancy of the roof is increased by the addition of gravel.

13.8 Unique Selling Points

Customizable
The system can be entirely customized to the specific need of the concerning household. It is scalable to the available square meter and is suitable for all types of PV panels and heat pumps. Furthermore, the anchors can be used to install other rooftop components, such as the outside unit of an AC, TV aerials, etc. The client can comprise a system suitable to their particular needs, while the installation is standardized by the P3 anchor in combination with the Flowblock.

Upgradable over time
With current solutions on the market, if the client decides to install a green roof or solar panels, they eliminate the possibility to later add the other. This solution however, enables the client to purchase a green roof or solar system and in the future upgrade it by adding other components to it.

Gradual system innovation
This system is the launch of the company as a design organization. The gradual nature of the solution fits their current expertise while providing the potential to grow into an entire product line to fit their vision.

Combined installation
A considerable share of the costs for the client a solar system, green roof or heat pump is the installation costs. In the current market, if a client wants to install a combination of these products, they would have to pay double installation costs. This solution combined the installation of the system, decrease the installation costs.

Functioning system by adding 1 product
One of the strengths of this design is that the company has to introduce one product, the anchor, and the entire system is able to combine solar panels, heat pumps and a green roof. It is a small design intervention with maximum result.

Potential to go pitched
Installing a grid to contain the green roof creates the possibility to develop the solution to suit pitched roofs. As explained in chapter 7.4.2, a pitched green roof requires a grid to avoid the substrate layer to erode and collapse. Choosing a grid to secure components to a flat green roof now, means that expanding to pitched roofs remains a possibility for the future.

13.9 Innovation opportunities

There are four compromises in this phase of the system. In this chapter, these are translated to innovation opportunities for the next phases. All innovation opportunities either reflect on the Flowblock, or the Van der Valk cablemanagement. Therefore, these will be upgraded in Phase 2 and Phase 3 respectively.

Modularity
The system of Phase 1 is only modular during the first phases of installation. When locked, the flowblock tiles cannot (easily) be de-installed. The locking system is made to be permanent, and the tiles have to be moved horizontally to remove the male part of the tile from the female part, which is not possible when a tile is in the middle of a grid. Innovating the system to be completely modular benefits the company during installation and the client, by making roof surface maintenance possible.

Tile bottom
As mentioned in chapter 13.7, the use of available ballast due to the green roof is not ideal because the Flowblock does not have a bottom. This results tile adaptations per case, which results in extra costs and increases the chances of human errors. Adding a bottom to the grid will eliminate this.

Integrated drainage
The green roof will always require a drainage layer. In this system this is implemented as a separate layer, resulting in extra costs and installation time. When a bottom is added to the tile, the possibility to add integrated drainage should be utilized. Improving the water retainment of the roof should be taken into account.

Cablemanagement
The cable management being used in Phase 1 is that of Van der Valk BV. This product had two drawbacks. First of all, the cables are not protected (R7.4). Furthermore, later phases of system development are focussing on improving the aesthetics of the system, e.g. introducing a heat pump casing. The Van der Valk cablemanagement does not fit this goal.

14. Phase 2: The P3 Tile

In the second phase of the system, the P3 greenroof tile and P3 cablemanagement. This will replace the Flowblock, the drainage and filter cloth layer.

The P3 Green tile is a modular solution, developed to hold a substrate layer to support the growth of a biodiverse roof, while enabling solar panels and heat pumps to be installed on the roof using the P3 anchors. This page states the innovations introduced to the system by the P3 tiles.

Locking system
De-installability due to a new interlocking system.

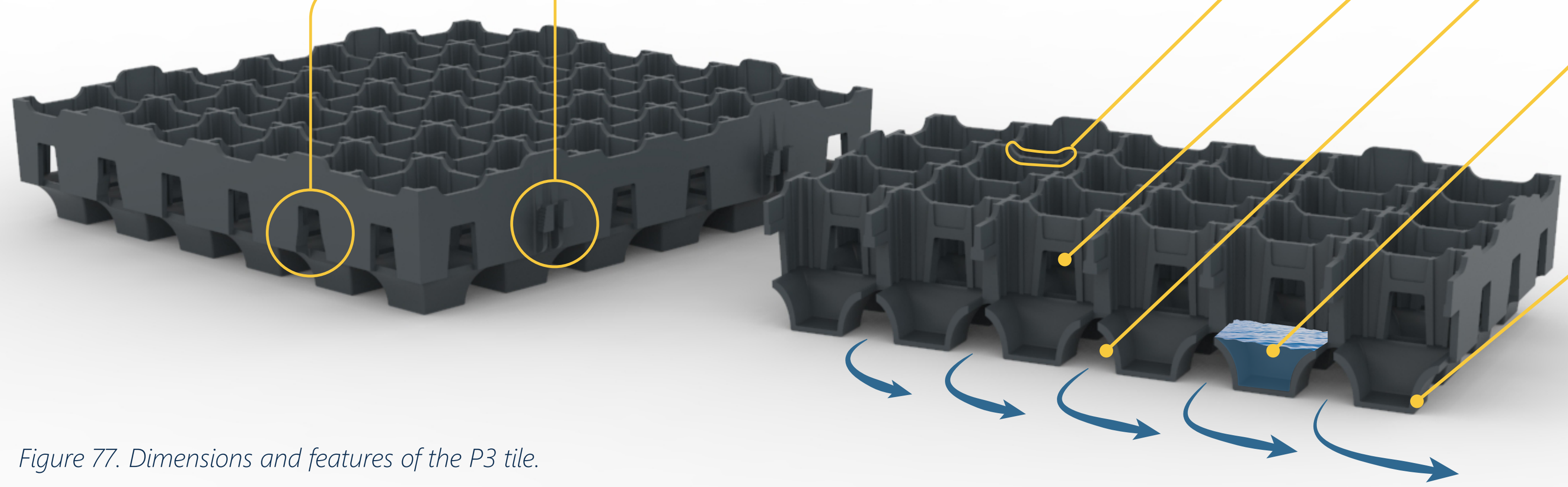
Cable management
Channels to support P3 cable management.

Anchor gaps
Gaps for the P3 anchor to lock into.

Drainage channels
Drainage channels to carry away excess water and prevent plant drownage.

Water reservoir
Water reservoirs to sustain plant growth (an extra benefit of this feature is that it acts as a rainwater buffer, and alleviates the drainage system of the city).

Pressure dividing bottom
Pressure dividing bottom to prevent damage to the roof surface when walking over the roof and support the modular function of the roof (possibility to pre-fill and replace/de-install tiles).



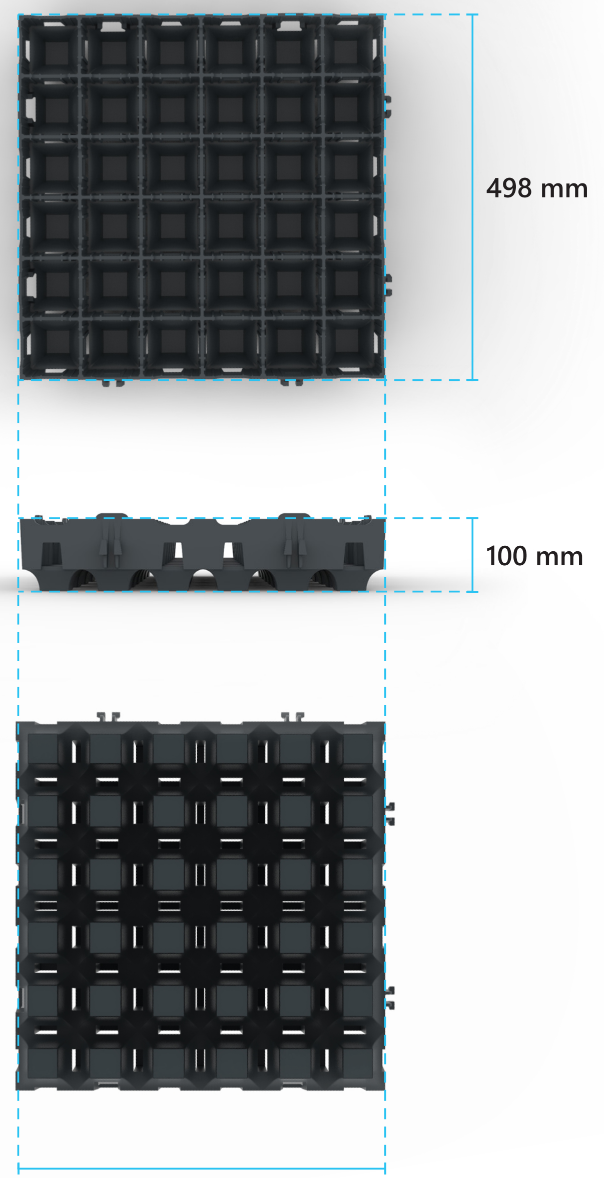


Figure 77. Dimensions and features of the P3 tile.

14.1 Green roof

The P3 Tile is designed to support all features of a green roof.

Vegetation layer

The first layer of the green roof is the vegetation layer. The P3 tile is made to support a biodiverse roof, helping the city's flora and fauna by sustaining native plants and grasses.

The substrate layer

If a biodiverse roof is opted for, the next layer needs to be over 8 cm (R3.2). However, it is also possible to apply a substrate layer height of 6,5 cm, to sustain a sedum green roof.

Hydro grains

The bottom cup of the tile is filled with hydro grains. These grains avoid rotting of the plant roots by improving water flow. They create a water reservoir, protecting the plants from drying out and relieving the city's rainwater drainage. Lastly they avoid clogging of the filter holes and drainage channels.

Filterholes

The P3 tile has filter holes at a height of 3,5 cm. This is the top of the water reservoir, where the water can leave the tile. Water below this height will remain to sustain the vegetation layer. Per square meter, the tile's substrate layer and waterreservoir can store over 30 L of water, meeting the requirements for Amsterdam's subsidy plan for green roofs (R3.5).

Drainage channels

The tile has spacious drainage channels to all sides of the tile. This allows proper drainage of the green roof.

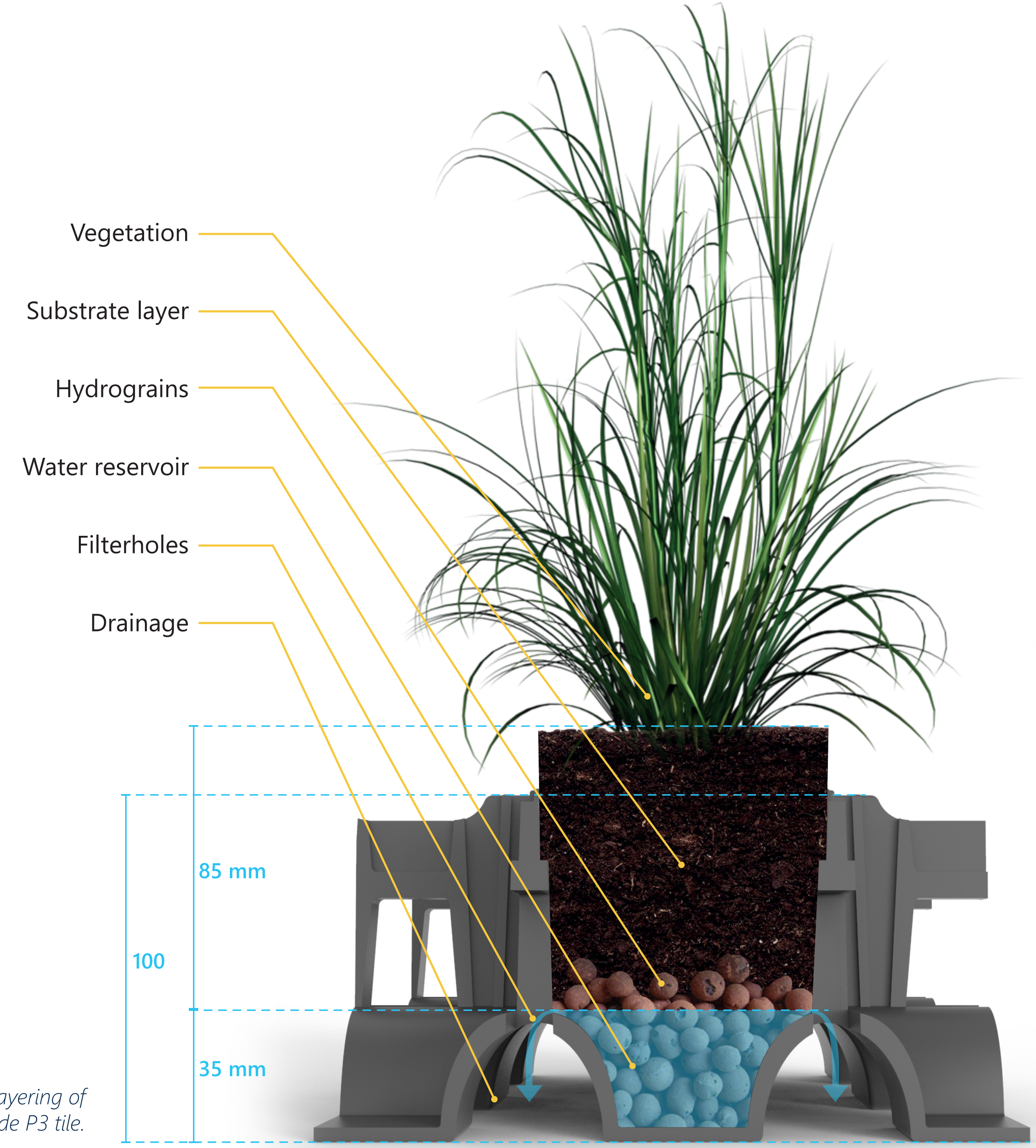
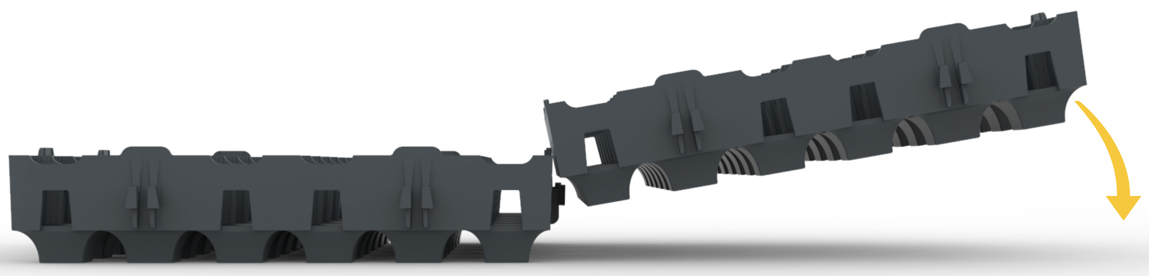
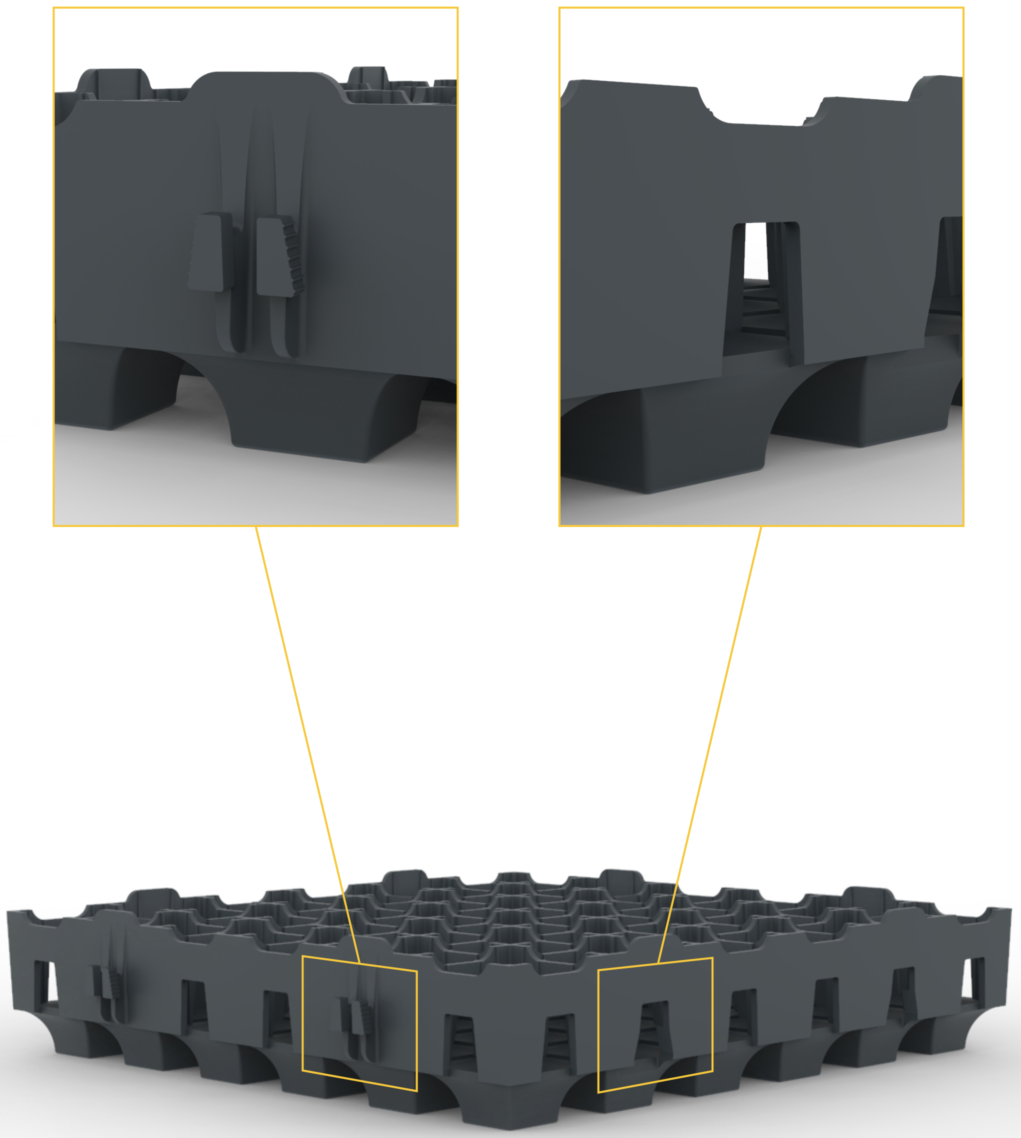


Figure 78. Cutview of layering of green roof inside P3 tile.

14.2 Installation

To install the P3 tile, no special tools or extra parts are required. The tile is equipped with an integrated locking system, of which two sides of the tile hold the male part, and the other two sides hold the female part. The tiles are locked by dropping the side of the female part over the male part. The male part is compressed and released once the tile is in place. The tiles are now interlocked.





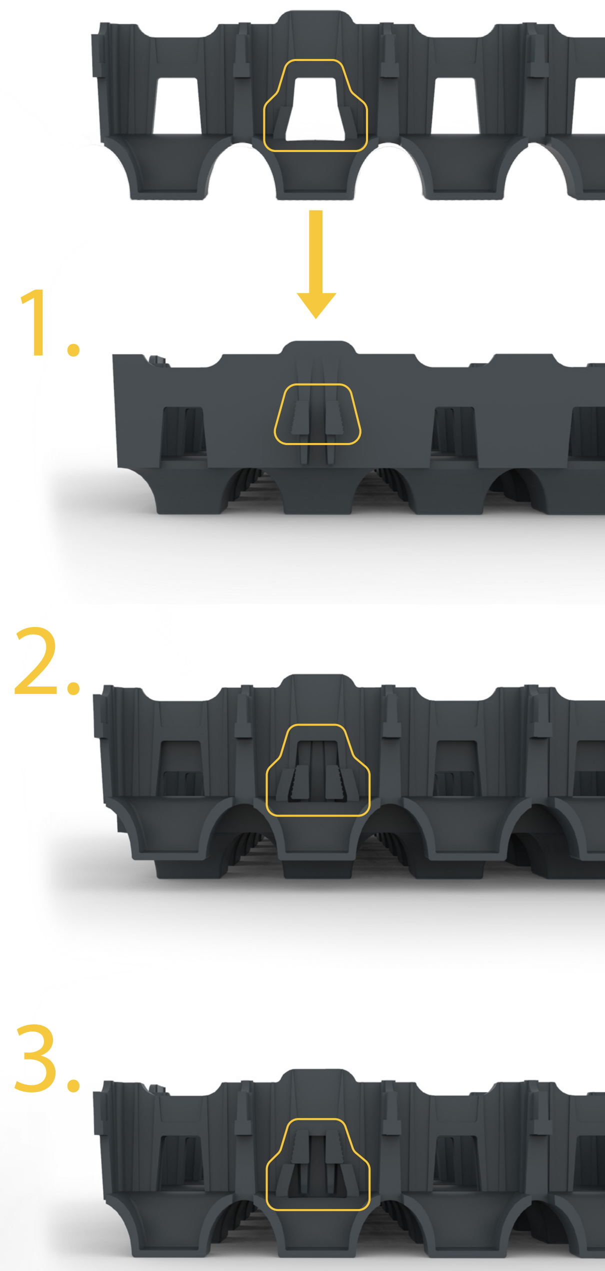


Figure 79. Installation of the P3 tile.

14.3 De-installation

An important feature of the P3 tile is that it creates a modular green roof. To fully profit from the modular functions, the tiles have to be de-installable. This allows for maintenance and local repairs of the green roof grid, but also provides access to the roof surface under the green roof.

The locking system of the P3 tile is designed with multiple features enabling de-installation:

In grid de-installation

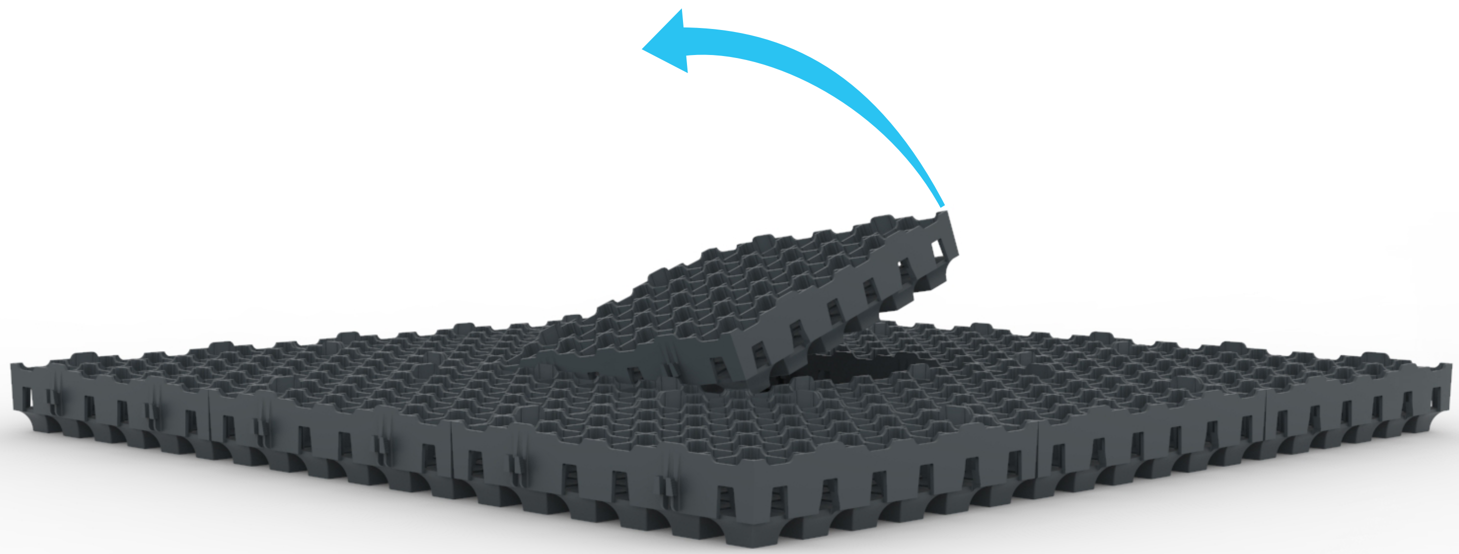
By equipping the tiles with an locking system which releases in an upward motion, it is possible to remove a tile which is situated in the middle of the grid. This allows for local repairs or roof access.

Standard plier as tool

To de-install a tile, the only tool required is a standard plier. These can be used to compress the male part of the locking system, which allows it to be squeezed through the female part.

Lock indication

When a tile needs to be replaced or removed, it will be filled with substrate and vegetation. This complicates locating the locking systems of the tile. To ease this search, the tile has elevated walls above the lock system.



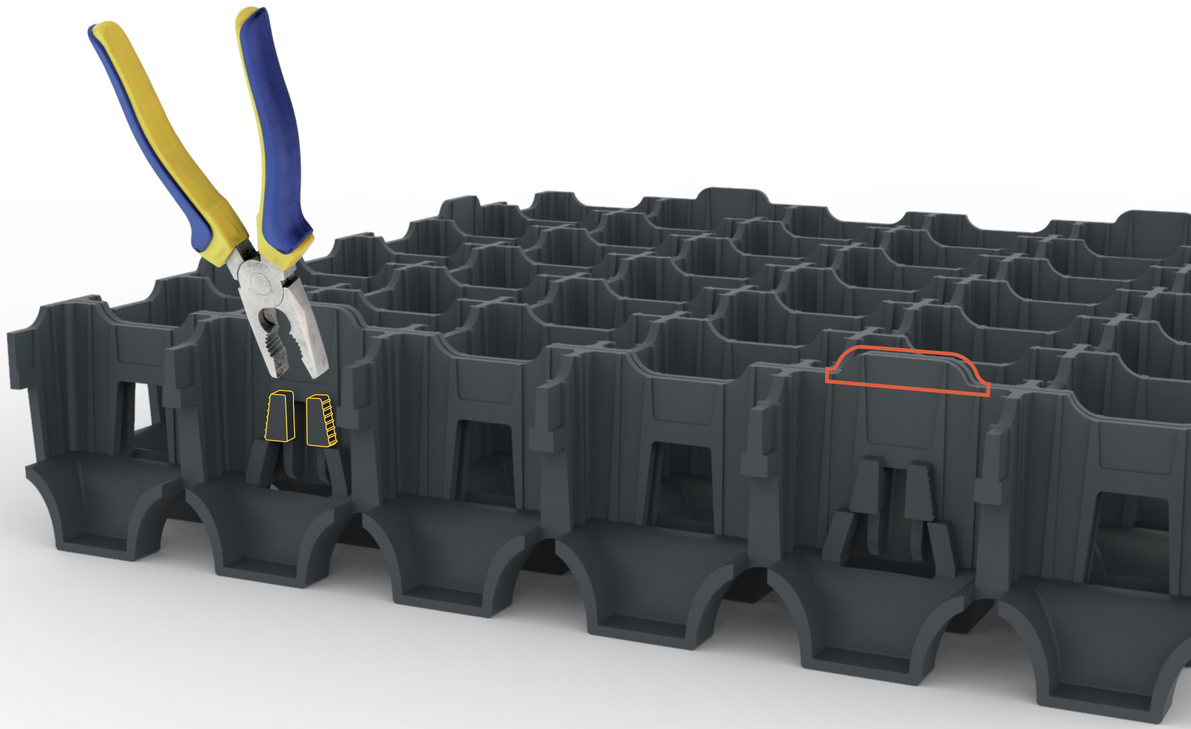
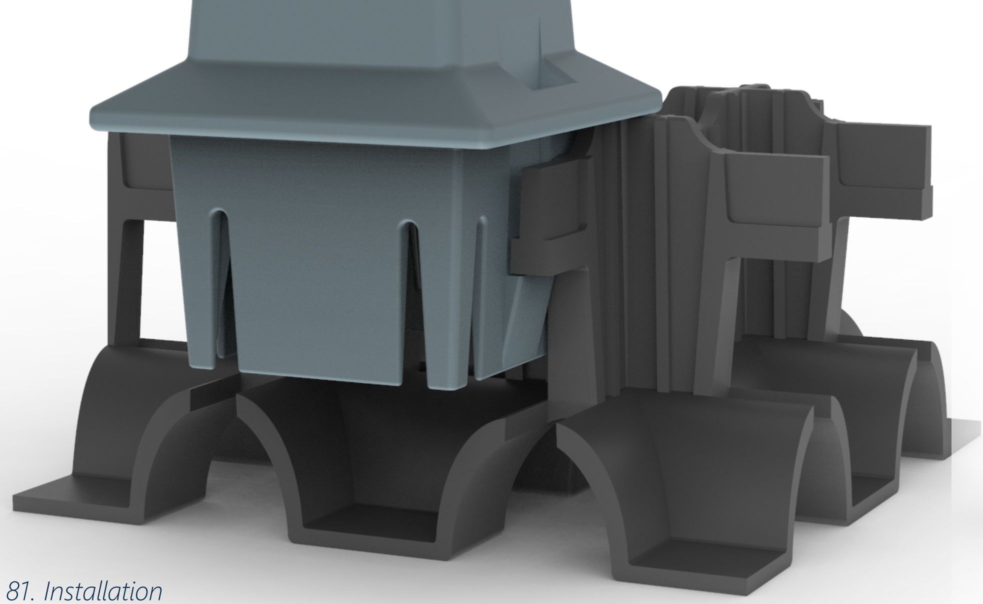


Figure 80. De-installation of the P3 tile.

14.4 Anchor installation

The anchor developed in Phase 1 of this concept is compatible with the P3 tile. By designing the two components in relation to each other, the company avoids having to redesign and re-invest in an altered design for the anchor. It is advised to approach the other component introductions in the same fashion. This allows the company to build upon their established product line.

The installation actions of the anchor remain exactly the same as when installing it in combination with the Flowblock.



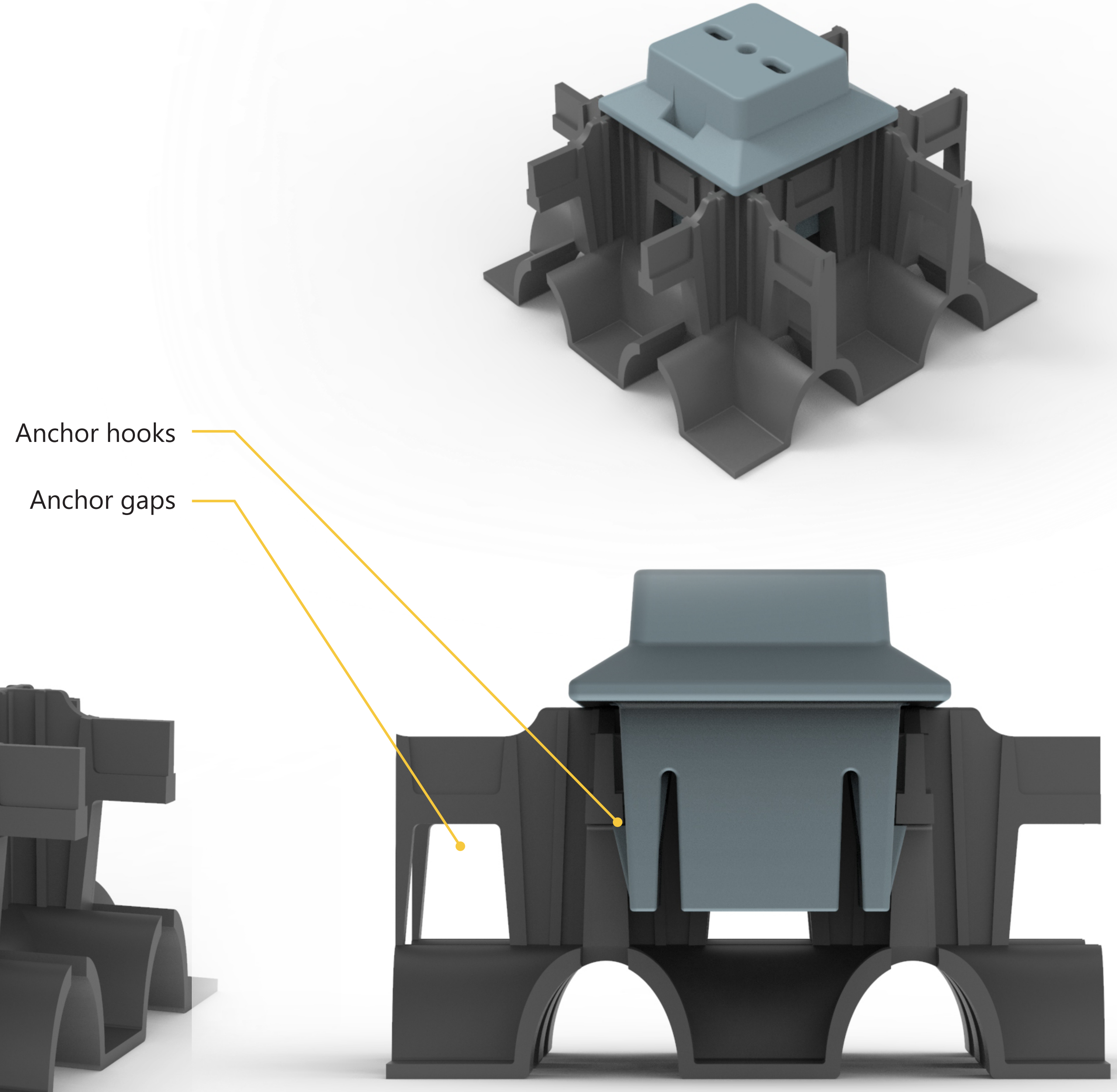


Figure 81. Installation anchor in the P3 tile.

14.5 Manufacturing

The P3 tile will be injection molded from recycled HDPE. In order to minimize production cost, the tile is designed to be injection molded with a two-part mold. By combining the filter holes and placing the anchor gaps as inserts in the female part of the mold, this is made possible.

Furthermore, all the walls of the parts are sloped to support the mold release, and the thickness of the walls are appropriate to be injection molded with HDPE.

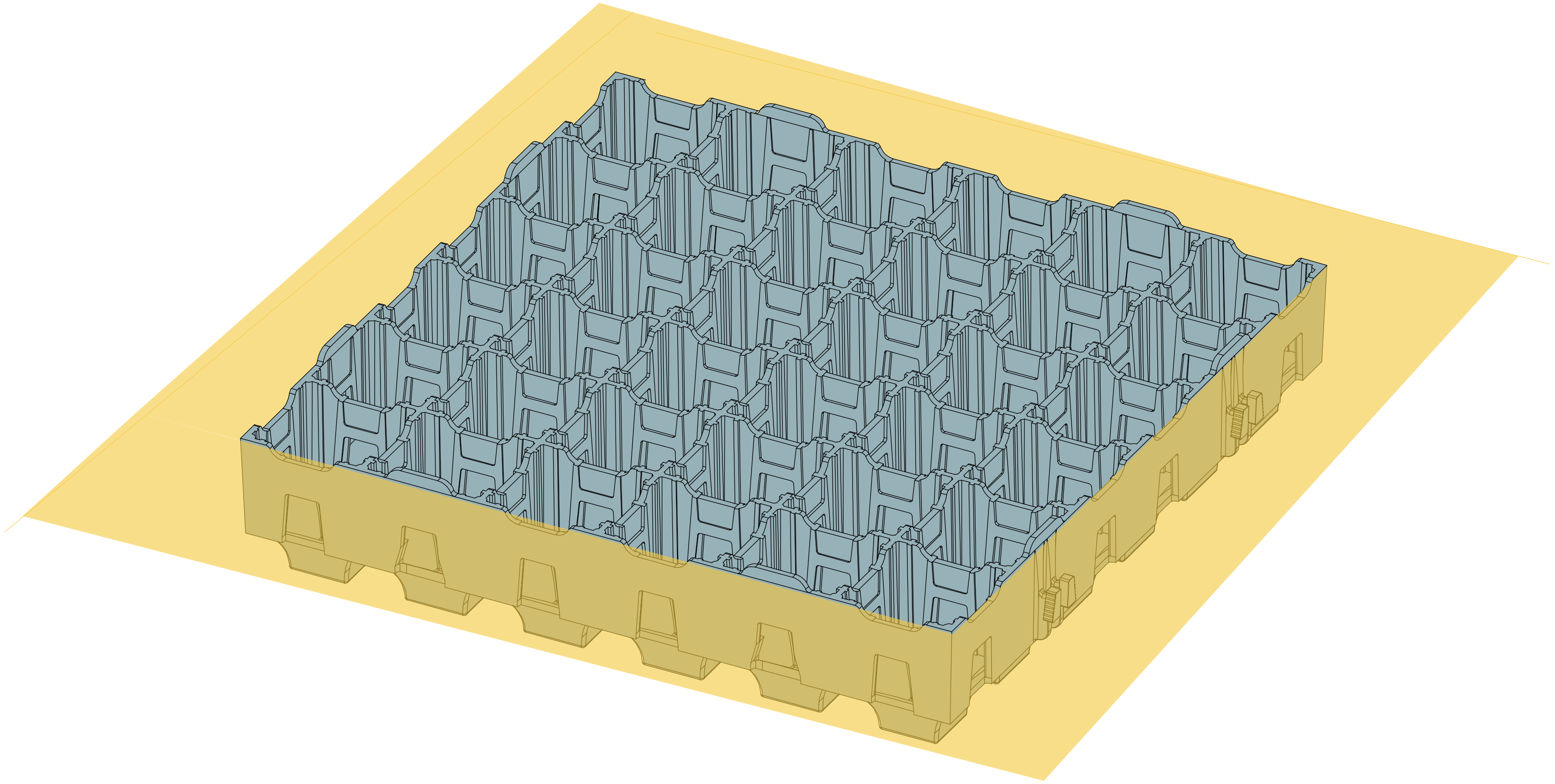
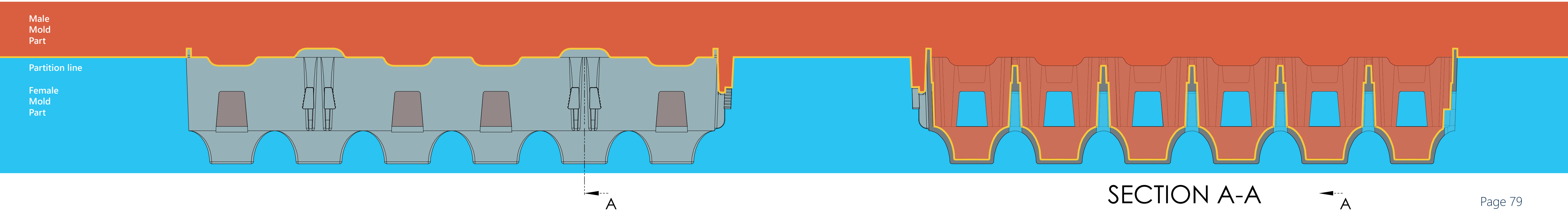


Figure 82. Manufacturing of the P3 tile.



Manufacturing the locking system

The locking system is taken into account in the mold. In the figures on this page section views are presented, to show how the female and male mold will enclose the part. All blue surfaces will be shaped by the male mold part, all red surfaces will be shaped by the female mold part.

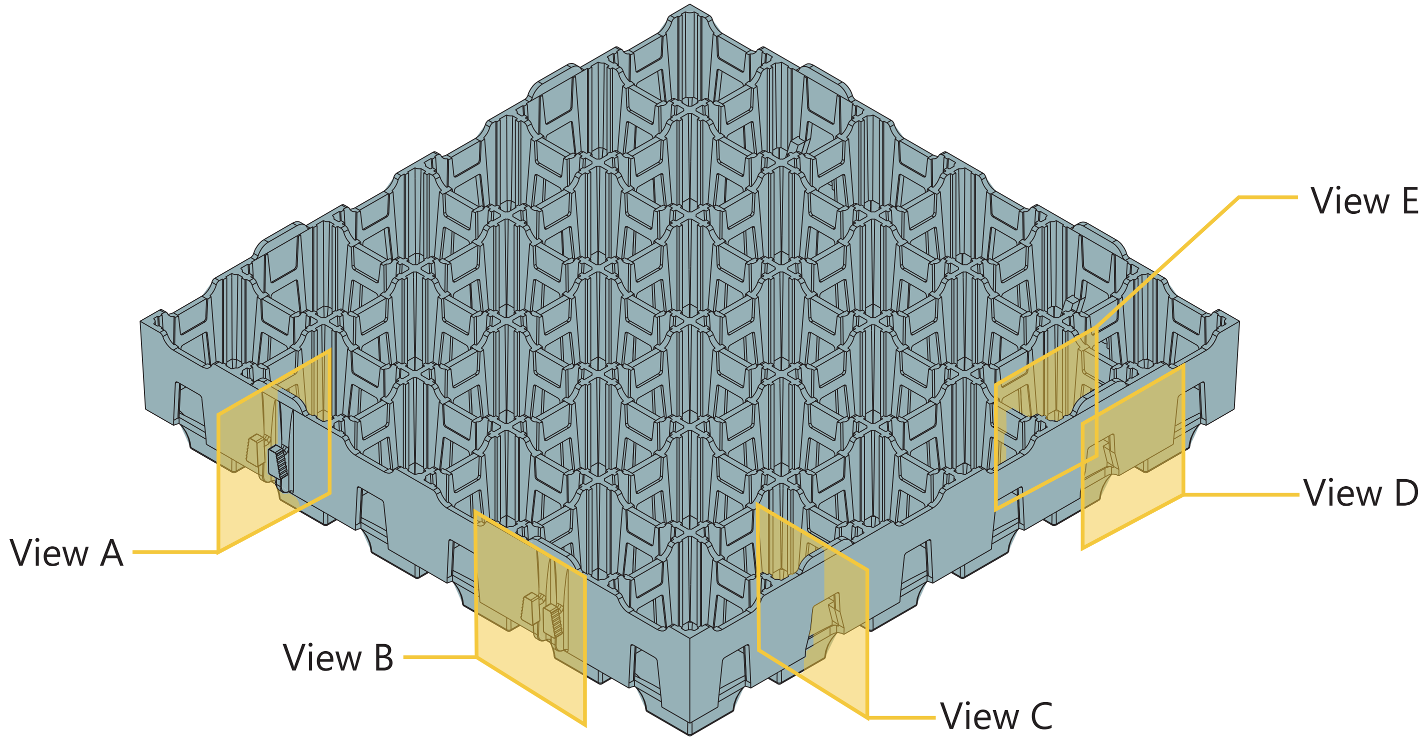
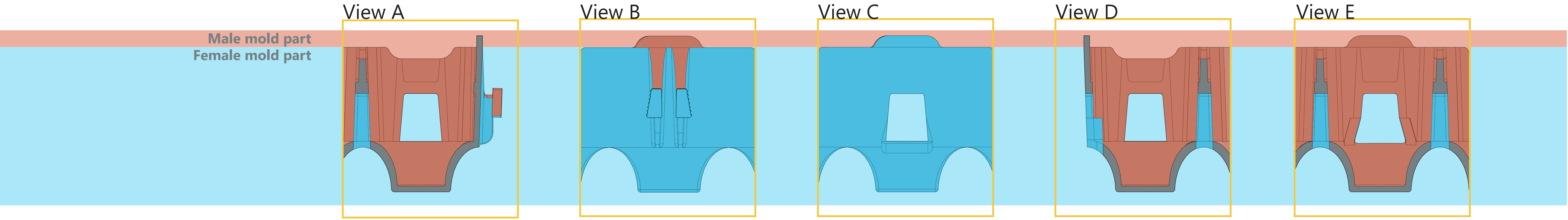


Figure 83. Manufacturing of the locking system of the P3 tile.



14.6 Costs

14.6.1 System costs

The excel of Appendix L, calculating the system's material costs based on the number of square meters of green roof, the number of solar panels and the number of heat pumps as input, has been extended to calculate the costs of the system if the Flowblock is interchanged with the P3 tile. An average of 40 square meters of green roof, 12 solar panels and 1 heat pump was applied. The system costs are estimated at €11.254,99. The increase in costs of roughly €500 is due to introduction of the introduction of the P3 tiles.

14.6.2 Manufacturing costs

The same company as approached for the anchor and plug, QDP, provided an estimation of the manufacturing price of the P3 Tile.
The investment costs for the mold are estimated to be a little around €21200 based on the material, weight and dimensions of the tile.

The combined costs, including return of investment costs of the mold, material costs of the part and set-up costs for the manufacturing company for a production volume of 20.000 parts would result in a price per part of €9,97. This translates to a price of €39,88 per square meter. See appendix L for more information.

The Flowblocks are around €17,50 per square meters. If this price is aimed to be approached for the P3 tile, it is advised to approach a different manufacturer, for QDP is mainly specialized in low production volumes. However, the Flowblock is produced in high production volume and is produced from less material, so it is expected this phase will result in a price increase regardless.

15. Phase 3: P3 Cable management

During Phase 2 of this project, cablemanagement will be introduced, fitting the P3 Tile. Te cablemanagement consists of multiple aluminium parts, rearrangeable into different layouts to match the needs per client case.

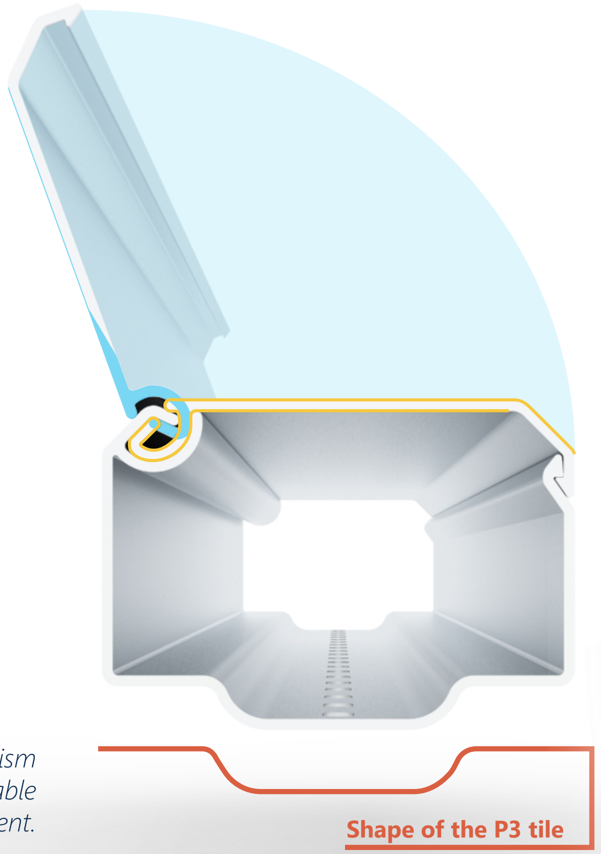


Figure 84. Mechanism of the hinge of the cable management.

Tray profile
The tray is a gulley through which the cables run. That will be produced in the standard length of 6 meters, and cut to use. The tray's bottom has holes to secure them to the connectors and to drain water, avoiding the cabling to be submerged in water. At the top, the tray has a groove into which the lid is slid.

Lid profile
The lid protects the cabling from deterioration by UV-exposure, weather conditions and animals. The lid is designed with a groove which slides into the groove of the tray, and acts as a hinge. This way, cabling remains accessible for maintenance, even after the entire system is installed.

Connector tray
The connector bottom is the piece which is secured to the tile grid using the toggle plug (see also chapter 15.2). They connect different tray profiles while also providing corners or junctions in the cable management.

Connector lid
The connector lids fit their respective trays, and are secured to the toggle plug. They enclose the lid profile, locking the hinge system closed by pushing it down.

Toggle plug
The toggle plug is the only store bought item of the cablemanagement. It anchors itself in the anchor holes of the P3 tiles and secures the connector pieces. A toggle plug in this case is preferred over the P3 anchor because the anchor is more expensive and overdefined for the function of securing the cable management. Moreover, the anchor would float the cable management above the green roof, instead of nestling it in the greenery layer. The latter is more aesthetically pleasing, and therefore preferred.

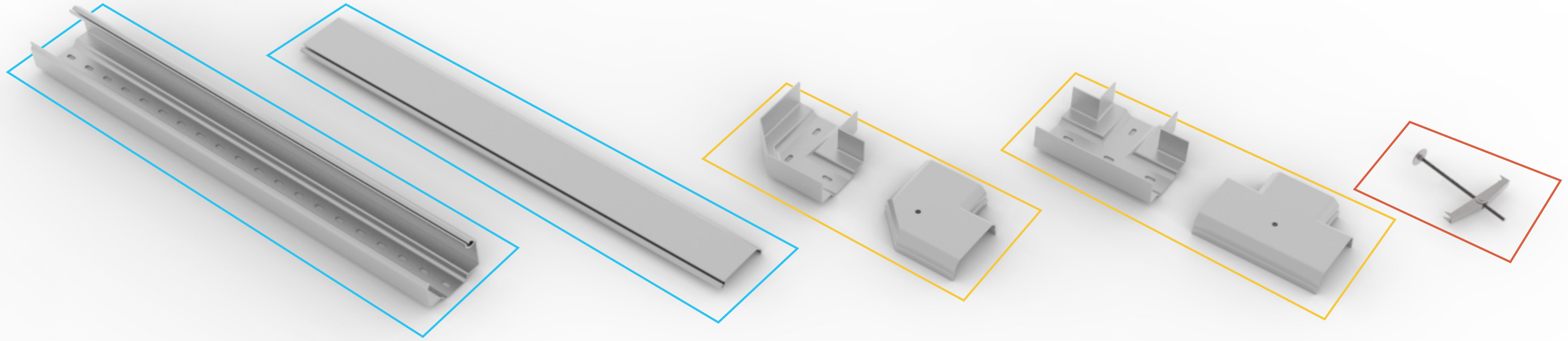


Figure 85. Components of the cable management.

15.1 Configuration

The cable management parts can be configured differently, depending on the need of the concerning client case. This modularity matches with that of the entire system.

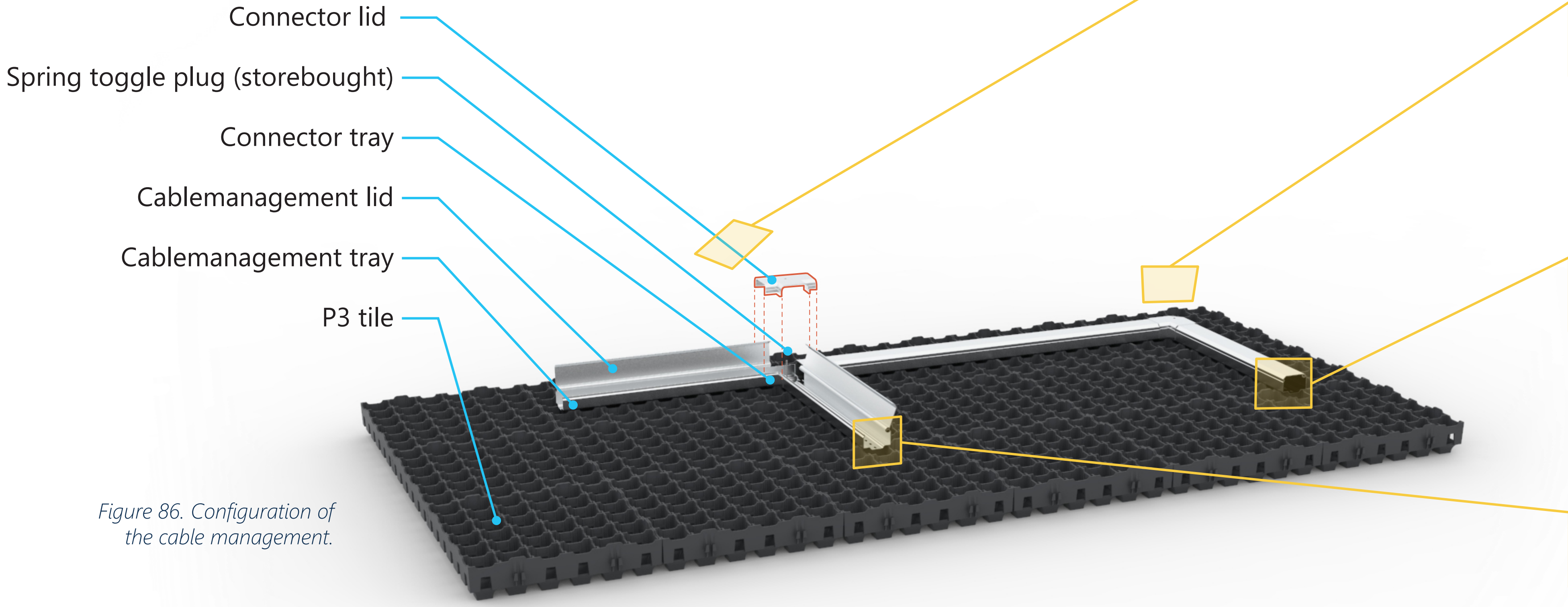
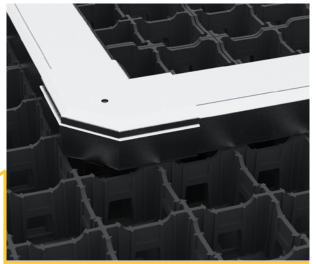


Figure 86. Configuration of the cable management.

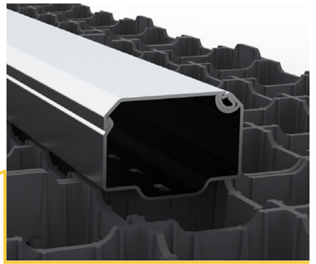
Connector lids

When installed, the connector lids close the cable trays, disabling the hinge function. During maintenance, the installer only needs to raise the connector lids to open the entire system.



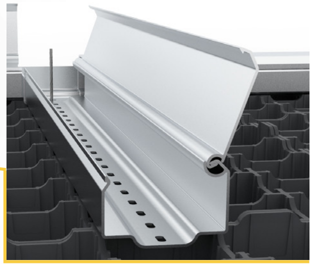
Different connectors

By using different types of connectors, different layouts of cable management can be achieved.



Closed for protection

When closed, the cabling to and from the other system components are protected from environmental factors.



Open for maintenance

When maintenance is needed, the cables are easily accessed over the entire length of all trays, due to the hinge feature integrated in the tray.

15.2 Securing to P3 tile

The cable management is secured to the entire roof system by using store bought toggle plugs in the connector pieces. These lock in the anchor gaps. The P3 tiles have a cutout corresponding to the shape of teh cable management. This eases the centration of the cable management to the whole system.

Firstly, the toggle plug is installed into a hole of the grid. A connector piece is placed over the screw thread (standardized M6) of the toggle plug. This is fastened using an M6 nut. After this step the other parts of the cable management can be assembled (see also the next page).

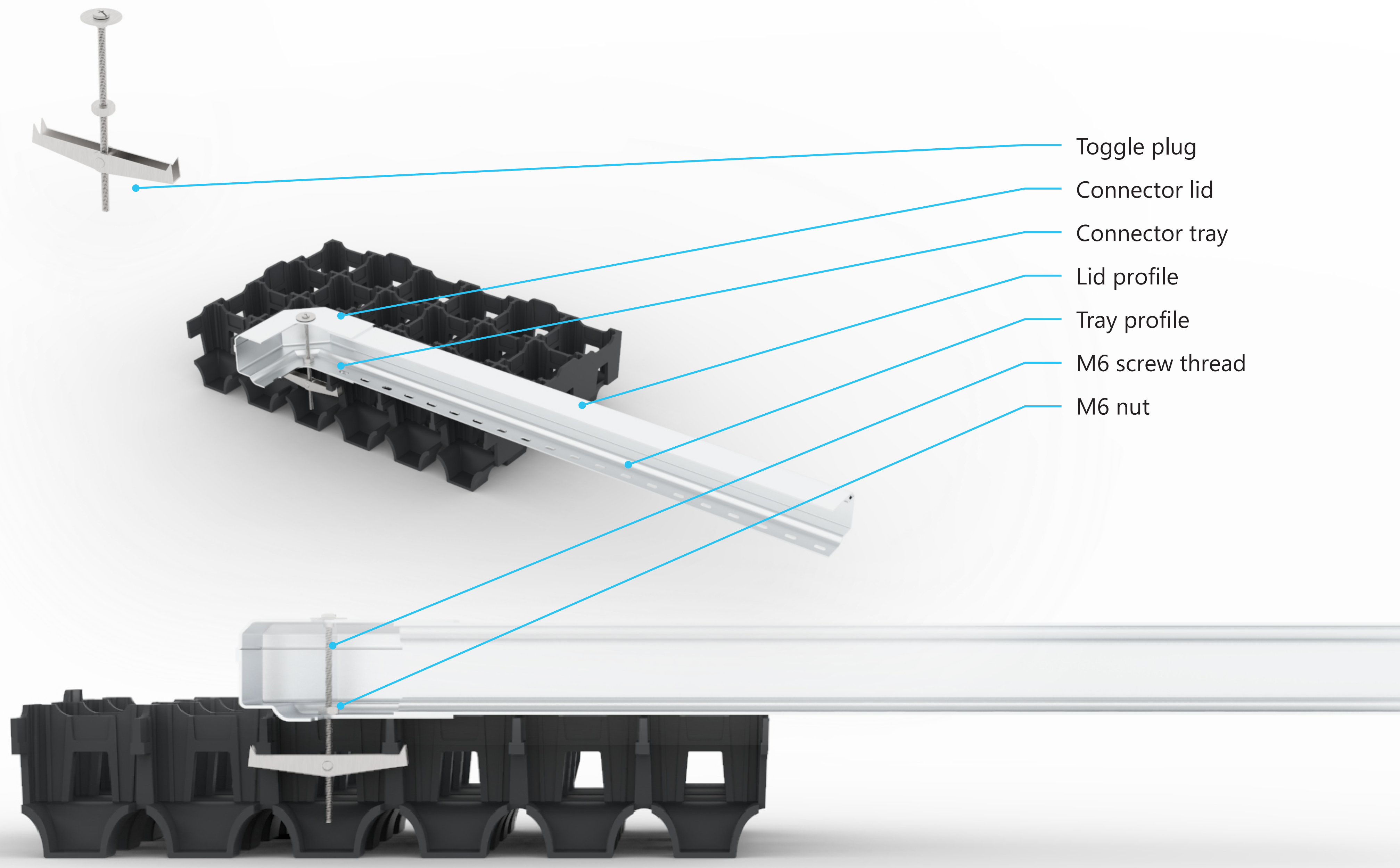


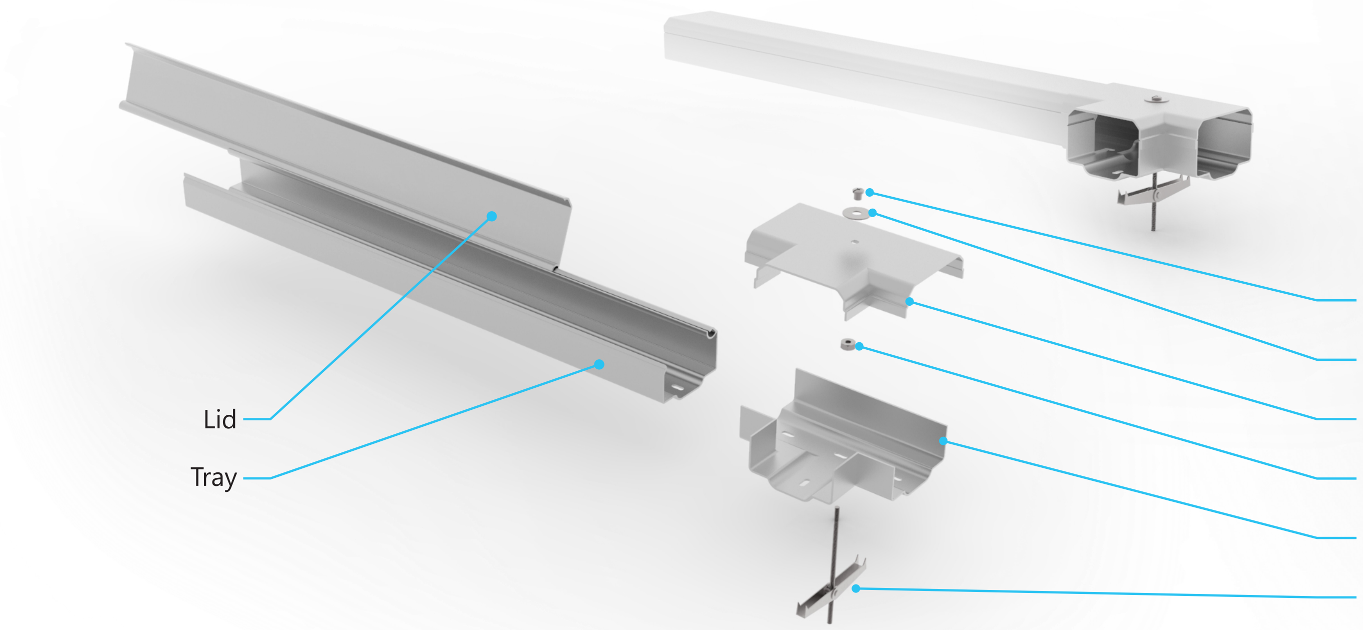
Figure 87. Installation of the cable managment to the P3 tile.

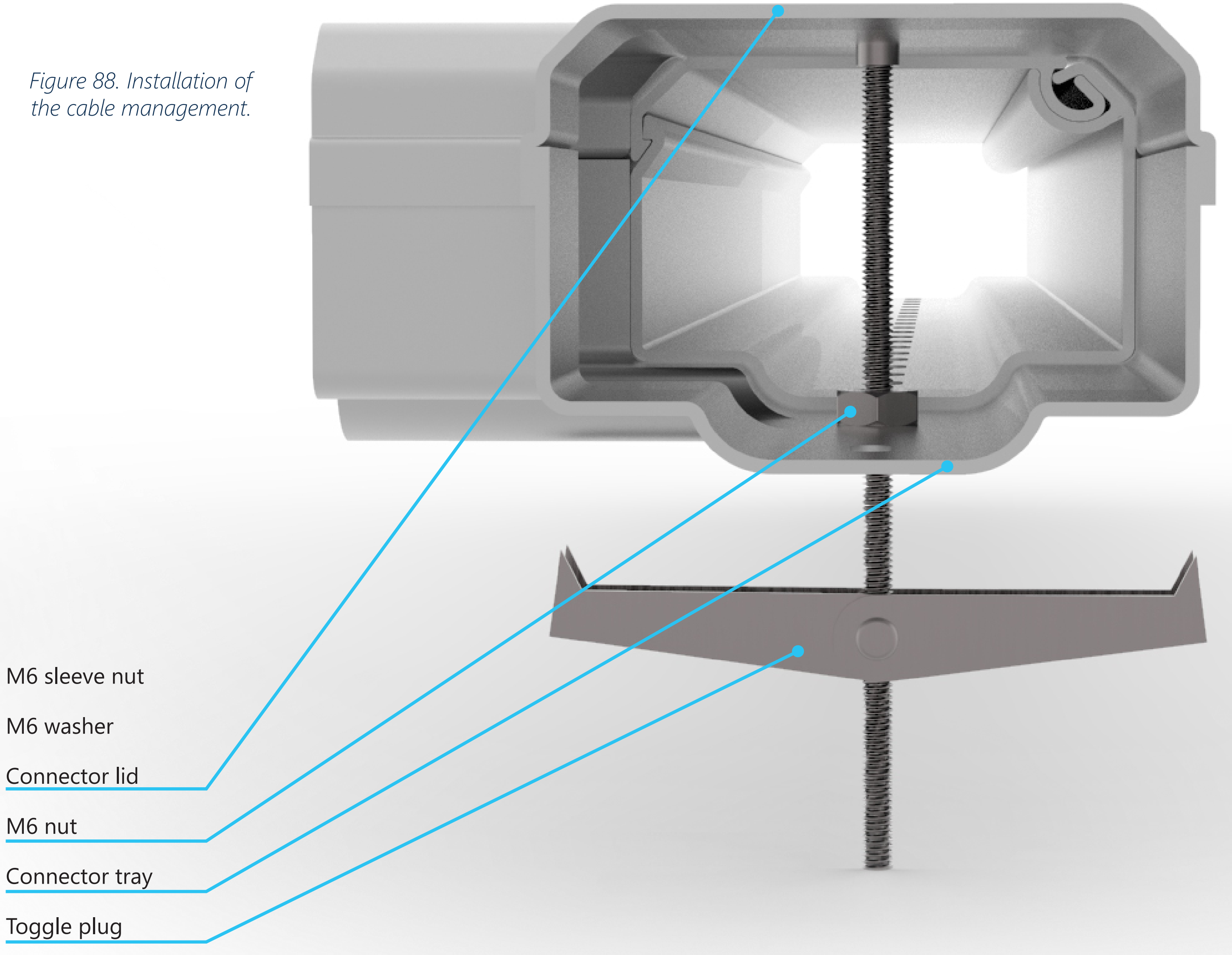
15.3 Installation

Once the connector pieces are in place, the tray profiles can be placed. They are connected to the connectors through the pre-perforated holes. When the trays are placed the cables can be run to the systems.

After all the cabling is in place, the lid profiles can be slid into the trays. After this the connector lids can be installed. These are secured using a M6 washer and sleeve nut.

Figure 88. Installation of the cable management.





15.4 Manufactering

15.4.1 Manufacturing the profiles

The profiles are designed to be extruded from aluminium. This is a fairly simple, low cost production method. The lid needs no post-processing. The tray needs to have holes punch over its length. In figure 89, a 2D cut view of the mold is depicted. The wall thickness of this model is 2 mm throughout.

Aluminium is well suited for both extrusion, and well equipped for the environmental context of the roof system. Furthermore, it is a lightweight material, which makes it attractive for this product.

15.4.2 Manufacturing the connectors

The connectors will also be made of aluminium. Both the lid as the tray of the connector pieces are deep drawn. Even though this is a more costly procedure than extrusion, because the both parts are smaller than 20 cm, the investment costs are feasible.

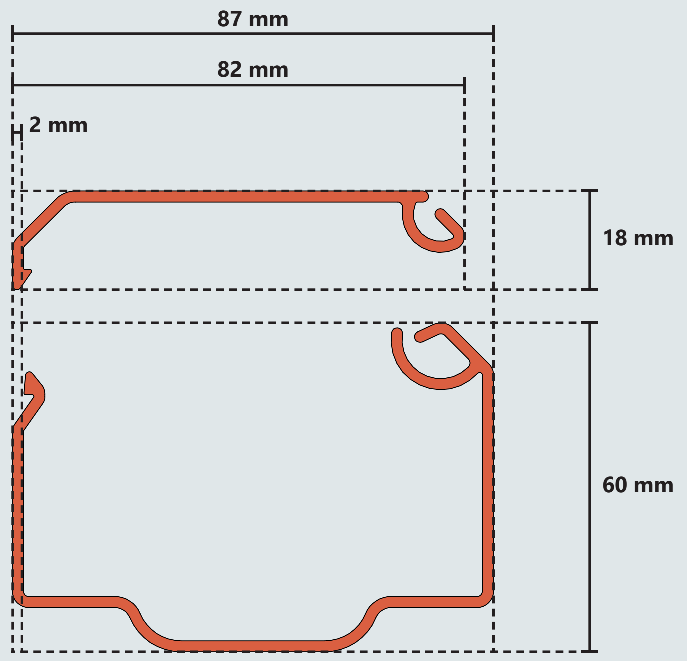
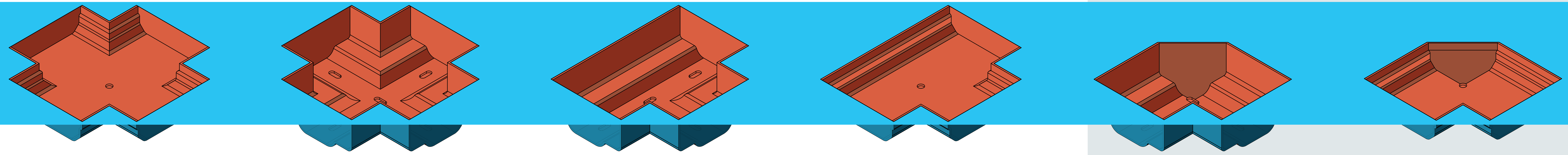


Figure 89. Manufacturing of the cable management.



15.5 Costs

15.6.1 System costs

Once again, the excel of Appendix L, calculating the system's material costs has been extended to calculate the costs of the system if the VanderValk Cable Care is interchanged with the P3 cable management.
An average of 40 square meters of green roof, 12 solar panels and 1 heat pump was applied. The system costs are estimated at €11.861,21. The increase in costs of roughly €600 is due to introduction of the introduction of the P3 tiles.

This number provides the argument to iterate on the design to decrease the cable management costs. Other redesign requirements are noted in chapter 17 and 18.

15.6.2 Manufacturing costs

The manufacturing costs of this Phase of the system are expected to be significantly higher, due to the increase in molds required to make all the different parts of the cable management. The parts are developed to be manufactured using relatively cheap production processes. However, the design is still in the development phase, so hard numbers on the deep drawing mold and extrusion dies are hard to provide and less relevant. An estimation of part costs has been made based on comparable products on the market. In this estimation, the low production volume has been taken into account.

The lid and tray profile are estimated to be around €12 and €15 respectively. The connector pieces are estimated to be priced €19 per piece.

16. Final prototype

A prototype was developed of the components of all three phases. The prototype was used to explore the functioning of component's designs, to iterate on optimal dimensions and to support the final company evaluation session. This chapter will discuss the aim of each prototype and the main findings.

On the right side you can find the final prototype, including the P3 tile, a T-connector tray with toggle plug and cable management tray and lid.

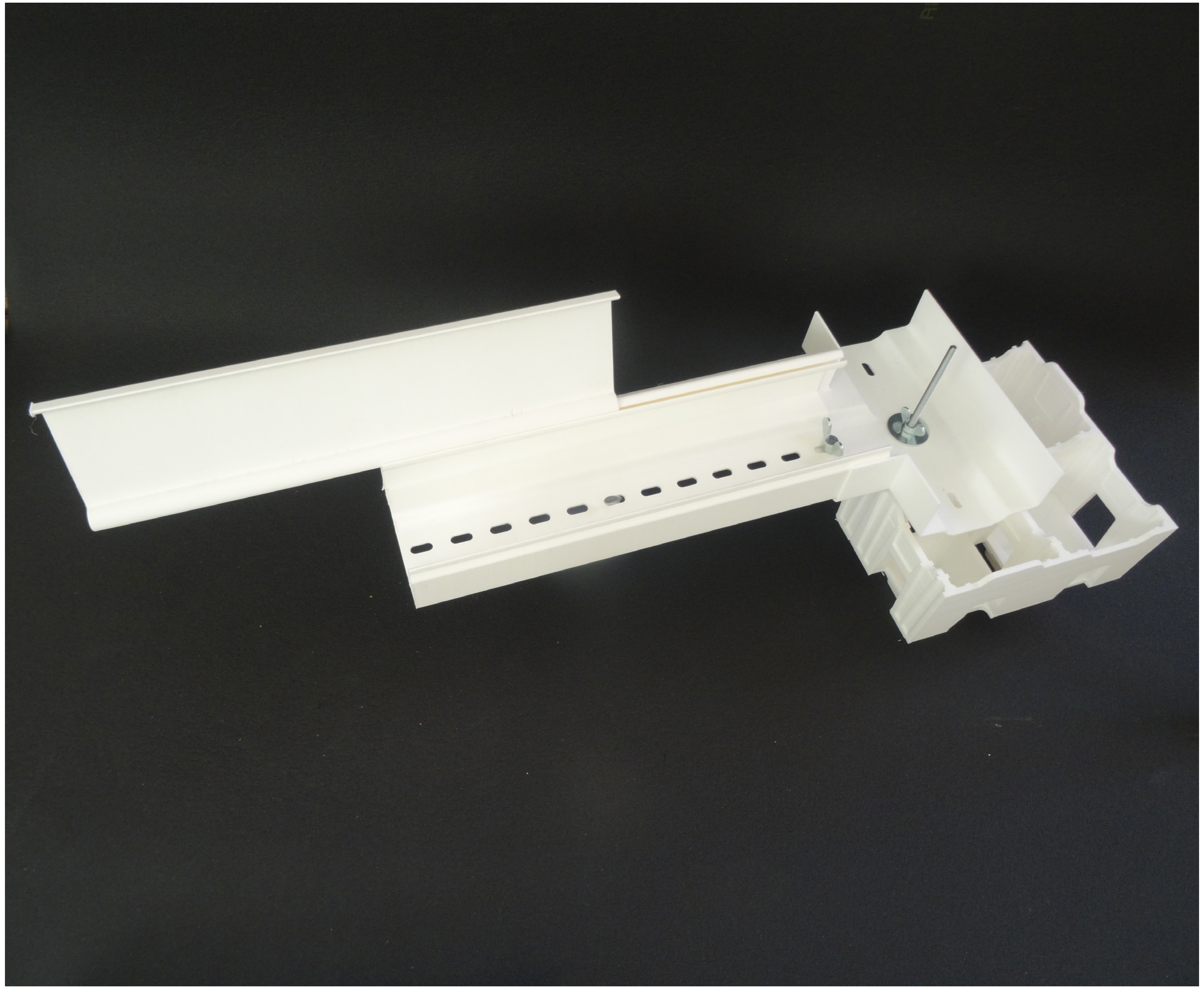
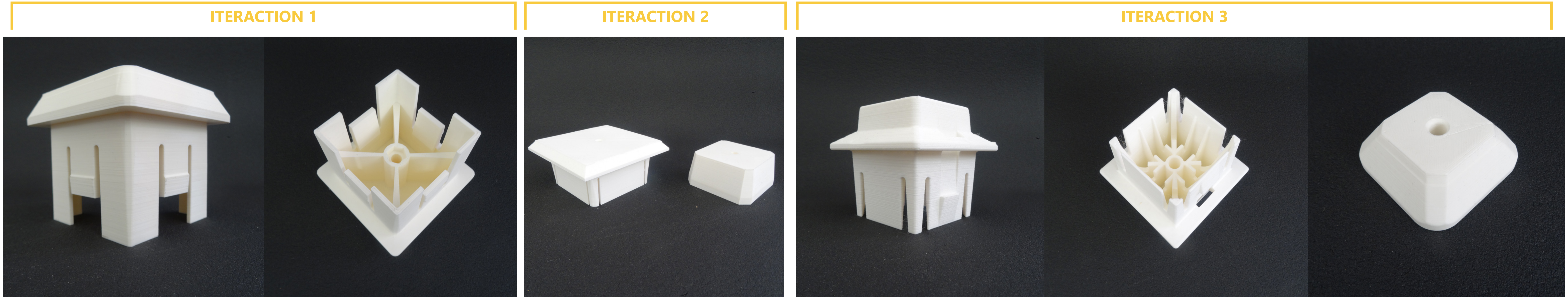


Figure 90. Final prototype, of cable management and P3 tile.

16.1 The anchor

On this page the main evolutions of the anchor are shown. The first iteration was without the plug and contained four hooks on each side which lock in the anchor holes of the tile. Due to the need of de-installation, iteration 2 was developed. This design included a plug and relied on expansion force to secure the anchor in the tile. Because of the performance context of the anchor, i.e. subjected to weather conditions, the hooks were re-introduced in the design in iteration three. At this point the dimensions of the product were established, and further testing would explore the expansion force due to material deformation caused by the force applied by the plug. Therefore, it was decided to change the prototyping material from standard PLA to Though PLA, a material which approaches the shear strength of HDPE. There were multiple attempts into printing the part in nylon, but the poor printability of this material posed too many complications.

Figure 91. Evolution of the anchor

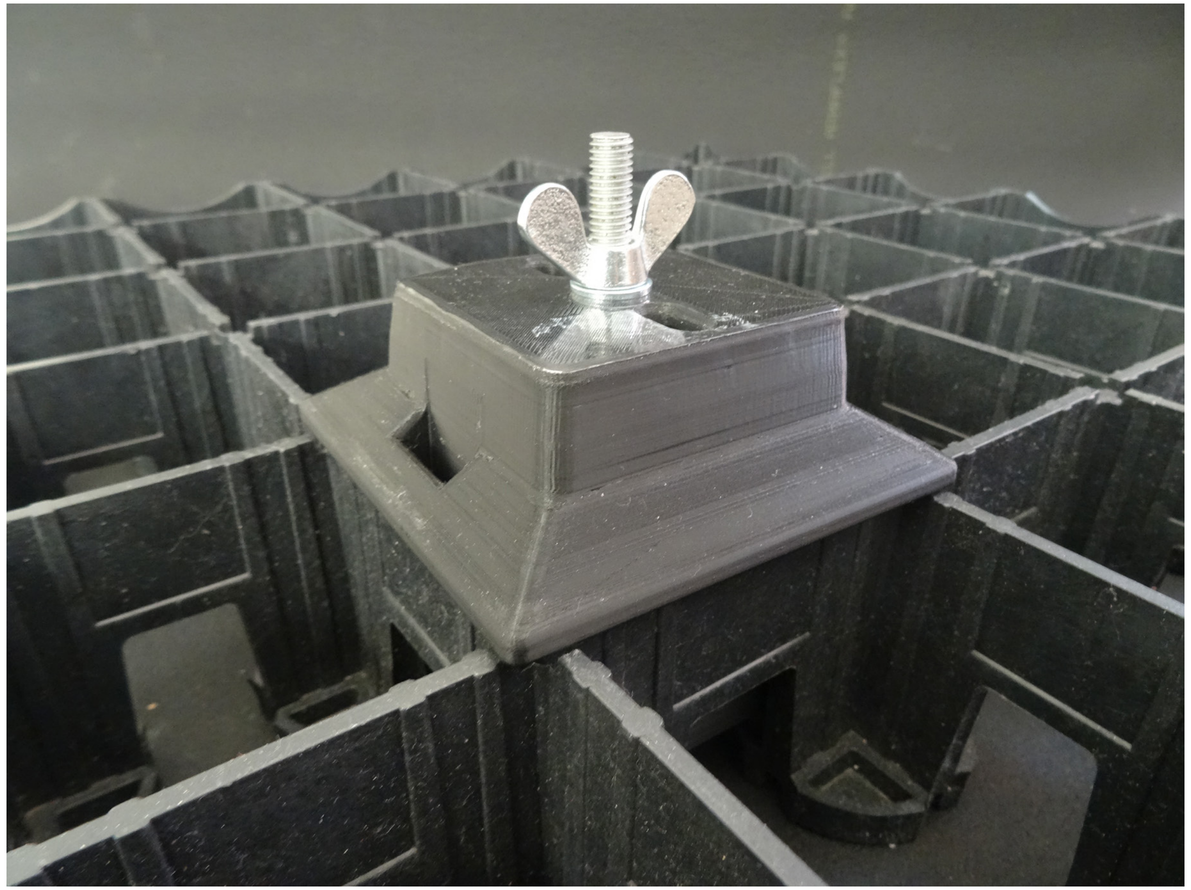


Force resistance

Tests of the anchor’s functioning when subjected to a pull force were performed on the 3D printed Though PLA prototype of the anchor and the plug. An average of 26,4 kg could be applied to the anchor before it malfunctioned. Every malfunction recorded was the anchor slipping from the Flowblock and not the shearing of the part’s material. Therefore, it can be concluded that the friction of the anchor on the Flowblock should be increased, which can be done by forcing more material displacement in the anchor caused by applied pressure of the plug, or the hook features should be enlarged.

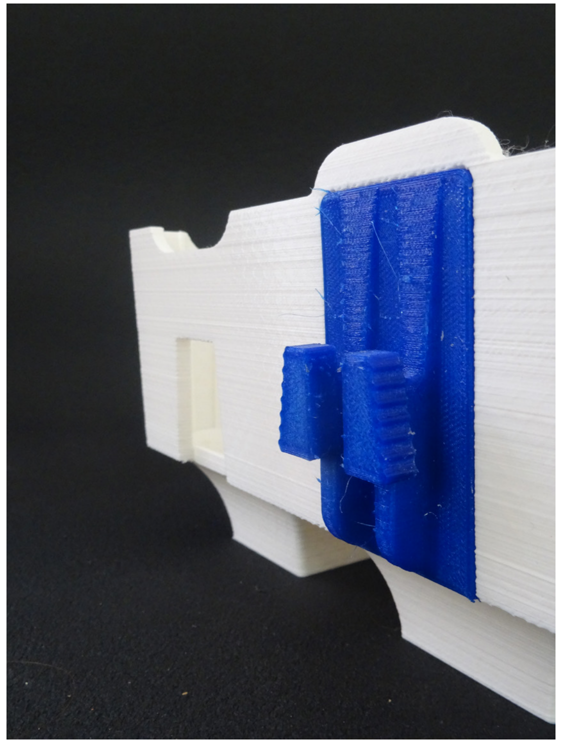
Due to the manufacturing method of the prototypes, it was possible to research the expansion potential of the part and do the first testing of part performance, but extensive tear testing to determine the tensile strength and durability of the product was not relevant. The applied force would be perpendicular to the layers of the print, and would therefore not approximate the behaviour of injection molded HDPE.

Figure 92. Prototype anchor of Though PLA.



16.2 The tile

Parts of the proposed design for the P3 tile were printed, to iterate on dimensions, fit of the parts and the interaction of the locking system. The ribs, the cutout for the cable management and the extended tile wall above the locking features were iterated during this prototyping. To simulate the locking system, the last version of tile iterations were provided with a flexible male part printed from TPU, to simulate the mechanical function of the snap fit.



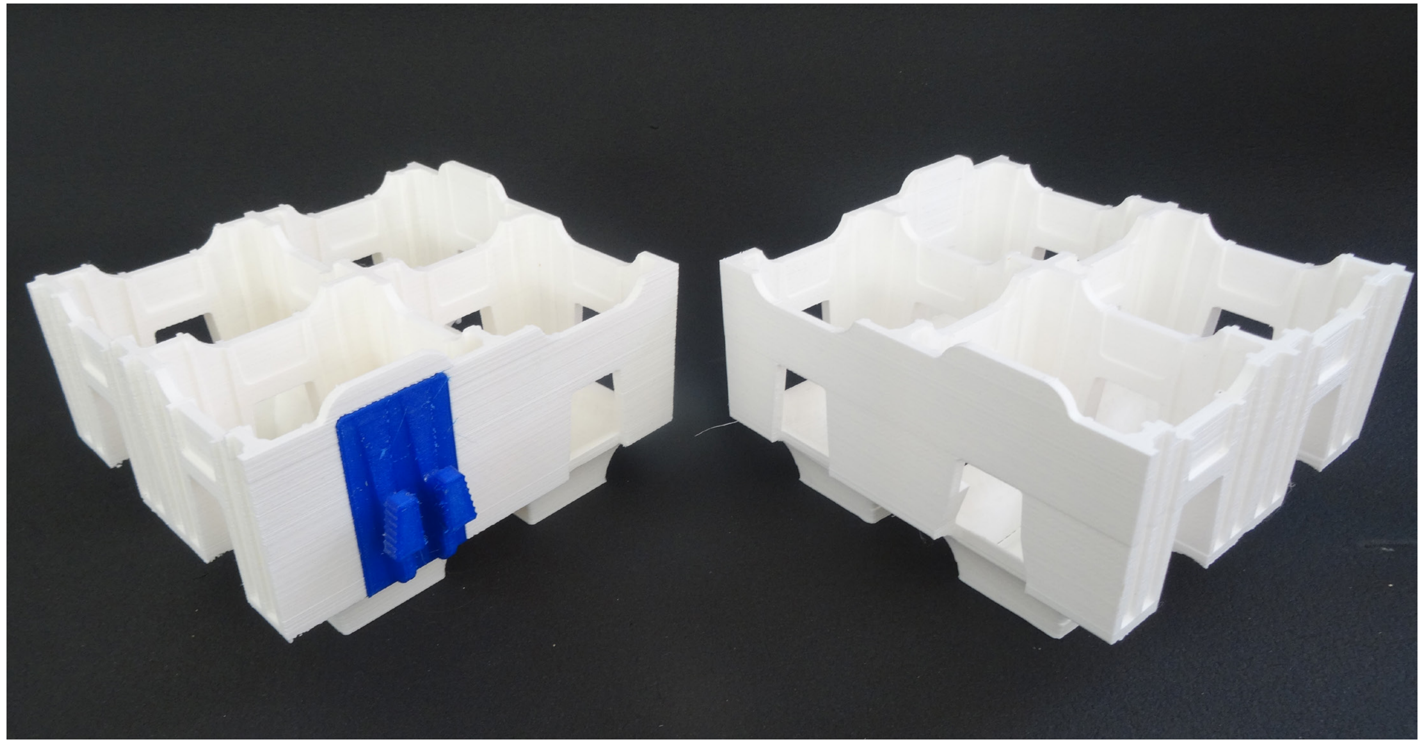
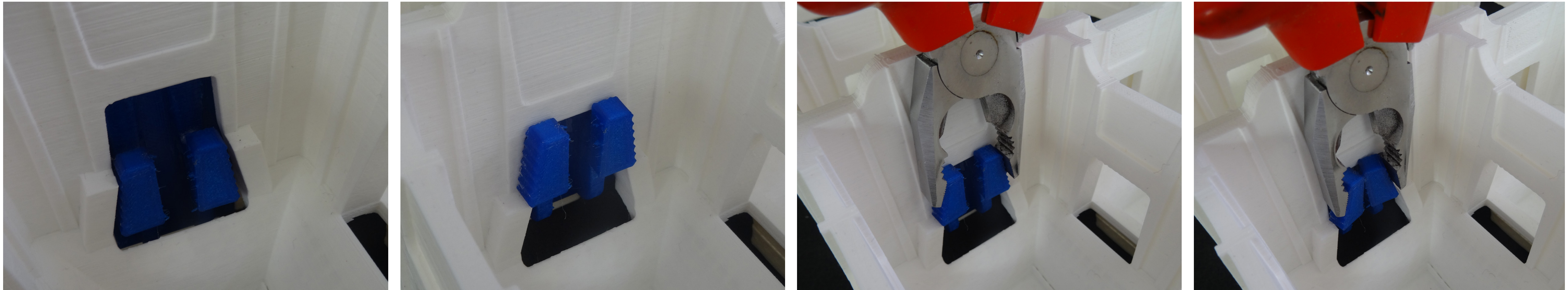


Figure 93. Interaction of installation and de-installation tile.



16.3 The cable management

The cable management was prototyped to obtain feedback on the instalment and dimensions by an installer of the company. The hinge feature was optimized. The print were developed to demonstrate the installation processes and depict the actions required for cable maintenance. Due to the aim of the prototyping stage, standard PLA filament could be used, for a realistic simulation of the intended material behaviour was not the focus of the print. The toggle plug was store bought.

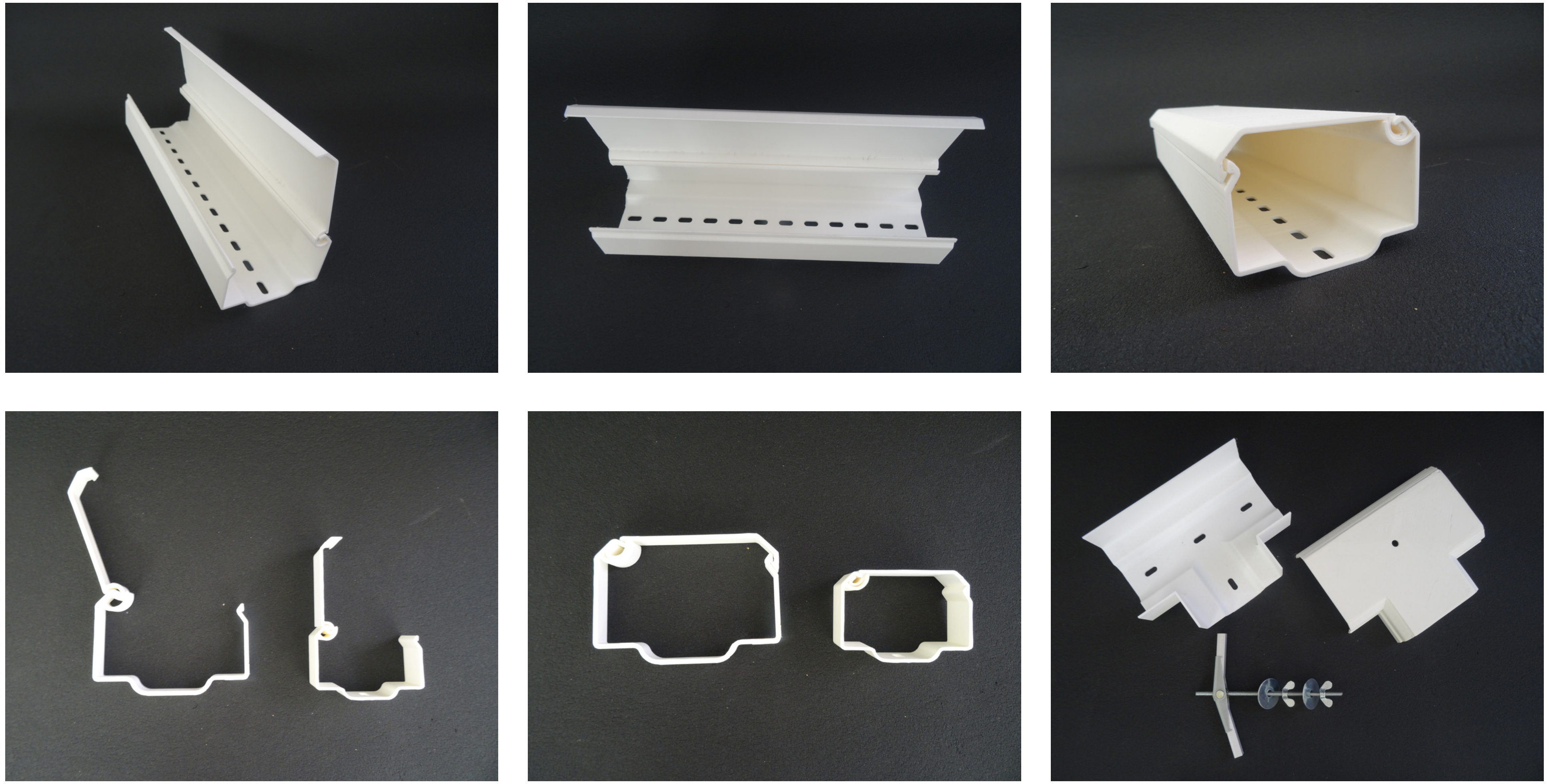


Figure 94. Cable management prototypes.

This page depicts the steps of installation for the cable management, as will be demonstrated to the company.

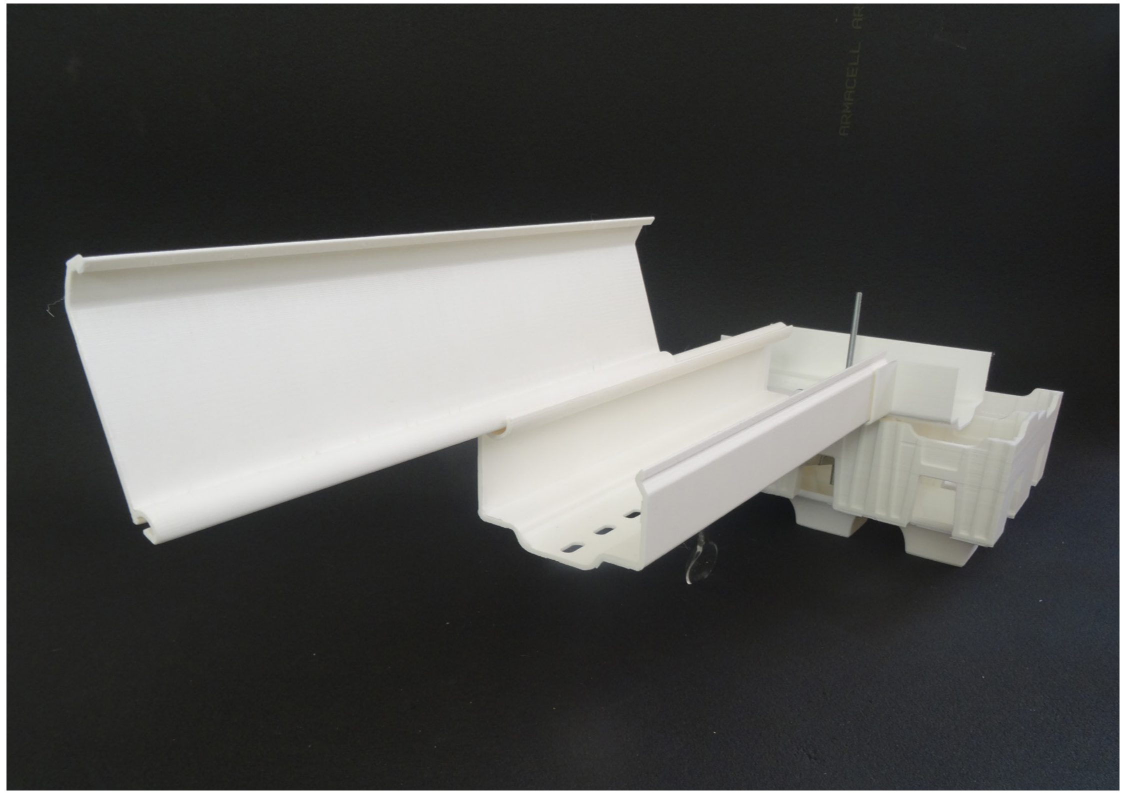
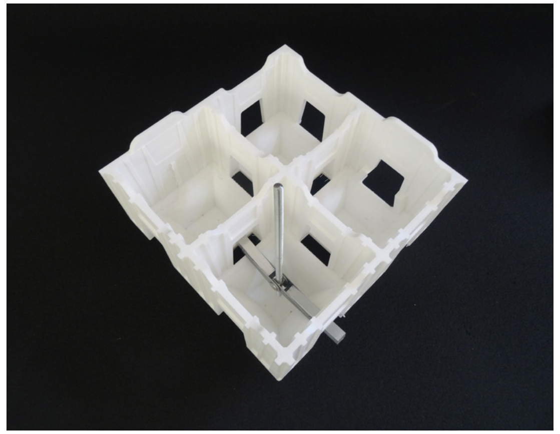
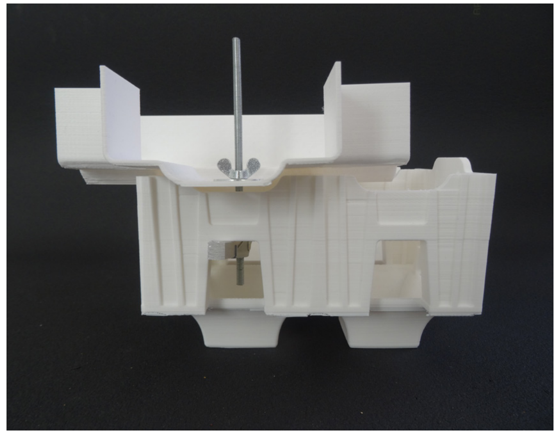


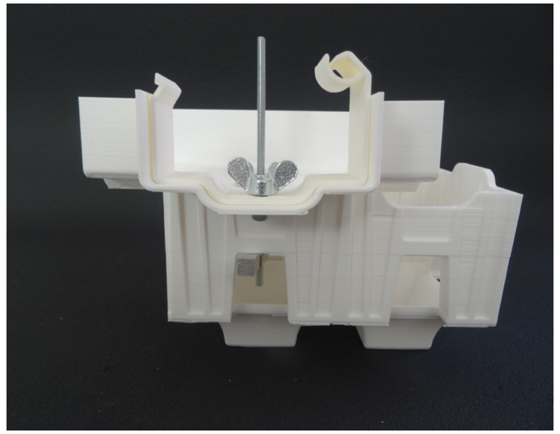
Figure 95. Prototype of the cable management, lid slid out, installed on tile.



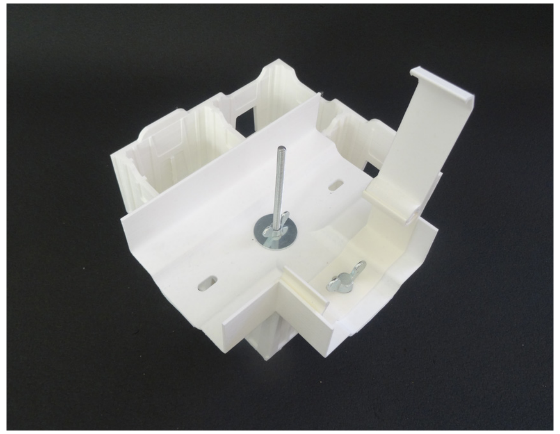
1. Install the toggle plug



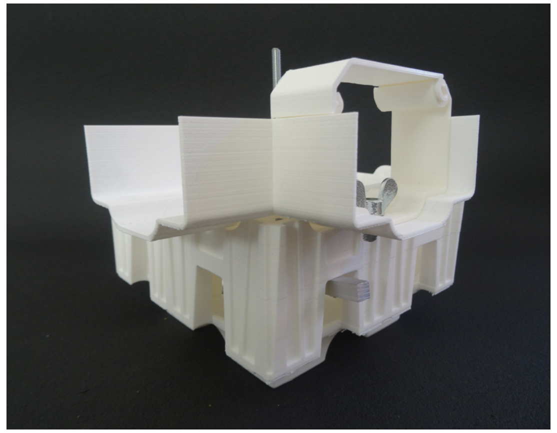
2. Secure the connecter tray



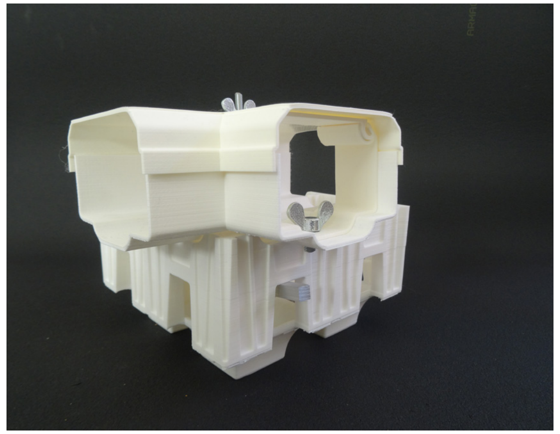
3. Place the tray profile



4. Slide in the lid profile



5. Close the lid profile



6. Secure the connector lid

17. Company evaluation

The prototypes were used to perform a company evaluation session. Present at the session were the company coach, Wouter Voskuijl, company co-founder Benjamin Scheers and installer Karel Jansen.

The company showed appreciation for the simplicity of the design, the gradual investment possibilities and the installation procedures of the components. The prototypes developed during this project are expected to be used in the following development phases of this system and to serve as a reference to acquire funding and further input of experts.

The feedback obtained regarding the development stages of the components corresponds to the projected phases of the future development roadmap.

Phase 1

Regarding the anchor, the development stage appears to be sufficient to enter performance testing using the proposed manufacturing materials. This allows the company to have an additional iteration on the feasibility and performance of the part, in combination with the Flowblock and other system components. This would also enable them to empirically establish the limits of the forces applied to part. This is the first step to obtain required quality marks for the system.

Phase 2

Regarding the Pavilion tile, the company proposed some alterations. The elevated part to indicate the location of the locking system obstructs the cable management. This was assumed to not be an issue, but the company noted a solution which would not interfere with the cable management is preferred.

They are interested in testing the performance of the tile on sloped rooftops, and the integration of solar panels into such a system. They see the possibility of marketing this to monumental buildings.

Reaching out to experts in the field of green roof development was advised to the company as the next step. This allows them to iterate on the established dimensions of the roof.
Furthermore, prototypes to determine the water retention time were discussed. The city of Amsterdam should be contacted to determine the exact requirements to qualify for subsidies.

Phase 3

The discussion of the third phase resulted in additions to the List of Requirements concerning the cable management. This concept is still in the embodiment phase, and user (installer) testing is advised.

The additional requirements for cablemangent are:

- R7.12 *Bends in the system should have a big radius and no sharp corners, in order to avoid cable damages*
- R7.13 *No obstructions may be present in the gutter of the cable management (this eliminates the current implementation of the toggle plug)*
- R7.14 *The gutter should have a feature to receive a gutter distributor to separate cables*
- R7.15 *The system should provide the possibility to attach the cables to the gutter (most commonly tie wraps are used for this)*
- R7.16 *The system should be impact resistance (in case an installer steps on it or drops it)*
- R7.17 *The material of the system should be UV resistant*
- R7.18 *The opening mechanism of the system should withstand dirt and weather conditions (expected is that the current design's hinge will get stuck by dirt or oxidation)*

Aspirations:

- A7.2 *The connector piece and the attachment to the system (currently the toggle plug) could be combined into 1 part, to ease installation*
- A7.3 *The tray and the lid of the system could be identical, to decrease the required dies and molds, therefore decreasing investment costs.*

Sustainable innovation

The use of sustainable materials was discussed with the company. The proposed materials for the tiles and the anchor is recycled HDPE. Biodegradable materials are not possible because the product will be used outside. The biggest potential to increase the sustainability of the system is by aiming for a closed manufacturing loop. Because the company will remain in contact with the client for maintenance, the infrastructure to reclaim materials of the system is feasible.

In order to be able to recycle and reuse the material of the components in their own manufacturing cycle, they have to avoid mixing materials, limit the number of different materials they use and use connections which can be disassembled. Further additions and developments to the system should adhere to this aim.

In order to minimize the number of materials, the use of HDPE for the cable management can be explored. The trenches of hte cable management can still be extruded, the connector pieces would most probably be injection molded, creating the possibility to integrate the function of the toggle plug into the connectors.

18. Recommendations

The company evaluation resulted in a set of recommendations regarding the project and the system components. This chapter will cover the recommendations which resulted from the design project itself.

Anchor

The anchor has very specific performance requirements, that are
They are currently not miserable in the final prototype. Because of the selected prototyping method (3D printing) and material (Tough PLA). This prototype was allowed to establish the suitable dimensions for the parts and to acquire feedback on the intended interaction from installers. This final prototype served this purpose, and the design is now ready for the next prototyping phase; performance testing.

In order to simulate the manufacturing method and material behaviour proposed for the production of the component, the recommendation is to mill the anchor and the plug from a block op HDPE. The advised test should include, shear pressure, material displacement and deformation when installed, and durability in weather and other context conditions, such as dirt, water and algae accumulation.

P3 Tile

The first recommendation regarding the tile is its redesign considering the optimization of its structural element and wall thickness, in aims to reduce its weight whilst maintaining current functional properties.

For further development of the tile, it is recommended to obtain advice from bio roof experts to identify the ideal layering of plantae considering endemic species in the Netherlands. The geometry of the tile, specifically the height of the filter holes, drainage layer and substrate layer, should respond to the plant's needs. Into the current design, these decisions were based on generic bioroof knowledge, and not specific to this region.

Similar to the anchor, the subsequent step would be testing the mechanical properties of the locking system of the tile in a closer simulation of the proposed material and manufacturing method.

Cable management

From the prototyping, it was learned that the hinge was prone to malfunctioning. The length of the profile results in a high friction surface within the hinge and a big lever force when the lid is opened on 1 side of the profile. This information, together with the findings during the company evaluation, argue a redesign of the cable management, considering the new functional and manufacturing requirements and aspirations listed in chapter 17.

Furthermore, the prototype showed the toggle plug generated problems regarding the installation ease and the potential damaging of the cables with the screw thread running vertically through the connector piece. The first step in redesigning the fixing element of the cable management, clear requirements should be set regarding the involved forces.

Project development

Concerning project development, besides the recommendations established in the future development roadmap, there are four points to mention.

An accurate estimation of the system costs including installation service as well as the expected profit margin should be done to determine the final retail price. This number can be used as part of user research into the desirability of the concept. Communication of the products benefits should be analysed.

It is recommended to approach experts in injection molding and extrusion methods, for consultation on the further development of the concept specifically for its manufacturing, to fill in the company's current knowledge gaps. Furthermore, it is recommended to seek support for optimization of the parts' dimensions to suit them to their intended manufacturing method.

In accordance with the findings from the market research of similar product solutions for a modular green roof, the company could explore the possibility to pre-frown their tiles. This could increase the desirability of the product, and decrease installation time. It is advised to outsource the pre-growing of the tile, because it would require expertise, location and equipment out of the company's scope.

The last recommendation for the project is concerning an insight which was rendered outside of the project scope. There is a need of the client to experience the system's configuration as transparent and tailored to their specific household.
Simultaneously, the communication effort of the company internally concerning project planning could be improved. When planning a project, lost information or wrong mapping of the roof layout, has repercussions for installation costs, which are accountable on the company. Both challenges could be solved in a combined solution.
Proposed is a document (beginning as hardcopy and to be developed into an app) to support the mapping, planning and communication to the client of a project. As inspiration the client journey of the kitchen industry can be used.

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